Conceptualizing the Role Geographic Information Capacity has on Quantifying Ecosystem Services under the Framework of Ecological Disaster Risk Reduction (EcoDRR)

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ABSTRACT:

The use of ecosystems such as the retention of water in wetlands to absorb storm surge for disaster risk reduction (DRR) is a beneficial and a viable option for community stakeholders. For example, ecosystems can mitigate the effects of hazards experienced in anthropogenic communities. Ecosystem services are the underlying reason for this benefit through their inherent process these services have the potential to significantly reduce the impact of a hazard. In terms of Disaster Risk Reduction, ecosystems can mitigate the effects of hazards experienced in anthropogenic communities. The use of ecosystems with regards to disaster risk reduction has been termed "Ecological Disaster Risk Reduction" or EcoDRR. EcoDRR is the idea of sustainable management, conservation, and restoration of ecosystems to maximize ecosystem services and reduce disaster risks and impacts. The use of geospatial technologies to monitor large scale ecosystems are often subject to Geographic Information Capacity (GIC), or the ability of ecosystem stakeholders to utilize all existing geographic information, resources, and capacities to monitor ecosystem services. For example, there are many geospatial tools that quantify ecosystem services in general, including InVEST, TESSA, and EcoMetrics as a few examples. Though these tools are useful, currently there is not a tool that specifically quantifies ecosystem services in the context of DRR. In this paper, we review current geospatial technologies that quantify ecosystem services. The main contribution of this paper is a conceptual framework intended to quantify ecosystem services in the context of EcoDRR. Ideally, future development of our proposed framework can form a scientific basis for informing communities, society, or organizations the abilities to quantify ecosystem services under the framework of DRR and understand how GIC factors into the efficacy of EcoDRR.

KEYWORDS

Disaster Risk Reduction, Ecosystem Services, Geographic Information Capacity, Hazards.

INTRODUCTION:

Importance of EcoDRR for Disaster Risk Reduction:

The use of ecosystem services in disaster risk reduction has been a viable option in certain cases over traditional engineered approaches. Ecosystems, by nature, carry out ecosystem services which continuously provide benefits to anthropogenic communities. Though definitions are vague, "ecosystem services are the aspects of ecosystems utilized, actively or passively, to produce human well-being" (Fisher et. al. 2009). These services, such as retention of water in wetlands and forests ability to retain soil, have to potential to provide significant hazard risk reduction and have been coined as "Ecological Disaster Risk Reduction (EcoDRR)" (Estrella et. al. 2013). The definition behind Ecological Disaster Risk Reduction is "the sustainable management, conservation, and restoration of ecosystems to reduce disaster risk and adapt to Climate Change with the aim to achieve sustainable and resilient development" (Sebesvari 2017). It is important for decision makers that utilize EcoDRR to have a clear definition of ecosystem services initially and maintain that definition in order to prevent misconceptions in published literature and government documents (Fisher et. al. 2009). Monitoring these services in general, and in the context of EcoDRR is vital for policy and management, though there is a gap in the understanding of indicators and monitoring approaches for ecosystem services to compare them to other geographic regions (Cord et. al. 2017). The "supply and demand" of ecosystem services are spatially explicit and vastly differ between ecological communities through a variety of means (Krol et. al. 2016). Though, since ecosystem services are spatial in nature, geospatial technologies like Geographic Information Systems (GIS) have proven to be a valuable resource to monitor and quantify these services (Krol et .al. 2016). The use of geospatial technologies to monitor large scale ecosystems are often subject to Geographic Information Capacity (GIC). Which we define as the ability of ecosystem stakeholders to utilize all existing geographic information, resources, and capacities to monitor ecosystem services. The goal of this research reported in this paper was to understand the relationship between Geographic Information Capacity, and current geospatial tools that quantify ecosystem services. Specifically, our goal was to develop a conceptual framework intended to quantify ecosystem services in the context of EcoDRR. Ideally, future development of our proposed framework can from a scientific basis for informing communities, society, or organizations the abilities to quantify ecosystem services under the framework of DRR and understand how GIC factors into the efficacy of EcoDRR.

Importance of Geospatial Technologies:

Risk is spatial in nature, requiring the use of geospatial analysis in order to take both spatial and temporal aspects into consideration (van Western 2010, Krol et. al. 2016). Spatial data can be collected through a variety of means, but the main methods used for environmental analysis are through earth observation satellites, sensors located on drones, and field collection. Earth observation satellites have been proven to provide temporal data over large areas and are a vital tool to monitor natural and anthropogenic variability (Cord et. al. 2017). Data from satellite earth observation tools can be used in all phases of a disaster including monitoring trends prior to a disaster, rapid decision making during a disaster within reason, and damage assessment post disaster. Since the data is already digital and georeferenced, it can be easily integrated into a GIS environment. This data can be rapidly obtained and processed during a disaster, making it a vital tool to make emergency relief decisions and handed to personnel in the field (Montoya 2003). Having a strong GIC will make the process fast and concise which are both vital in disaster response. Through spatial modeling, data from earth observation satellites can be used to monitor changes in ecosystem services and provide stakeholders the opportunity to toggle parameters with the potential to provide optimal outcomes (Cord et. al. 2017). Ecosystem services can be quantified by connecting ecosystem functions to specific services and ultimately human well being (Cord et. al. 20017). Modeling ecosystem services spatially provides the ability to quantify how much an ecosystem will mitigate the impact of a disaster. For example, understanding the relationship between water retention within a wetland and wetland area can significantly help a disaster manager when thinking about potential flood inundation. Knowing a wetland that is a certain number of hectares in area and will hold a certain quantity of water can provide disaster managers a better idea as to where they should build engineered structures to coincide with already active ecosystem services. These geospatial models, like the wetland retention example previously given, are used to estimate where services are produced, where the ecosystem is functioning optimally thus providing the most services, temporal changes in ecosystems, and the impact land use has on surrounding ecosystem services (Krol et. al. 2016). The models take a variety of parameters into consideration thus making them highly customizable to specific locations, and for specific instances. For example, weighted overlay models can examine different risk reducing scenarios for exploring new policies and ideas in turn providing a good understanding regarding potential impacts on ecosystem services (Krol et.al. 2016). All the concepts previously stated are subject to GIC, without proper personnel training, equipment, and available data resources final products will not be able to be created in a manner that is effective in a disaster scenario. A strong GIC will also allow for more precise indicators to be utilized for a specific region. For example, ecosystem service indicators specific for South East United States will drastically differ from indicators for Indonesia. Institutions and communities that have a strong GIC will be able to utilize EcoDRR models created from local indicators and potentially be more resilient than communities that do not have a strong GIC.

Integrating GIS and EcoDRR:

The use of ecosystem services in DRR contributes to sustainable development and have proven to be far more cost effective than traditional engineered approaches for post disaster response and recovery efforts (UN 2005). The combination of EcoDRR and engineered disaster risk reduction can be modeled in a GIS environment giving results that will be the most cost effective and is very useful in areas where land is scarce (Krol et. al. 2016). Having a better understanding of Geographic Information Capacity, as it relates to EcoDRR, will provide insight on what the risk reducing effect of EcoDRR will be along with how ecosystem services compare with other risk reduction alternatives (Krol et. al. 2016). Thus, ensuring that knowledge, technology, and expertise is transferred will build capacity for disaster risk reduction (UN 2005). The capacity to use GIS can also provide the means to understand and make informed decisions regarding ecosystem services. GIS can be used to analyse consequences, predict impacts, disseminate information, allocate personnel, equipment and resources, along with calculating optimal transportation routes (Montoya 2003). All this information is subject to GIC, and vital to decision makers and helps facilitate decisions regarding which areas are exposed to hazards, areas at greater risk than others, and the occurrence of multiple hazards (Krol et. al. 2016).

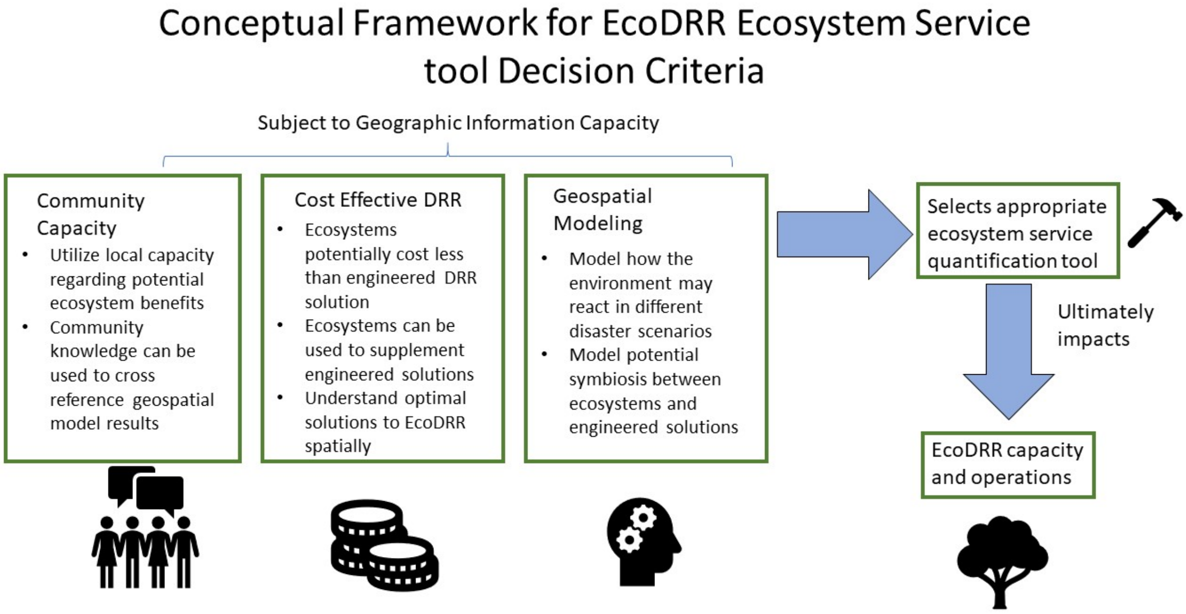

Figure 1: Conceptual model of our research. The focus of the research presented here is looking at how GIC plays a role in identifying a proper ecosystem service quantification tool in the context of EcoDRR.

METHODS:

A desk review was conducted with the specific intention to aggregate publications that were focused on utilizing ecosystem services in the context of EcoDRR. To do this a variety of literature was found in the field of EcoDRR and had some sort of reference to GIC. Although there was no literature that specifically discussed the concept of GIC in the framework of EcoDRR, it was inferred that GIC plays a role in the application of spatial methodology. Once literature was aggregated, it was then analyzed to find trends between works along with differences among publications. Case studies were found that utilized existing ecosystem service quantification tools to gain an understanding on the framework that these tools are being used in. To begin two widely used ecosystem service tools (Integrated Valuation of Ecosystem Services and Tradeoffs - InVEST and Toolkit for Ecosystem Service Site-Based Assessment - TESSA) were searched for to gain an understanding on how professionals are using these tools, and from there search for other tools present, along with how they are being used as well. Many of these publications were not specifically focused on disaster risk reduction and were only focused on other applications of ecosystem service tool software. Based on our review, we determined that there was a lack of framework regarding the use of spatial ecosystem service quantification tools in terms of EcoDRR. This is where concepts from publications focused on DRR was merged with the concept of GIC to develop a conceptual framework on the role GIC plays in EcoDRR (as seen in Figure 1).

QUANTIFYING ECOSYSTEM SERVICES SPATIALLY:

Table 1: Introduction to geospatial tools used in quantifying ecosystem services. (Source: Christin et. al. 2016).

ARIES	This framework is intended to integrate multiple modeling paradigms in spatial modeling and mapping of ecosystem services. Supports artificial intelligence-based data and model selection through semantic modeling to quantify ecosystem service flows from ecosystems to beneficiaries. http://aries.integratedmodelling.org/
Co$ting Nature	Mapping and modeling tool for multiple ecosystem services using global datasets. Quantifying ecosystem services as opportunity costs (IE avoided costs of producing those services from a non-natural capital substitute). http://www.policysupport.org/costingnature
Envision	GIS based tool for scenario based planning and environmental assessment. Enables “multi-agent modeling” to represent human decisions on landscape simulations. http://envision.bioe.orst.edu/
InVEST	Spatial mapping and modeling of multiple ecosystem services. Includes a diverse set of provisioning, regulating, and cultural services from marine and terrestrial environments. The models primarily provide results in biophysical terms to which valuation can be applied. https://www.naturalcapitalproject.org/invest/
MIMES	Modeling platform designed to quantify causal linkages between ecosystems and the economy. MIMES allows an individual to map decisions/ policies, and the output illustrates how those choices affect the economy and ecosystems. http://www.afordablefutures.com/orientation-to-what-we-do/services/mimes
EcoMetrix	Field based tool designed for the use of relatively fine spatial scales. Primarily use is to illustrate the effects of human activities. (Development, or restoration scenarios) on ecosystem services. http://www.ecometrix.ca/
SolVES	Spatial mapping and modeling tool primarily used for quantifying cultural ecosystem services using PPGIS. https://solves.cr.usgs.gov/

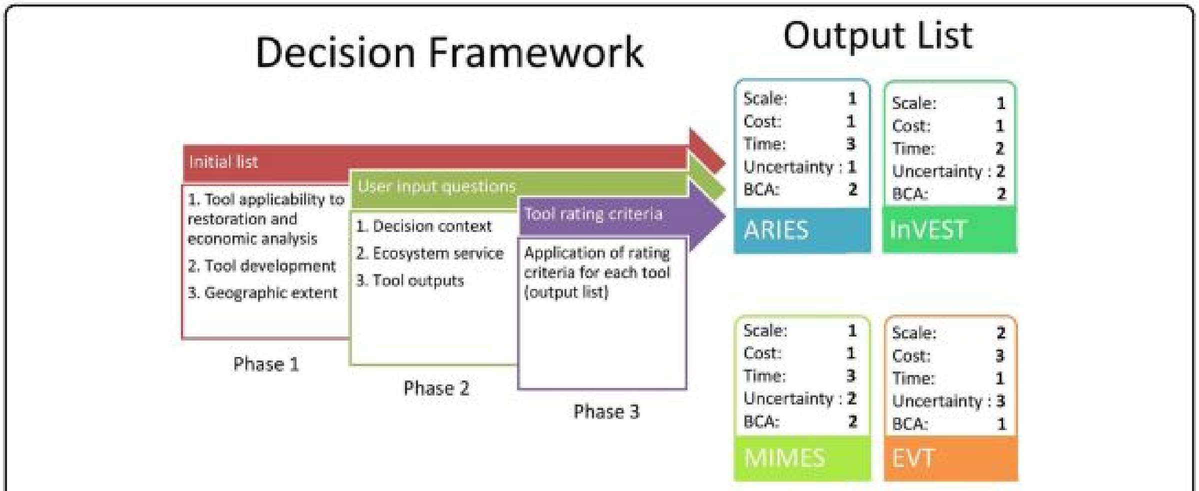

Fig. 1 Restoration Ecosystem Service Tool Selector (RESTS) decision framework. Acronyms: Artificial Intelligence for Ecosystem Services (ARIES), Ecosystem Valuation Toolkit (EVT), Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), Multiscale Integrated Models of Ecosystem Services (MIMES)

Figure 2: RESTS framework Source: Christin et. al. 2016. *BCA stands for Benefit Cost Analysis

Current Ecosystem Service Quantification Framework:

As seen in Table 1 above there are many geospatial tools currently available to use as means of quantifying ecosystem services. Many of these tools have differing end goals as means of measuring ecosystem services creating difficulty in deciding what tool is best for a specific region or instance (as seen in Figure 2). Though the tools presented in Table 1 can be used in DRR efforts, none of them are specifically designed for DRR measures. The Restoration Ecosystem Service Tool Selector (RESTS) is a framework designed to provide decision makers the means to decide what ecosystem service assessment tool is best for their needs (Christin et. al. 2016, Figure 2). The RESTS framework filters tools based on user's criteria outputting tools that are best for the user (Christin et. al. 2016). To do this the framework assigns each tool values based on attributes and evaluates those values based on user input (Chrisin et. al. 2016). Though, the RESTS framework is only for quantifying ecosystem services in general, or for a specific interest of an ecosystem restoration stakeholder. Currently there is no framework that is specifically designed for EcoDRR measures. As seen in Figure 2 the three phases of the RESTS framework provide users outputs with 5 variables that the user may find valuable when deciding what ecosystem service quantification tool is best for them. Creating an EcoDRR framework that performs an analysis that is very similar to the RESTS framework would be very beneficial for disaster risk stakeholders and provide geographic information capacity building. Utilizing such framework would require DRR stakeholders to understand their end goals and understand how they plan to implement EcoDRR measures. Outlined in the following sections are some measures that should be taken into consideration when designing and implementing a framework designed specifically for EcoDRR.

SUGGESTIONS FOR ECODRR FRAMEWORK:

Utilizing Community Capacity:

Utilizing ecosystem services has proven to be a viable option for communities attempting to reduce the impacts of hazards. Many different ecosystems can be utilized for a variety of reasons. For example, coastal wetlands provide protection against flooding, coastal erosion, saltwater intrusion, inland wetlands store rainwater preventing flooding while also postponing the issue of drought by retaining water (Fowler 2017). In many cases spatial information is not enough to obtain a complete picture of the processes going on in the environment. For example, the phenomenon of "Bush Encroachment" is not visible even with some of the best resolution imagery, and the need of local community members who know what is happening is needed to supplement spatial data (Szarzynski 2017). Trained locals who know what they are looking for are vital to supplement spatial data. These locals provide locations where they may have seen areas where "Bush Encroachment" is happening allowing for maps of these areas to be made, and ultimately allowing decision makers to make the most informed decision. Local people can "cross check" remotely sensed data and models, while also providing valuable information on valuable community assets and attitudes towards policies (McCall 2015). Especially in rural communities, the knowledge is present on how to best manage their local ecosystems and resources and should be utilized to sustainably manage local ecosystems (Karanja 2016). Understanding how local people cope with hazards will also help EcoDRR modelers understand changes in the environment and socio-economic indicators that may not have been picked up in remote sensed data or published data (Peters-Guarin et al. 2011). These local approaches conform to one of the guiding principles in the Sendai Framework. This principle is "Accounting of local and specific characteristics of disaster risks when determining measures to reduce risk" (United Nations 2015).

Utilize Savings:

Utilizing ecosystem services also conforms to another guiding principle in the Sendai Framework. This is "Addressing underlying risk factors cost-effectively through investment versus relying primarily on post disaster response and recovery" (United Nations 2015). By enacting Eco DRR measures the ability for the environment to protect nearby community greatly increases ultimately improving the resilience of the nearby community. Research has shown that every dollar invested in resilience measures equates to seven dollars in savings during the aftermath of a disaster (Karanja et. al. 2016). This is important to consider for regions that may not have significant sums of money but are looking to implement DRR measures. Though, in reality, it has been found that there has been a reluctance to implement Eco DRR measures. According to Levy and colleagues this is because "National and International systems lack 3 main factors when it comes to eco based DRR. These are incentives, few actors have the incentives to carry out high quality assessments and monitoring, the inability to obtain data necessary to assess and monitor measures, and the methods used to understand environmental-political linkages are not sufficient and must be developed through innovation." (Levy et. al. 2004). To make Eco DRR more appealing a standardized framework could be made for each ecosystem type. For example, there could be a wetland framework, a forest framework, grassland framework, etc. Each of these frameworks can then be refined for the specific region at hand. Levy and colleagues propose solutions themselves, "Proposed solutions to the deficiencies mentioned above are to set priorities and identify key assessments and actions, establish clear responsibilities and incentives to produce data, establish a financial basis to create a knowledge grid through data dissemination and bridge cross scale divides." (Levy et. al. 2004). Connecting these proposed solutions to indicators from the Sendai Framework could potentially help create a standardized framework for each ecosystem type.

Utilizing Geospatial Modeling:

Historic environmental maps are seldom referred to in Eco DRR publications. These maps provide a clear logistical visualization as to impacts induced from hazards. Historical maps are generally reference maps throughout time and show how human modification to the land surrounding them ultimately potentially introducing unknown vulnerabilities. Historic maps can be used as hazard maps serving as probability maps for future disasters, signifying that similar events can be predicted in the future based on information in the past (Neussenr 2014). All the essential data for these maps are generally not available. For example, in the United States the United States Geological Survey has quadrangle maps dating back to the 1800's showing locations of settlements, but ecosystems were rarely captured. On top of this dilemma there is a lack of digital elevation data. It may be assumed that the elevation has not changed much, or elevation can be interpolated from what markings are available. These issues are often subject to GIC and plays a vital role in the accuracy and completeness of geospatial models. As stated in the Sendai Framework indicators technical review, one of the critical issues on monitoring global issues is developing a baseline. This includes aggregating, and utilizing historic data between a given time period, though should not impede the development of new indicators (Maskery 2015).

FUTURE WORK AND CONCLUSIONS:

Geographic information capacity plays a valuable role in the understanding on how ecosystem services operate, and the potential to mitigate hazards. The Restoration Ecosystem Service Tool Selector (RESTS) framework is a valuable tool that compares each geospatial ecosystem service quantification tool (Table 1) and provides decision makers costs and benefits of each tool (Christin et. al. 2016). This type of framework significantly helps decision makers with their GIC allowing them to pick specific tools for their needs. These tools then use spatial information and the outputs can then be used in GIS models. Once ecosystem services are quantified a decision maker can use a multicriteria approach to locate where to build ecosystems, and what factors are necessary for a constructed ecosystem to thrive in a given location (Krol et. al. 2016). The multicriteria model is then easily manipulated to give results of optimal location for ecosystems used in DRR (krol et. al. 2016). For example, hydrological models provide valuable information when preparing for flood events.

Moving forward additional data will be collected from DRR experts that have first hand account of utilizing the concept of GIC either directly or indirectly. A variety of interview questions have already been formulated and will be asked to the experts. These questions are (1) What do you perceive the relationship is between EcoDRR and GIS? (2) Do you see tools like InVEST and TESSA as useful for EcoDRR implementation and projects? (3) Do you see specific regions/ countries obtaining the training and infrastructure necessary to implement EcoDRR measure themselves, or will the help of the UN and other NGO's always be mandatory? (4) Do you see EcoDRR projects improving a region's ability to utilize GIS? (5) The infrastructure needed to successfully use GIS is expensive, do you think regions that decide to implement Eco DRR measures will skip the investment in GIS and just focus their resources in the project? (6) How can the use of GIS be expanded in the field of eco DRR? Should more standardized models be built and then refined for specific regions? (7) How are regions overcoming data problems? Do they go out and record their own data? Are they finding professionals to show them how to create data? (8) How do you perceive the use of historical environmental maps? Are they a necessity, or do they only supplement Eco DRR work? (9) How have you seen the use of local community knowledge assist with Eco DRR projects? Has this knowledge been spatial in nature/ able to represent geographically? If not, how can this information be implemented spatially? (10) How do you see the Hyogo Framework and the Sendai Framework influencing GIS and a country's ability to increase their GIC? From there, it may be possible to work in historical environmental models to the findings of this research paper. The ability of a country/ region to utilize historical environmental models in terms of DRR can greatly improve their GIC due to the ability of these models to clearly indicate regions that will be impacted by specific hazards. It may also be useful to create a specific Environmental Geographic Information Capacity model, where the only indicators would be environmentally related. With critiques from professionals this model may be feasible for regions who are interested in only using ecosystems as means for DRR for any variety of reasons.

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ACKNOWLEDGMENTS:

This research was funded through a grant from the US National Science Foundation and the project International Research Experience for Students: Quantifying Disaster Risk Reduction Geographic Information Capacity with United Nations University Institute for Environment and Human Security and University of Bonn Germany (NSF OISE-1559450).