Conceptualization of territorial resilience potential indicators to coastal hazards through the use of Unmanned Aerial Vehicles

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Abstract:
Major natural hazards in recent decades have led to a revisiting of the concept of resilience, particularly in order to analyze traditional models of response to an unforeseen event and post-crisis management mechanisms. For resilience to be an applicable/operational concept to guide management and inform decisions, it must ultimately be characterized for its assessment. This assessment can be done through the identification of indicators specifically contextualized to the study site and object of study. However, today, operationalizing of the concept of resilience tends to draw on annual censuses or aggregated data, providing a generalized large scale view of the territorial resilience potential. The objective of this study is to identify a table of territorial resilience potential indicators to coastal hazards applied to coastal island territories, supplied by data from UAVs to allow for rapid and site specific data acquisition for repetitive surveys. This acquisition method makes it possible to calculate a number of relevant indicators for assessing the resilience potential of coastal areas. In particular, it allows rapid updating of data following major meteorological events and identification of hot and cold spots of resilience potential of a specific study site. To demonstrate the applicability of this method to island territories, the island of Bora Bora in French Polynesia was used as a case study. Finally, these kinds of results can be fed through a spatial decision support system to help decision-makers choose an adaptation and protection strategy in order to move towards resilient territories, over a long period of time.

1.0 Introduction

One of the many consequences of climate change can be observed today by the increase of extreme events and natural hazards both in intensity and frequency (Collins and Sutherland, 2019). While these effects are global, some populations are more at risk than others, most notably, populations that live close to coasts due to sea level rise (SLR), flooding, intense cyclones and hurricanes, erosion, and other associated coastal hazards (Barnett and Campbell, 2010). Island territories can be made up of coastal plains, sometimes quite narrow, such as on volcanic islands, on which are concentrated the majority of the population and infrastructures such as airports. The spatial configuration of these island territories means they are more exposed to the hazards of the sea and ocean and therefore more vulnerable. Small Island Developing Nations are a group of 52 global south countries in 3 different regions (Caribbean, Pacific, and Africa, Indian Ocean, Mediterranean and South China Sea) that face unique social, economic and environmental vulnerabilities (Betzold, 2015) and are also exceptionally vulnerable to these coastal hazards, specifically, floods, marine submersion, and erosion (Meheux et al., 2007). Part of these islands, are of small sizes and at low elevations (Taylor and Kumar, 2015), and their coastal zones play an integral role in the settlement and development of the territory. For instance, about 79% of the French Polynesian population is living less than 1 km from the sea (Andrew et al. 2019). Additionally, the high climate sensitivity of their physical, ecological, and societal features (e.g. reef-dependent beach and reef island systems) are driving increased exposure and vulnerability. And finally, these Small Island Developing Nations are already regularly experiencing extreme events, such as tsunamis and cyclones (Hoeke et al. 2013; Magnan et al. 2022). While climate prediction averages on a global scale are accelerating at an alarming rate, the Pacific averages for SLR are even higher, sometimes reaching even four times higher than the global mean (Gemenne et al., 2019; Nurse et al., 2014). In conclusion, islands are amongst the most susceptible territories to climate change specifically because of the concentration of inhabitants, infrastructure, agriculture, recreational activities and/or tourism in their coastal areas (Oppenheimer et al., 2019). In fact, two-thirds of the territories most impacted by climate change and experiencing the highest rates of Gross Domestic Product (GDP) losses due to man-made disasters are island nations, with annual average GDP losses ranging from 1 to 9%. (Giardino et al., 2018). The high stakes of these territories in regards to these risks requires the implementation of new management strategies such as the resilience concept.

Natural hazards can have an important impact on the population and produce significant material damage. These losses undermine the sustainable development of these territories (Guha-Sapir et al., 2012). Accurate forecasts and warnings in a form that is readily understood and educating people on how to prepare against such hazards, before they become disasters, can improve the protection of lives, property, and the environment (IPCC, 2022; Oppenheimer et al., 2019). Until recently, the concept of risk management orbited around reacting to a hazard and rebuilding. However, due to the increase in frequency and intensity of extreme events as well as the amount of stakes in urban development, risk management methods have had to adjust. Catastrophes like Hurricane Katrina showed weaknesses in forecasting and prevention, as well as an insufficient organization of those responsible for crisis management, not only in New Orleans but on a global scale. These disasters mobilized the world of research to modify traditional response methods to unforeseen events and more specifically the post-crisis management techniques and mechanisms allowing for new concepts to be brought forward (Lhomme et al., 2010; Toubin, 2014; Serre et al., 2016; Heinzlef et al., 2022).

Resilience, a long-standing notion, is a key concept within the field of risk management, that has now become an imperative. This concept defines the capacity of a territory to return to "normal" or even improve after a damaging event. An important distinction is made between the ability of a society to "withstand" an event, with the ability of a society to return to its original state or "normal" functioning (Masselink and Lazarus, 2019). While the scientific literature varies on the definition of resilience due to the variety of types of resilience: biologic, political, territorial, occupational and others. This study defines resilience as a system's ability to anticipate, absorb, and recover or adapt from a shock or stress and its impacts in a timely and efficient manner (Heinzlef et al., 2022; Jessin et al., 2022). The concept of resilience often implies the occurrence of a crisis or damage, however, the measurement of resilience does not wait for a crisis to occur. Resilience can thus be considered intrinsic to the environment and inherent to the internal functioning of the system. This is referred to as the Territorial Resilience Potential (TRP). In this context, a TRP is the potential capacity of the socio-ecological systems to cope with disturbances, induced by factors, by adapting whilst maintaining their essential functions.

While resilience is widely used as a theoretical concept, it is confronted with complexities in regards to its operationalization due to its multi-disciplinary origin, the complexity and interconnections of dynamic natural systems, the multitude of definitions, as well as the lack of data availability (Cimellaro et al., 2018; Jessin et al., 2022).

There are a variety of tools useful for operationalizing the concept of resilience starting from the phases of data acquisition all the way to data valorization. Studies have been carried out to operationalize this concept by using statistical databases such censuses which can provide information such as population demographics and land use; (Cutter et al., 2008; MacAskill and Guthrie, 2014; Cai et al., 2016; Cutter, 2016; Rus et al., 2018; Serre and Heinzlef, 2018; Song et al., 2018; Zheng et al., 2018; Cariolet et al., 2019; Heinzlef et al., 2019; Assarkhaniki et al 2020; Santos et al., 2020). These databases can allow for the creation of indicators to evaluate the resilience of a territory in regards to natural hazards. These studies tend to provide a global view (spatially speaking) of the territory's resilience, without the possibility of frequent data acquisition. Dynamic environments such as islands and their coasts that are particularly vulnerable to the threats of climate change and can benefit greatly from such updated data. For this reason, this study focuses on the implementation of two spatial tools that can bridge the gap between rapid, site specific data acquisition for repetitive surveys and effective communication of this information while focusing primarily on land use indicators. Unmanned Aerial Vehicles (UAVs) and photogrammetric techniques have shown to be able to produce high spatial resolution, low cost, site specific data at high temporal frequencies (Gonzalves and Henriques, 2015). Data sources today can come in the form of satellite images or national databases and are too costly both in time and price for frequent surveying. They allow for a global overview rather than a zoom on a specific portion of the coast. This UAV data, when paired to the methodology of resilience evaluation has the potential to produce precise, up to date, and repetitive data to define the resilience and to identify key spots of vulnerability on dynamic territories such as littoral zones on islands (Jessin et al., 2023). This analysis by UAV is not exhaustive of all the factors that make up the resilience of a territory but can bring complementary information (Jessin et al., 2023).

After obtaining data from sources of information such as statistical databases and/or UAVs, it is fundamental to structure and store the processed data in order to extract tangible information that can aid decision-makers in their complex task of providing optimal coastal management solutions (Fabri, 1998; Kardel et al., 2011). The implementation phase is often over-looked within scientific studies today, drastically reducing the efficiency of risk management strategies. This step will help reduce the complexity of such a concept and render it more accessible outside of the scientific community. A recent study (Berrang-Ford et al., 2021) screened 1682 articles on the adaptation to climate change to assess the extent of implementation. This study found that while 62% of papers provided evidence that adaptation efforts can reduce the risk or vulnerability, only 3.4 % of papers indicated that the risk reduction outcomes of adaptation responses were formally assessed after implementation (Berrang-Ford et al., 2021). The recent rise of articles on climate change adaptation is documented in review papers (Haunschild et al., 2016; Callaghan et al., 2020; Nalau & Verrall, 2021), implying that while there are increasing efforts to propose solutions to cope to climate change, these studies show there is little implementation phase of their respective projects. Access to and communication of the acquired knowledge are important factors within this issue and can serve to close the gap between research and action. Spatial decision support systems

(SDSS) are efficient tools that have the capacity to agglomerate data from a variety of sources (Fabri, 1998; Kardel et al., 2011). A contextualized SDSS is an effective approach for processing raw data into tangible knowledge which will render raw information accessible and more comprehendible to decision-makers, so that they can make informed decisions on strategies at the local scale.

Overall, this article aims to conceptualize a table of TRP indicators specifically acquired by UAVs for the operationalization of the concept of resilience to highlight the ability of socio-ecological systems in island coastal environments to cope with disturbances.

Firstly, this study will agglomerate a list of indicators and their variables. Secondly, the inter-connection between the variables themselves and their associated natural hazards will be identified. And lastly, to assess the feasibility of this method, this study will use UAV data acquired in French Polynesia (Bora Bora) as a case study and quantify two of the indicators as an example for the evaluation of the TRP.

2.0 Literature Review

Defining Resilience

The scientific literature varies on the definition of resilience due to the variety of types of resilience; biologic, political, territorial, occupational and others (Holling, 1973). However, throughout the variety of definitions presented, three main essential phases are remain present; anticipation, absorption, adaptation (Holling, 1973; Cutter et al., 2008; Twigg, 2009; Peacock et al., 2010; Chelleri, 2012; Frazier et al., 2013; Cai et al., 2016; Cimellaro et al., 2016; Asadzadeh et al., 2017; Santos et al., 2020).

Before the shock (anticipate), resilience means:

- The capacity to anticipate unpredictable events and scenarios, to maintain the operational capacities of systems and organizations.
- The capacity to learn.

During the event (absorb), resilience means:

- The capacity to resist and cope with a shock, requiring a certain flexibility;
- The capacity to preserve the essential functions, structures and organizations during the event.

After the shock (adapt), resilience means:

- The capacity to recover and rebuild;
- The system's capacity to preserve its integrity and return to either the former equilibrium or reach a new one (Twigg, 2009).

Resilience is built up before a disturbance, manifested during the disturbance, and continues to build after the disturbance is over (Cutter, 2016; Folke, 2006; Heinzlef et al., 2022; Holling, 1973; Lei et al., 2014; Lhomme et al., 2010; Meerow et al., 2016). These disturbance can be abrupt and unexpected such as tsunamis and flash floods, or continuous, for instance, erosion and SLR (Masselink and Lazarus, 2019). Resilience is based on the idea that a system requires capacities of anticipation, absorption, or reactive adaptation to shocks or disturbance, particularly in a changing environment, such as coastal environments (Lei et al., 2014).

Coastal island territories are dynamic systems and with complex interconnections between a wide array of factors. That must now learn to balance previously natural environmental dynamics that have been supplemented by human-dominated systems. Because of this, identifying a TRP requires the resilience assessment to take into account both the fluctuations and the long-term stability of this dynamic coastal environment (Gonzalves and Henriques, 2015). Thus, coastal resilience is defined, in this study, as the capacity of socio-ecological systems in a coastal setting to cope with disturbances/shocks, induced by coastal hazards, extreme events and human impacts, by adapting while preserving the essential functions (Horton et al., 2018; Masselink and Lazarus, 2019).

Resilience Assessment Through Indicators

Resilience is a multi-dimensional concept, which requires tools capable of representing different kinds of social, artificial or natural geographic data on the territory. The indicator-based approach is well established for the assessment of geographic phenomena (Gallopín, 1997 ; Merkle and Kaupenjohann, 2000). An indicator accomplishes two main functions: to synthesize the factors that are typically required to explain a circumstance; and to simplify the understanding and interpretation of the results for the user. An indicator is a measure (quantitative or qualitative) that simplifies and represents complex reality (Freudenberg, 2003). An indicators objective is to measure the relative position of the phenomena being observed. Over time, this positioning can demonstrate a change either in magnitude, as well as direction (Satour et al., 2021).

Evaluating the resilience of a territory using indicators will assess the socio-economic and natural capacities of the community/environment to resist, absorb and recover from disruption as well as serve as a tool for territorial decision-making (Fabbri, 1998). Finally, for resilience to be an applicable concept that helps guide management and political decision-making, it ultimately requires the quantification indicators (Pimm et al., 2019). A variety of studies are based on a systemic assessment of resilience through the use of indicators followed by a cartographic approach (Cutter et al., 2008; Cariolet et al., 2019; Lamaury et al., 2021; Rus et al., 2018 ; Song et al., 2018). This cartographic approach allows for the knowledge to be more visually communicated to decision makers which tends to improve comprehension. Some studies have evaluated resilience by prioritizing indicators such as critical infrastructure, however these studies tend to be technical centric (Serre, 2016). While this evaluation is evidently a crucial aspect of the resilience evaluation, it is also important to integrate other additional components in order to gain a more holistic understanding of the territory. Studies assessing resilience in a holistic manner allow for the categorization of resilience indicators into several broad dimensions: social, economic, institutional, urban, technical, community capital, infrastructural, and natural dimensions. These dimensions defined by indicators such as; accessibility to electricity and sanitation, water supply demands, infrastructure drainage, as well as shoreline evolution and surface elevation, respectively (MacAskill and Guthrie, 2014 ; Cutter, 2016 ; Cai et al., 2016 ; Song et al., 2017; Serre and Heinzlef, 2018 ; Zheng et al., 2018 ; Santos et al., 2020 Lamaury et al., 2021). The natural dimension is often left out (Song et al., 2018), because the data supplying this dimension generally comes from large databases which do not offer the high spatial resolution necessary for the analysis of this dimension. This higher resolution allows for a finer analysis, facilitating site specific research.

Table 1 provides examples of studies and their respective dimensions in which the indicators have been categorized as well as the data sources that supply said indicators. This table highlights the previous points that the natural/physical dimension is often left out, and most studies that do evaluate the natural dimension tend to obtain data from large federal annual censuses as well as use aggregated data, which does not permit a zoom on at-risk spots (Cutter, 2008, 2016; Song et al., 2018). This study aims to bridge the gap by integrating the natural dimension within the resilience analysis through the use of UAVs as the data acquisition source which will additionally allow for the acquisition of site specific data as well as controlling the temporality of the data (i.e. acquiring data before and after a storm) (Jessin et al.,2023).

Table 1: Examples of resilience dimensions and the data sources used for assessment within various studies

Reference	Dimensions	Data sources
Cutter et al., 2010	Social, economic, institutional, infrastructure, community capital	Federal census and county wide databases
Lamaury et al., 2022	Social, urban, technical	National census
Assahkahani et al., 2020	Social, economic, institutional, infrastructural, environmental	Nationwide statistical surveys
Rus et al., 2018	Infrastructural, socio-economic, organizational	Commune-wide statistics
Zheng et al., 2018	Economic, social, ecological, infrastructure	City wide statistical yearbook
Santos et al., 2020	Socio-economic, Technical, Environmental	National census

3.0 Material and Methods

Study Site

French Polynesia is composed of 121 islands and atolls (71 of which inhabited), containing a wide array of geographic diversity, stretching over 2.5 million square kilometers and 5 archipelagos in the South Pacific Ocean (Figure 1). Today, the population of French Polynesia is roughly around 300,000, of which 69% live on Tahiti, the largest island (ISPF, 2017). The economy is moderately developed and dependent on tourism, imported goods, and the financial assistance of mainland France. The Pacific islands are generally considered as one of the most exposed to natural hazards areas on the globe, with the most disaster-related deaths, accounting for 75% of the global mortality between 1970–2011(Edmonds & Noy, 2007; Guha-Sapir et al., 2012). Coastal areas have played a decisive role in human settlement history and continue to be the main places for settlement, economic activities, and infrastructure development. Coastal tourism (transportation, accommodation, catering, and related services) accounts for 27% of the GDP (ISPF 2017), and pearl farming plays a critical and reputational role (IEOM 2020). Within the islands of French Polynesia, urban development is specifically concentrated within the narrow coastal strip and generally does not go very far up the mountains located right at the foot of the coasts. Roads and infrastructure are also mainly coastal such as the Faaa international airport on the island of Tahiti which is located only 2 m above sea level (Bessat et al. 2006). This is the only international airport of the 5 archipelagos and one of the main source of import/export locations. This role coastal systems play in French Polynesia prompted the selection of the study site. This study focuses on the island of Bora Bora as a case study, more specifically the Matira peninsula of Bora Bora, in the south of the island. This location was selected due to its urban development and high rates of tourism. This zone is the most visited location by tourists on the island, it is composed of public beaches, hotels, restaurants, and local residential homes. This island is dominated by luxury hotels and restaurants specifically along the barrier reef and on the southern tip. Additionally, the Matira peninsula has previously been listed as at risk of erosion and marine submersion by other studies and local officials (Gabrie et al., 1994; Gairin et al., 2021). Bora Bora is the most famous island within the 5 archipelagos and was crucial in the development of the international tourism industry for French Polynesia.

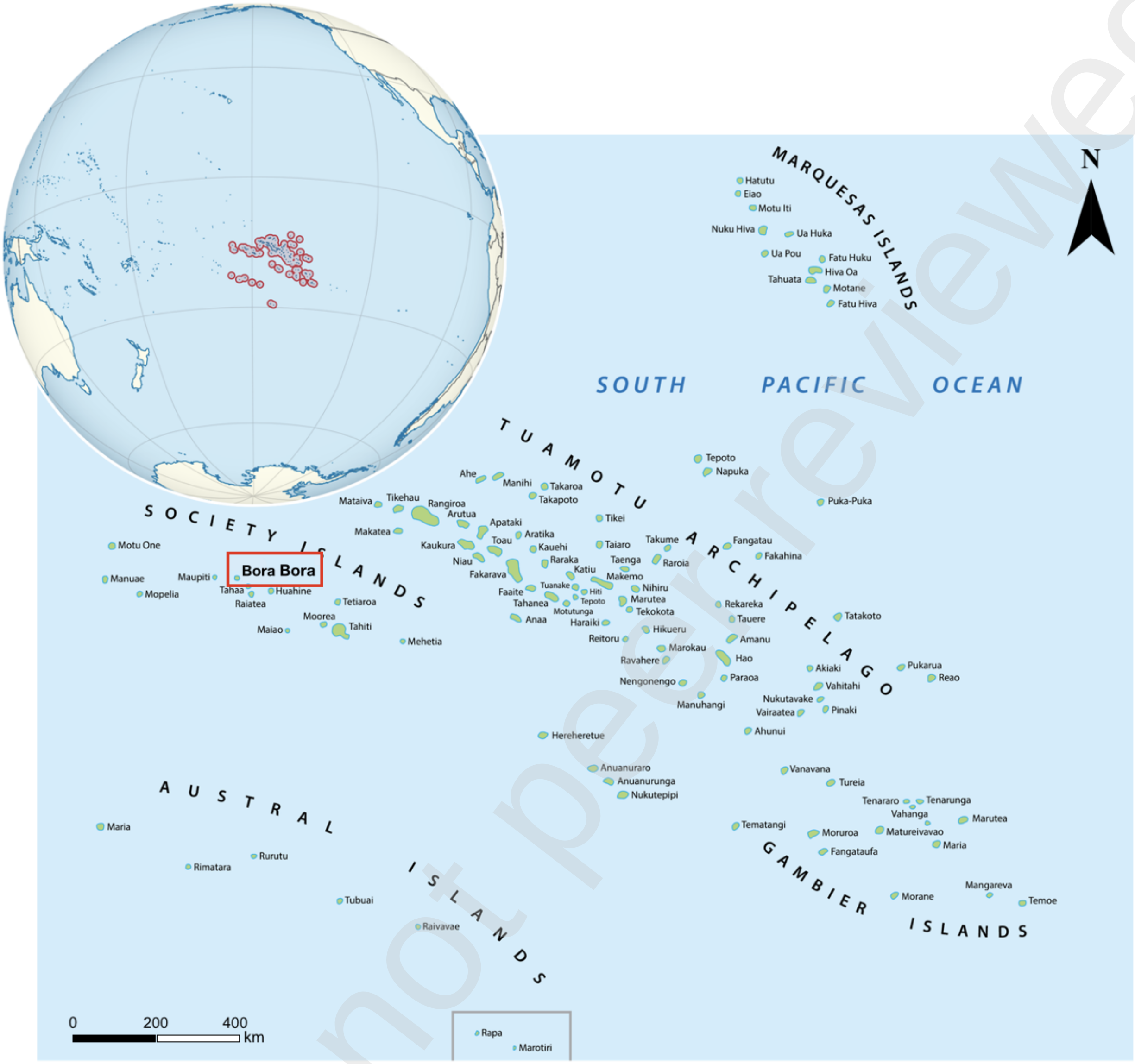

Figure 1: Location of French Polynesia and Bora Bora. Adapted from World Atlas ©

Selected indicators for Resilience Potential Assessment

Within the field of evaluation and management, indicators can supply data to measure characteristics, in order to evaluate performance. An indicator thus provides a description of how to measure an issue. The development of resilience indicators was originally adopted from the science of vulnerability indicators, which argues that indicators are not values, but variables, that are an operational representation of an attribute (Gallopin, 1997, Schönthaler and Von Andrian-Werburg, 2010). An indicator's goal is to simplify the understanding and interpretation of results. An indicator does not, however, reflect the reality of a territory, but rather provides an image of something at a given moment (Maby, 2003). It is, however, a relevant tool for characterizing the evolutionary processes of resilience in the face of risks.

The assessment of the TRP must take into consideration the geographical and even cultural context of the study site. As mentioned previously, coastal island territories have unique specificities (insularity, dynamic, and vulnerable environments), therefore the indicators are selected in regards to the literature review on disaster resilience, as well as the context of coastal island territories and the specific study site. The selected indicators were either created based on the context of the study site or chosen from existing literature. A search was conducted on Google Scholar, ScienceDirect, and JSTOR, identifying studies that evaluated resilience through the use of indicators in order to analyze potential indicators that could be applied to this specific study. The search terms used were: “resilience indicator assessment”, “resilience evaluation”, “resilience to natural risks”, “resilience indicators to coastal hazards” “resilience to floods” “resilience to man-made disasters”, and “conceptualization of resilience”. The search only included articles in English and did not have a date limitation. Articles were first selected on a preliminary comb through based on title and abstract that corresponded to an evaluation of resilience to natural hazards. A second effort was then conducted, which consisted of hand selecting specific indicators within these studies. The indicators selected were only those which could be potentially observed or complemented by a specific data source as well as applied to a the specific territory of coastal island territories.

The originality of this table of indicators lies in the data acquisition sources. Only indicators capable of being identified by UAV or that UAVs would bring complementary data to were selected. This study was able to construct site-specific indicators to represent the different components of resilience. This study recognizes that the agglomeration of these indicators will not be able to measure the entirety of a territory’s resilience but simply bring additionally information to its assessment. The indicators are categorized first by dimension of resilience (artificial or natural environment), followed by the variables that constitute each specific indicator and the unit of measure. Other dimensions such as social, economic, and other dimensions were excluded from this study because their data sources could not be acquired by UAV. The artificial dimension deals with the building characteristics of the infrastructures and the land use of the territory (Cutter et al., 2014 ; Cimellaro et al., 2016 ; Asadzadeh et al., 2017 ; Serre and Heinzlef, 2018 ; Alberico et al., 2020), while the natural dimension deals with the environmental and physical characteristics of the territory (Cutter et al., 2014). Additionally, the contribution of impact an indicator has on the TRP is listed. This column identifies whether the indicator has a positive or a negative impact on the resilience of the territory justified through the scientific literature in regards to a specific hazard. For instance, the presence of groynes/shoreline protective structures variable within the infrastructure indicator was determined as having a positive impact on the TRP because it reduces the impact of erosion, thus protecting the urban development. Since these indicators and variables have been identified in regards to the human perspective, variables such as groynes and shoreline protective structures will consider the advantages of using these structures to combat storms and SLR rather than the natural disadvantages that accompany these structures i.e. blocking sedimentary dynamics. Finally, since disasters occur over a certain period of time, resilience assessment has to integrate this temporality (Boin, 2005). When assessing the temporality of the impact, the time scale is limited to the timeline of the disaster itself. Three scenarios are analyzed: before, during and after the disaster (Figure 2). Lamaury et al., (2021) use this methodology and state that not all variables are included in each scenario, for example; the employment situation does not impact the before and during phases much but is necessary for the last phase (after), this will aid in rebuilding and reviving economic activity (Lamaury et al., 2021). However, when conducting a similar analysis for these indicators and their variables, all variables were found to have an impact during all three phases. Figure 2 demonstrates how the three phases of analysis (before, during, and after) come into play with previous and future shocks. The “after” phase of a shock is separated from the future risk’s “before” phase. After the shock constitutes of immediate efforts post disturbance such as: exiting shelters and returning home (if possible). The rebuilding efforts will occur in the “before” phase of the previous shock.

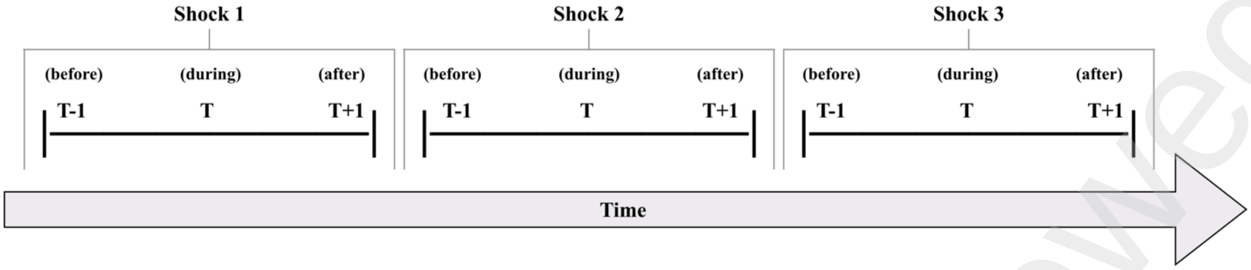

Figure 2: Conceptual schema of the temporality of a shock. Time is shown as a linear arrow with 3 shocks or disasters represented temporally. Within each shock, three phases are identified (before, during, and after), with T serving as the moment in time in which the shock occurs.

Data Acquisition by UAV

In order to demonstrate the application of this indicator-based methodology, this study begins the quantification process by calculating two variables from each dimension (artificial and natural environments): beach presence and presence of groynes/shoreline protective structures. This case study serves as an example of the feasibility of this method. The data was acquired by UAV imagery during a larger campaign to acquire data on a variety of different archipelagos and islands in French Polynesia, in December of 2022 (Jessin et al., 2023). The protocol for the UAV data acquisition is adopted from the Long et al., 2016 study, which consist of using commercial UAVs for image acquisition of the study site, geo-referenced to ground control points that were acquired during a GNSS survey. The UAV flew at an altitude of 70 meters, a 5.2 meters per second and captured an image every 2.5 seconds, i.e. at equal distance intervals. The camera was angled at 90 degrees (at nadir) and the percentage of image overlap consisted of 80% on the front and 70% on the side. Four flights were conducted on the Matira peninsula in order to respect the legislation and flight times, which were then all merged together for the post processing procedure. Combining both the UAV images and the GNSS data allows for the application of photogrammetry techniques to create 3D models from 2D images. As results, a digital elevation model and an ortho-mosaïc are produced, through the use of photogrammetry software: Pix4D Mapper. Finally, when uploaded into GIS software (ArcGIS), the processing of the data can occur, such as cartographic efforts for spatialization and visualization which will later allow for the indicator quantification.

Indicator Spatialization Method

Through the use of GIS software (ArcGIS pro), the selected variables were able to be spatialized. For the calculation of the beach presence, a polygon was created all along the coast of the study site. This zone was defined as the area from the water line to the first appearance of vegetation or artificial structure. As for the second indicator identifying the presence of shoreline protection: groynes and shoreline protective structures, this indicator was spatially digitalized and mapped on the orthomosaic obtained by the UAV.

Synthesis of Procedure for TRP Analysis Through UAV Data Acquisition

Figure 3 present a schematic representation of the procedure adopted during this methodology along with the elements involved, which highlights 3 specific phases: input, data processing and outputs.

The input phase is comprised of the raw data acquisition by UAV which consists of the aerial images taken by the UAV as well as the GNSS survey conducted needed for accurate geo-referencing. Additionally, this raw data source can be complemented by census data from federal/district/local databases as have done other studies that have conducted resilience evaluations, which would thus be added within the input portion of the schematic presented below. Subsequently, these input elements require data processing which leads to the second step. In step 2, the raw data undergoes processing in GIS and/or photogrammetry software, these software provide the tools necessary to create the models and ortho-mosaics as well as the digitizing of the indicators and their variables. Step 3 uses the produced elements: the models and the spatialized indicators and applies the resilience formula and evaluation rules while aggregating the variables in order to create a map of indicators which when aggregated will lead to a cartographic representation of the TRP.

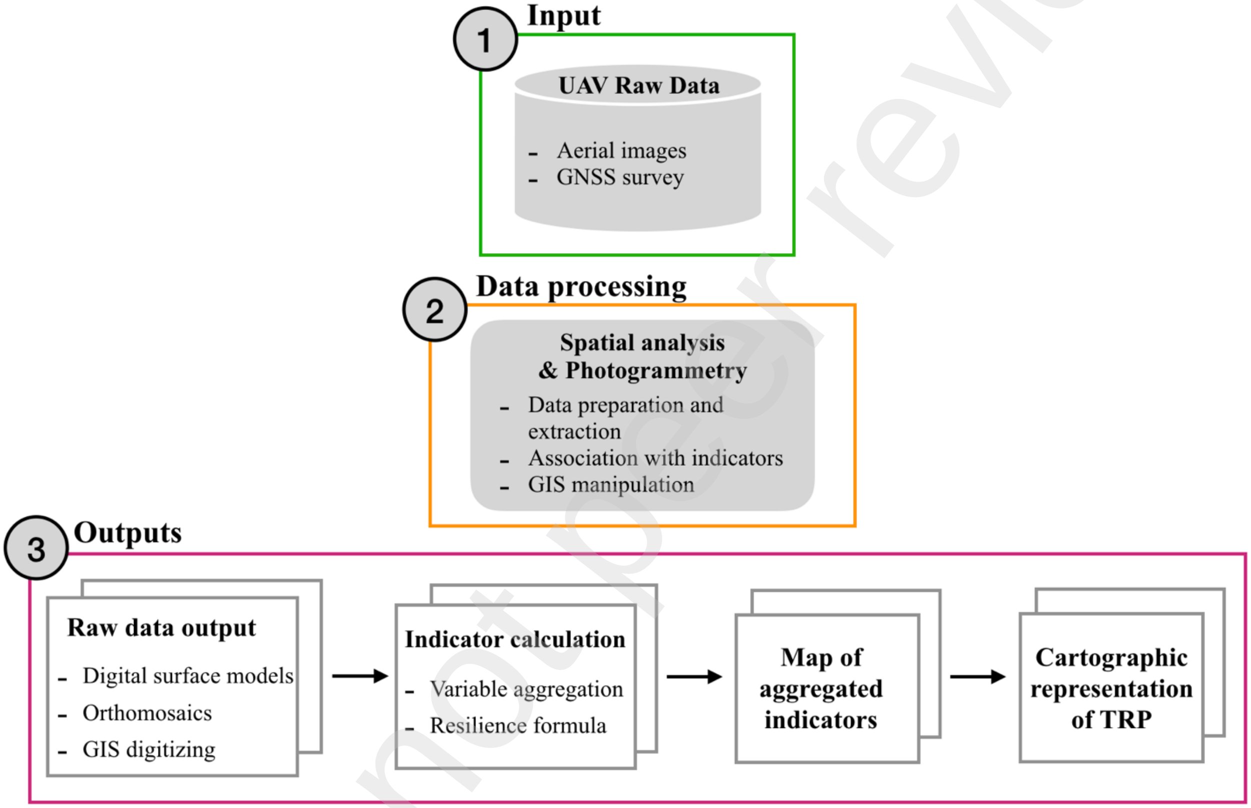

Figure 3: Synthesis of Procedure for TRP Analysis Through UAV Data Acquisition

4.0 Results

Defining a Table of Resilience Indicators

This study selected/created the following set of indicators and their variables to be evaluated by UAVs and represent the TRP in islands in regards to the context of island coastal territories around the globe, which included taking into consideration three of the most prominent coastal hazards impacting these territories: floods (fluvial), marine submersion, and erosion (coastal). There are two main resilience dimensions in which the indicators are organized into: artificial and natural environment. These four indicators are based on the existing literature and selected by their spatialized nature (table 2). The indicators are: Community strength and well-being; Infrastructure; Land; and Ecosystem functionality, and are discussed below. Finally, each indicator is represented by a certain amount of variables.

The analysis of which hazards come into play with each variable will allow for the identification of which factors most impact specific hazards and risks. Aiding decision makers later on to adapt to the specific needs of certain zones within their community. Figure 4 highlights which variables are impacted by which of the three coastal hazards listed previously. Marine submersion is the only hazard to have an impact on all of the variables, while floods and erosion split the rest of the variables (7 and 8 variables respectively). Only the surface elevation, presence of wetlands, and the presence of natural vegetation variables are inter-connected by all three hazards. Table 2 and figure 4 are described and presented below.

Community strength and well-being

Within the "community strength and well-being indicator," two variables are identified: bulky debris and presence of sidewalks. Both of these variables are connected to two of the three hazards: floods and marine submersion (figure 4). The bulky debris variable consists of abandoned vehicles, household appliances, furniture, scrap metal etc. These debris contribute to the waste of a territory and are susceptible to being washed away by floods, storms, and/or landslides and potentially blocking the flow of streams and rivers, thus contributing negatively to the TRP (Serre et al., 2016). Bulky debris were assessed as having an impact on the TRP for all three phases of the shock (before, during and after). Knowing the location of these large debris beforehand allows for the identification of zones most susceptible to the movement of dangerous debris during a disaster. After the shock these debris can end up blocking the flow of rivers and streams. The presence of sidewalks variable assumes that sidewalks increase the walkability of a community, thus rendering an area more accessible to the population. This variable is also playing a role before, during, and after a shock by allowing for movement to and from shelters and safe spaces especially in the case of road infrastructure failure. This variable therefore has a positive impact on the TRP (Hu et al., 2018; Fu and Wang, 2018; Tumini et al., 2017).

Infrastructure

The "infrastructure" indicator is represented by two variables: built and unbuilt spaces and the presence of groynes/shoreline protective structures. Both of these variable are connected to the marine submersion hazard, while the built and unbuilt spaces variable is connected to flooding and the presence of groynes/shoreline protective structures variable is connected to erosion (figure 4). The expansion of built-up areas can generate an increase in impermeable surface areas thus rendering the territory more susceptible to flooding and impacting the TRP negatively (Burton, 2015; Hung et al., 2016; Wheater and Evans, 2009; Tumini et al., 2017; Delgado-Ramos and Guibrunet, 2017). Groynes and shoreline protective structures however, provide protection from extreme events, reducing the impact of floods regarding human stakes, SLR, and storms. This variable has been deemed to positively contribute to the TRP (Burton, 2015; DasGupta & Shaw, 2015; Kammouh et al., 2019). Both of these variables play a role in the first two phases: before the shock (identifies zones less susceptible to flooding and marine submersion) and during (reduced risk in these zones). The built and unbuilt spaces variable also plays a role in the after phase as the reduced flooding causes less destruction and damages, allowing for a faster return to equilibrium. The presence of groynes/shoreline protective structures variable in regards to the "after" phase negatively impacts the TRP because the structures are blocking the sedimentary dynamics, therefore, in cases of erosion, the beach will not be able to replenish on its own. Thus, due to the negative impact, the after phase of this variable is not considered to play a role.

Land

The “land” indicator is represented by seven variables: beach presence, surface elevation, beach slope, presence of coastal shoreline restoration, proximity to rivers, presence of natural vegetation, and the presence of wetlands. The surface elevation, presence of natural vegetation and presence of wetlands variables are connected to all three hazards. The beach presence, beach slope and presence of coastal shoreline restoration variables are connected to marine submersion and erosion hazards, and finally, the proximity to rivers variable is connected marine submersion and floods hazards (figure 4). The presence of a beach provides a buffer zone against coastal hazards protecting the environment and urban development behind it. Therefore the presence of beaches positively contribute to the TRP (Kim and Park, 2018; Toubes et al., 2017). On the other hand, in regards to the surface elevation variable, greater elevation change along a study site is linked to greater slope and therefore more at risk to erosion and landslides, thus the surface elevation variable has a negative contribution on the TRP (Song et al., 2018). Similarly, the greater the beach slope, the more susceptible the beach becomes to erosion and increases wave power, this variable also contributes negatively (Kim and Park, 2018; Toubes et al., 2017). Zones with shoreline restoration activity serve to protect beaches which are natural buffer zones, the presence of these zones thus provides a positive contribution to the TRP (Cutter, 2015; Dasgupta and Shaw, 2015). However, increasing the proximity to a river increases the risk of flooding during extreme events, thus this variable negatively contributes to the TRP (Hung et al., 2016; Kotzee and Ryers, 2016; Toubes et al., 2017). And finally, natural vegetation and wetlands both serves as ecological buffer zones from hazards, specifically floods and marine submersion. Therefore both of these variables positively contribute to the TRP (Beatley and Newman, 2013; Kaye-Blake et al., 2019; Brody et al. 2012; Manyena et al., 2019). These seven variables play a role in all three phases: before the shock (identifies zones less susceptible to their associated hazards), during (reduced risk in these zones), and after (less destruction and damages allows for a faster return to equilibrium).

Ecosystem functionality

Finally, the “ecosystem functionality indicator” is represented by the presence of windbreaks and environmental plantings variable. This variable is connected to both the marine submersion and erosion hazards (figure 4). Windbreaks and environmental plantings serve as ecological buffers from weather conditions and reduce soil erosion and landslides. Therefore this variable is listed as a positive contribution to the TRP (Burton, 2015; Cutter et al 2008). This variable play a role in all three phases: before the shock (identifies zones less susceptible to harsh conditions and erosion), during (reduced risk in these zones), and after (allows for a faster return to equilibrium).

Table 2: Selected indicators for territorial resilience potential assessment by UAV

Dimension	**Indicator**	**Variable**	**Unit**	**Contribution of Impact**	**Justification**	**Temporality of Impact**
Artificial Environment	Community Strength and Well Being	Bulky Debris	number	-	Serre et al., 2016	Before, During, and After
		Presence of sidewalks	:	+	Hu et al., 2018; Fu and Wang, 2018; Tumini et al., 2017	Before, During, and After
	Infrastructure	Built and unbuilt spaces	:	-	Burton, 2015; Hung et al., 2016; Wheater and Evans, 2009; Tumini et al., 2017; Delgado-Ramos and Guibrunet, 2017	Before and During
		Presence of groynes/shoreline protective structures	%	+	Burton, 2015; DasGupta & Shaw, 2015; Kammouh et al., 2019	Before, During, and After
Natural environment	Land	Beach presence	%	+	Kim and Park, 2018; Toubes et al., 2017	Before, During, and After
		Surface elevation	m	-	Song et al., 2018	Before, During, and After
		Beach slope	degree	-	Kim and Park, 2018; Toubes et al., 2017	Before, During, and After
		Presence of coastal shoreline restoration	km²	+	Cutter, 2015; Dasgupta and Shaw, 2015	Before, During, and After
		Proximity to rivers	m	-	Hung et al., 2016; Kotzee and Ryers, 2016; Toubes et al., 2017	Before, During, and After
		Presence of natural vegetation	%	+	Kaye-Blake et al., 2019; Manyena et a., 2019	Before, During, and After
		Presence of wetlands	%	+	Beatley and Newman (2013) and Brody et al. (2012)	Before, During, and After
	Ecosystem Functionality	Presence of windbreaks and environmental plantings	%	+	Burton, 2015; Cutter et al 2008	Before, During, and After

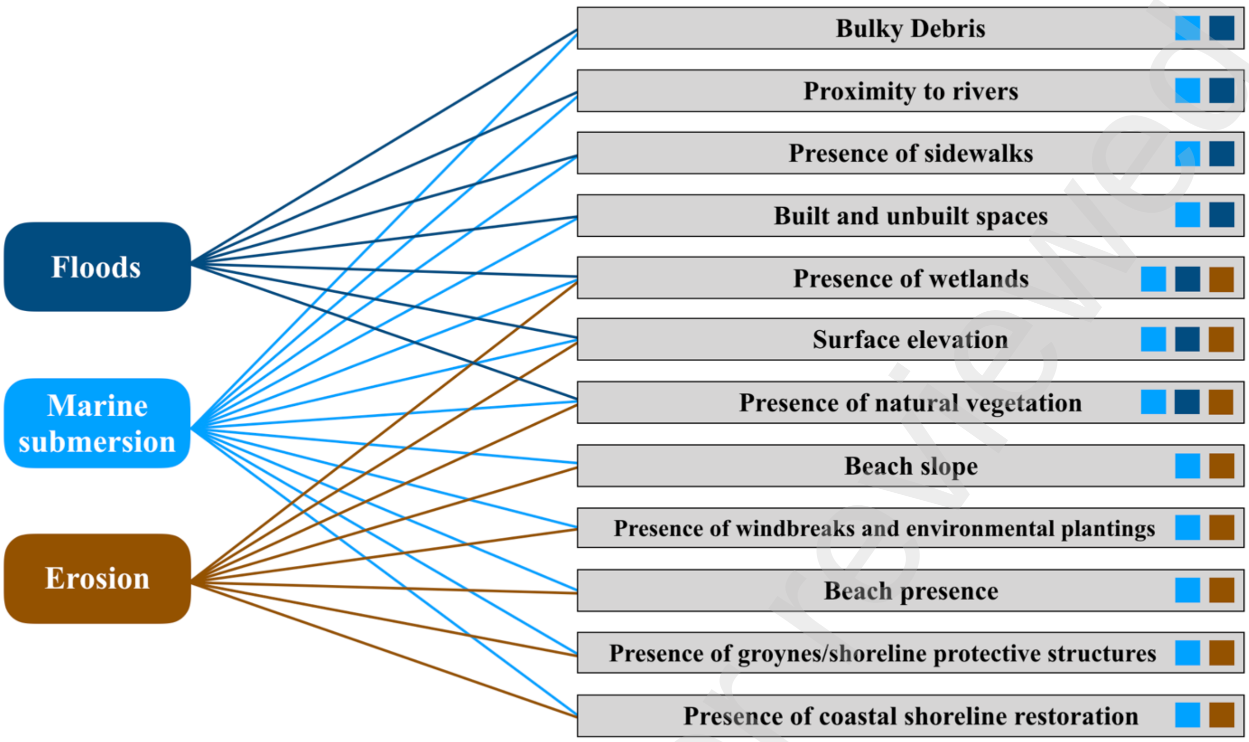

Figure 4: Inter-connections of Floods, Marine Submersion and Erosion on the 12 variables

In addition to classifying which variables are associated with which of the three most prominent hazards, the inter-connection between the variables themselves has been identified. Natural systems are complex, and risks often result from a combination of multiple factors. Identifying inter-connections between different indicators and their variables allows for a more comprehensive and holistic understanding of the risks involved. Additionally, inter-connected variables can act as early warning signals for potential disasters or adverse events as well as prevent cascading effects where one hazard event sets off a chain reaction of other events. Understanding how hazards can propagate and impact different areas, helps work towards building resilience across systems. This includes designing infrastructures and policies that can absorb shocks and recover more quickly from disruptive events. Hazards and their associated risks often evolve over time, and their inter-connections may change as well. Regularly assessing and identifying new connections helps in adapting long-term risk management plans to stay relevant and effective. In conclusion, understanding the inter-connections of variables in risk management enhances our ability to anticipate, prepare for, and respond to potential hazards. It enables a more integrated and comprehensive approach to risk reduction and builds greater resilience in the face of disasters.

Figure 5 demonstrates these inter-connections between the selected variables for each hazard. In figure 5, each circle represents one specific hazard containing all the associated indicators identified. The direction of the arrow indicates the course of impact, for instance, in figure 5a, the proximity to rivers variable has an arrow pointing to the bulky debris variable, meaning the proximity to rivers impacts the bulky debris variable because the debris closest to rivers are most the susceptible to being carried off in the event of flooding. This analysis was conducted for every variable of every hazard. Within the flooding hazard, the most impacting variable is the proximity to rivers variable. This is most likely due to the fact that rivers tend to be at the origin of floods and thus the proximity to the source can prove to be impactful. Figure 5b demonstrates the inter-connections within the coastal erosion hazard. The most impacted variable is the beach presence. The presence of a beach is impacted by the surface elevation, beach slope, the presence of natural vegetation, wetlands, windbreaks and environmental plantings as well as the presence of coastal shoreline restoration and groynes/shoreline protective structures. Occasionally, the arrows will go in both directions which indicates that both variables are impacting and impacted by each other. For instance, natural vegetation can serve as a buffer zone for beaches from weather conditions and maintain the integrity of dunes as well as relying on beaches for their own protection. Finally, figure 5c highlights interconnections of the variables in regards to the marine submersion hazard. Beach presence was additionally a prominent variable within this hazard. This variable is impacted by the presence of wetlands, natural vegetation, windbreaks and environmental plantings as well as the presence of groynes/shoreline protective structures. Beaches will be one of the first land elements to be affected or even submerged in the event of rising sea levels and storms, thus explaining why it is the most impacted variable. Surface elevation was also more heavily impacted and impacting than other variables because topography and slope play a major role in SLR, both over the long term and during extreme events.

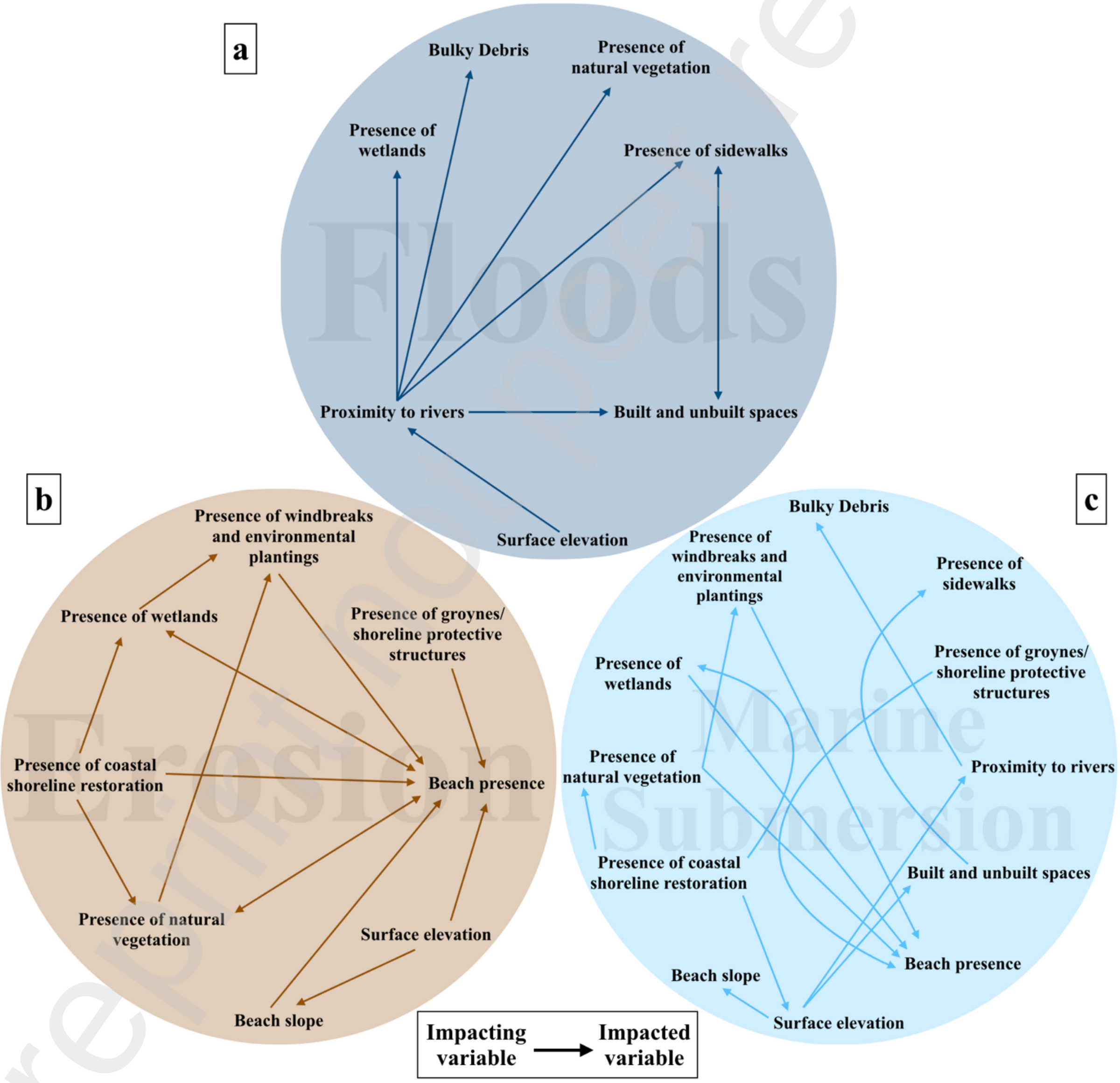

Figure 5: Inter-connections of variables within each risk: Floods (a), Erosion (b), and Marine Submersion (c). The direction of the arrow identifies the course of impact, indicating which variable is impacting and which is being impacted.

Geo-visualization for TRP resilience mapping

This portion serves as an example of application of the aforementioned methodology to assess its feasibility. The following figures cartographically present the spatialization of two variables: the beach presence and the presence of groynes and shoreline protectives structure within the case study of Bora Bora. The UAV imagery and post-processing obtained an orthomosaic and a digital surface model with a root-mean-square error of 10.45 centimeters on the z axis. These models allowed for an updated digitalization of the shoreline, the status of the beach, groynes and other shoreline protective structures along the study zone.

Figure 6 presents the spatialization of the beach presence variable on the Bora Bora study site. This study site was selected due to its strong urban development, thus accompanied by anthropic pressures. This figure shows the presence of a beach (more or less wide) along the entirety of the study site, except at the very tip of the peninsula where the beach has been covered by a shoreline protective structure. Because of the high rates of erosion this coast was reinforced by rockfills and shoreline protective structures. Along the rest of the study site, the beach is generally less than 10m wide, with occasional areas reaching up to 15m. These larger beaches are generally found in front of hotels and restaurants that are most likely actively invested in maintaining the beach for tourism practices. The presence of a beach contributes positively to the TRP (Kim and Park, 2018; Toubes et al., 2017). These zones of wider beaches therefore more positively impact the TRP of this study site.

Figure 6: Geo-visualization of the beach presence variable

In continuation of attempting to attest the feasibility of this methodology, this study selected a second variable to spatialize: the presence of groynes and shoreline protective structures. This variable was chosen for two reasons, first, while the beach presence variable was of the natural dimension, this second variable represents the second dimension: the artificial dimension. Secondly, because beach presence was assessed to have an inter-connection with the presence of groynes and shoreline protective structures as identified in figure 7. Two main types of shoreline protective structures were identified; perpendicular to the waterline, also known as groynes, (Figure 7a) or parallel (Figure 7b). Figure 8 represents the geo-visualization approach to spatializing the presence of groynes and shoreline and other protective structures on the study site. These structures were most likely put in place in an attempt to protect the shoreline from waves, flooding, and limit sand displacement. While both types of structures, parallel and perpendicular serve to protect the shoreline, they are purposefully identified apart from one another because groynes tend to be used to reduce sand displacement, while the parallel shoreline protective structures are used to absorb wave impact and limit the impacts of SLR (Williams et al., 2016). Figure 8 shows the presence of these structures on the entirety of study site, with a zoom on the southern end because of the concentration of such structures in this specific area and a lack thereof within the rest of the study site. The end of this peninsula is the most exposed as well as where most of the tourism on the island is concentrated. In fact, most of the coast of the very tip of this peninsula has been entirely rebuilt by a substantial shoreline protective structure. The literature (Burton, 2015; DasGupta & Shaw, 2015; Kammouh et al., 2019) associates zones in the presence of such structures with a higher territorial resilience potential because of the protection it provides to the urban development. The southern tip of the study site is the most dense in terms of presence of groynes and shoreline protective structures, thus this area could be considered to have a higher TRP.

Figure 7: Examples of the two main types of shoreline protective structures found on the Bora Bora study site. Perpendicular (a) and parallel (b) to the water line.

Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA,

Figure 8: Resilience potential for presence of dykes and embankments indicator on Bora Bora

Figure 5 identified interconnections between the variables, including a link between beach presence and groynes/shoreline protective structures. More specifically, that groynes and shoreline protective structures have an impact on beach presence. When combining the spatialization of both variables this becomes more evident. Figure 9 presents the same southern portion of the study site as in figure 8 where these variables come into play with each other. The beach of the western coast is much more eroded when compared to the eastern coast. As mentioned before, there are two types of structures, perpendicular groynes and parallel structures (in this case) made of rockfill, which tend to accomplish different goals (sand displacement vs. limiting waves and SLR impacts). The groynes on the east coast are in good condition made up of solid cement while the ones on west coast are in worse conditions, most likely withered away by weather conditions. The groynes are made up of loose rocks that are often partially or entirely submerged underwater (as evident by their irregular shapes and sizes in figure 9). The structural condition of the groynes plays a large role in their functionality as they tend to no longer serve their purpose when not properly maintained (Williams et al., 2016). Additionally the western coast is has more parallel protective structures, which prevents beaches being replenished by sedimentary deposits, which most likely also contributes to the lack of beach on this coast. The western coast is almost entirely composed of residential houses while the eastern coast is (separated by a street and 2 meter stone wall) is home to a luxury hotel. This dichotomy most likely explains the well maintained groynes and therefore a more present beach. The tourism industry relies on the beach and has the financial capacities to put forward resources to protect it, as well as even possibly recharging the beach with foreign sand.

Figure 9: Spatialization of interconnections between beach presence variable and groynes/shoreline protective structures variable

5.0 Discussion

This study has produced a table of contextualized indicators for the assessment of territorial resilience potential (TRP) of oceanic island coastal territories through the use of UAVs. This table not only identifies the indicators but the dimensions, variables, units of measurement, contribution of impact to the resilience potential, references to the justification by the scientific literature and lastly, the phase of resilience temporality in which it occurs. Additionally, this study attempted to demonstrate the feasibility of using UAVs as a data source for resilience assessment by geo-visualizing two different variables, one for each dimension.

Benefits and Advantages

The objective of this study was to introduce an original data source to a risk management strategy that would allow for the acquisition of high spatial resolution data, at high temporal frequencies. Obtaining site specific data would help decision makers choose appropriate policies for specific locations within their community, especially when faced with the ever increasing frequency and intensity of coastal hazards due to climate change. With the evolution of the resilience concept and technologic advancements in the field of UAVs, the link between the two has become feasible however relatively undocumented within the scientific literature. While further efforts are required to test this method to the full extent, this study serves as a baseline study in order to demonstrate the feasibility of using UAVs for the assessment of the territorial resilience potential.

There are a variety of advantages when adopting this method. Firstly, this assessment allows for a holistic approach by incorporating different dimensions which enables the previously technical-centric efforts to extend their analyses from critical infrastructure (ex. communication, energy, transportation infrastructure). This multi-dimensional assessment approach allows for the development of other types of resilience such as the natural dimension which is often left out in resilience evaluation studies. Secondly, as mentioned previously, the resilience assessment method can prove to be a complex concept due to its many definitions, multifaceted nature, and weighted indicators. This complexity can also prove difficult to integrate local actors outside of the scientific domain. The simplified methodology (i.e. non-weighted indicators) proposed within this study can facilitate the comprehension of the resilience concept for local stakeholders and users of the evaluation model which would allow for more collaborative measures. Subsequently, a handful of studies (Cutter et al., 2008; Jessin et al., 2021; Song et al., 2018) have argued that one of the major limits of the indicator based method is the availability of input data in a given territory, specifically in global south countries where annual census and large national databases are not as complete or accessible. UAVs would provide additional data that could be renewed more quickly than the institutions in charge of to do it, specifically in regards to land use. Additional benefits from using UAVs are: relatively cheap data acquisition, site specific data, allows for repetitive surveys, adaptability, rapid deployment, and high resolution data (Jessin et al., 2023). UAVs thus have several advantageous factors that will allow them to serve as effective data acquisition tools for a resilience assessment that will supply local authorities and decision-making bodies with a more specific knowledge of their territory.

Limitations and challenges

There are additionally some shortcomings to this method. First, when considering the impact a variable or indicator has on the resilience, there can be several answers depending on the perspective, the type of island, and the hazard being considered. More concretely, the indicators simply identify a negative or positive contribution to the TRP. When going through the literature to justify an indicator, at times the interpretations of the indicator/variable's characteristics lead to different or even contradictory interpretations depending on the spatial, political and/or cultural context. For instance, in regards to the presence of groynes and shoreline protective structures, this study chose to assign this variable a positive contribution of impact on the TRP. This is due to the shoreline protection and short term limitation of sand displacement that these structures provide, serving as a buffer zone, protecting the urban development behind them (Burton, 2015; Kammouh et al., 2019). However, these structures can also have a negative impact on the natural environment of a territory by increasing erosion (Muthusankar et a., 2017)). Some of these structures can modify hydro-sedimentary dynamics, which in some cases can lead to erosion. UAVs, while providing numerous advantages, have their shortcomings as well, such as; reduced spatial coverage (compared to manned aircrafts or satellites), various laws and regulations involving UAV flights (depending on the country), and certain geo-referencing complexities (outlined in Jessin et al., 2022).

Another challenge to consider is that some of the variables are going to be more or less present on certain islands due to their economic status, local risk perception, or legislation. For instance, the bulky debris variable, while very present on islands in French Polynesia will not be a factor on certain islands that have the resources to implement services and systems that collect and sort bulky debris in allocated locations.

Assarkhaniki et al., 2020 argued that the initial challenge to comprehensively incorporating resilience measurement is the lack of a common understanding about resilience. The problem is the existence of several overlapping definitions and dimensions. This complexity can additionally cause a lack of involvement from the local community. The inclusion of local actors allows for the acquisition of cultural and applicable knowledge only available through the association of these local actors. Therefore, a collaborative approach, prioritizing open access data and communication with local actors would provide a solution to these issues. These factors do however require a long term approach and the constant updating of data and result, one of which can use UAVs to remedy the issue, the other however can benefit from the implementation of a spatial decision support system. UAVs and spatial decision support systems are both tools capable of filling the gap of lack of data and lack of effective communication within the scientific domain. While certain limitations are present within this resilience assessment method, these tools have the potential to serve as solutions and fully operationalize the concept of resilience.

Perspectives and Link to Resilience Observatory

As mentioned before, this study serves as a foundation for the introduction of UAVs in the TRP assessment method. The next step is to pair this spatialization effort with resilience evaluation rules. These rules paired with the quantification of the variables would assign a numerical score of the TRP. Additionally allowing for the cartographic representation of the contribution of impact on the TRP. Essentially creating a map that combines all the variables to physically show which zones have a more positive or negative resilience potential.

In order to promote territorial collaboration, this methodology is anticipated to be connected to a localized resilience observatory. This study serves as a foundation for this project as it would finalize the cycle of data collection by providing up to date, accessible, agglomerated knowledge in order to assist decision makers. The next step will be to provide tools that are capable of linking the previously acquired data to such an observatory. Tools such as GIS approaches are useful for the geo-visualization aspects but also as concepts such as the participative GIS. The application of the Resilience Observatory for it to function as a spatial decision support system in French Polynesia is just beginning. A variety of studies have now been conducted on the operationalization of the concept of resilience as well as linking the study to application into an observatory (Heinzlef & Serre, 2020; Bourlier et al., 2021; Lamaury et al., 2021; Serre & Heinzlef, 2021; Heinzlef et al., 2022; Heinzlef & Serre, 2022; Jessin et al., 2022; Jessin et al., 2023;). The previously listed studies have begun to identify the role of the Resilience Observatory, the main objectives, its internal functions, the local actors, existing strategies and tools to facilitate the operationalization of the concept and finally how it will valorize data pre-existing and newly acquired data to supply the resilience observatory with an accurate representation of the environment being observed.

6.0 Conclusion

The operationalization of the concept of resilience is a complex endeavor that requires a wide array of data in order to represent a variety of factors at play. The concept of resilience often implies the occurrence of a crisis or damage, however, the measurement of resilience does not wait for a crisis to occur. Thus, this study analyses the territorial resilience potential which is defined as the potential capacity of the socio-ecological systems to cope with disturbances, induced by factors, by adapting whilst maintaining their essential functions. The use of indicators to categorize and assess a territory's resilience has been documented, however tends to utilize large databases that do not allow for site specific data, giving a rather global view (spatially speaking) of a territory's resilience. The use of contextualized, site specific indicators would allow for a zoom on hot and cold spots within a territory facilitating the decision making process for local decision makers.

Acquiring data with this level of precision however is not commonly accessible or in some cases does not even exist. UAVs have shown to be a data acquisition source that provide high resolution data capable of repeating frequent surveys at a relatively low cost. This study has attempted to bridge the gap between this data source and territorial resilience assessment methods, by conceptualizing resilience indicators capable of being acquired by UAV. By using Bora Bora as a case study, this study provided a table of territorial resilience potential indicators applicable to coastal island territories, composed of four indicators each with its own variables in order to test the feasibility of this method. These variables underwent an analysis which combed through the inter-connections in regards to the coastal hazards at play as well as the inter-connections between the variables themselves. This revealed that a couple of variables play an important role in a territory's resilience potential to coastal risks. Beach presence, surface elevation, and the proximity to rivers, are notably the variables most impacting of, or, impacted by other variables. In order to further the demonstration of feasibility of using UAVs for resilience assessment, ortho-mosaics and digital surface models were produced from the acquired UAV imagery. Two variables are spatially identified: beach presence, and the presence of groynes/shoreline protective structures (one from each dimension).

This method comes with its limitations: complexity within the concept causing a difficulty in comprehension especially when communicating with actors outside the scientific world as well as varying factors which impact the resilience of a territory differently causing the contribution of impact to be based on perspective. A spatial decision support system would help agglomerate the acquired knowledge and render this data more accessible to local actors as well as providing collaborative approaches, reducing some of the limitations of this methodology. While this method does not permit for a complete assessment of a territory's resilience potential, it does provide data that has been previously inaccessible and adds complementary information to the resilience assessment, ultimately aiding decision makers in rendering our communities stronger when faced with disaster.

7.0 References

Abeykoon, L.C.K., E.P.D.N. Thilakarathne, A.P. Abeygunawardana, T.W.S. Warnasuriya, and K.P.U.T. Egodauyana. 2021. Are Coastal Protective Hard Structures Still Applicable with Respect to Shoreline Changes in Sri Lanka?. ADBI Working Paper 1240. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/coastal-protectivehard-structures-still-applicable-shoreline-sri-lanka

Alberico, I., Iavarone, R., Petrosino, P., 2020. A procedure for the resilience mapping in urban systems exposed to natural hazard: The Ischia Island (southern Italy) test area. International Journal of Disaster Risk Reduction 50, 101893. https://doi.org/10.1016/j.ijdrr.2020.101893

Andrew, N., Bright, P., Rua, L. de la, Teoh, S., Vickers, M., 2019. Coastal proximity of populations in 22 Pacific Island Countries and Territories. Faculty of Law, Humanities and the Arts - Papers (Archive). https://doi.org/10.1371/journal.pone.0223249

Asadzadeh, A., Kötter, T., Salehi, P., Birkmann, J., 2017. Operationalizing a concept: The systematic review of composite indicator building for measuring community disaster resilience. International Journal of Disaster Risk Reduction 25, 147–162. https://doi.org/10.1016/j.ijdrr.2017.09.015

Assarkhaniki, Z., Rajabifard, A., Sabri, S., 2020. The conceptualisation of resilience dimensions and comprehensive quantification of the associated indicators: A systematic approach. International Journal of Disaster Risk Reduction 51, 101840. https://doi.org/10.1016/j.ijdrr.2020.101840

Barnett, J., Campbell, J., 2010. Climate Change and Small Island States: Power, Knowledge and the South Pacific. Climate Change and Small Island States: Power, Knowledge and the South Pacific 1–218. https://doi.org/10.4324/9781849774895

Beatley, T., Newman, P., 2013. Biophilic Cities Are Sustainable, Resilient Cities. Sustainability 5, 3328–3345. https://doi.org/10.3390/su5083328

Berrang-Ford, L., Siders, A.R., Lesnikowski, A., Fischer, A.P., Callaghan, M.W., Haddaway, N.R., Mach, K.J., Araos, M., Shah, M.A.R., Wannewitz, M., Doshi, D., et al., 2021. A systematic global stocktake of evidence on human adaptation to climate change. Nat. Clim. Chang. 11, 989–1000. https://doi.org/10.1038/s41558-021-01170-y

Bessat, F., Anselme, B., Decoudras, P., 2006. Impacts du réchauffement climatique sur les petites îles du Pacifique, modélisation et perception du risque : application au littoral de l'agglomération de Papeete (Polynésie française).

Betzold, C., 2015. Adapting to climate change in small island developing states. Climatic Change 133, 481–489. https://doi.org/10.1007/s10584-015-1408-0

Boin, A. From Crisis to Disaster: Towards in Integrative Perspective; Xlibris Press: Bloomington, IN, USA, 2005; pp. 153–172.

Brody, S.D., Peacock, W.G., Gunn, J., 2012. Ecological indicators of flood risk along the Gulf of Mexico. Ecological Indicators 18, 493–500. https://doi.org/10.1016/j.ecolind.2012.01.004

Burton, C.G., 2015. A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study. Annals of the Association of American Geographers 105, 67–86. https://doi.org/10.1080/00045608.2014.960039

Callaghan, M. W., Minx, J. C. & Forster, P. M. A topography of climate change research. Nat. Clim. Change 10, 118–123 (2020).

Cai, H., Lam, N.S.N., Qiang, Y., Zou, L., Correll, R.M., Mihunov, V., 2018. A synthesis of disaster resilience measurement methods and indices. International Journal of Disaster Risk Reduction 31, 844–855. https://doi.org/10.1016/j.ijdrr.2018.07.015

Cariolet, J.-M., Vuillet, M., Diab, Y., 2019. Mapping urban resilience to disasters – A review. Sustainable Cities and Society 51, 101746. https://doi.org/10.1016/j.scs.2019.101746

Casadio Tarabusi, E., Guarini, G., 2012. An Unbalance Adjustment Method for Development Indicators. Social Indicators Research 112. https://doi.org/10.1007/s11205-012-0070-4

Chelleri, L., 2012. From the «Resilient City» to Urban Resilience. A review essay on understanding and integrating the resilience perspective for urban systems. Documents d'Anàlisi Geogràfica 58, 287–306. https://doi.org/10.5565/rev/dag.175

Cimellaro, G.P., Arcidiacono, V., Reinhorn, A.M., 2021. Disaster Resilience Assessment of Building and Transportation System. Journal of Earthquake Engineering 25, 703–729. https://doi.org/10.1080/13632469.2018.1531090

Collins M., M. Sutherland, L. Bouwer, S.-M. Cheong, T. Frölicher, H. Jacot Des Combes, M. Koll Roxy, I. Losada, K. McInnes, B. Ratter, E. Rivera-Arriaga, R.D. Susanto, D. Swingedouw, and L. Tibig, 2019: Extremes, Abrupt Changes and Managing Risk. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 589–655. https://doi.org/10.1017/9781009157964.008.

Cutter, S.L., Ash, K.D., Emrich, C.T., 2014. The geographies of community disaster resilience. Global Environmental Change 29, 65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005

Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., Webb, J., 2008. A place-based model for understanding community resilience to natural disasters. Global Environmental Change, Local evidence on vulnerabilities and adaptations to global environmental change 18, 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Cutter, S.L., 2016. Resilience to What? Resilience for Whom? The Geographical Journal 182, 110–113. https://doi.org/10.1111/geoj.12174

DasGupta, R., Shaw, R., 2015. An indicator based approach to assess coastal communities' resilience against climate related disasters in Indian Sundarbans. J Coast Conserv 19, 85–101. https://doi.org/10.1007/s11852-014-0369-1

Delgado-Ramos, G.C., Guibrunet, L., 2017. Assessing the ecological dimension of urban resilience and sustainability. International Journal of Urban Sustainable Development 9, 151–169. https://doi.org/10.1080/19463138.2017.1341890

Duvat, V.K.E., Volto, N., Costa, S., Maquaire, O., Pignon-Mussaud, C., Davidson, R., 2021. Assessing atoll island physical robustness: Application to Rangiroa Atoll, French Polynesia. Geomorphology 390, 107871. https://doi.org/10.1016/j.geomorph.2021.107871

Fabbri, K.P., 1998. A methodology for supporting decision making in integrated coastal zone management. Ocean & Coastal Management 39, 51–62. https://doi.org/10.1016/S0964-5691(98)00013-1

Folke, C., 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change 16, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Frazier, T.G., Thompson, C.M., Dezzani, R.J., Butsick, D., 2013. Spatial and temporal quantification of resilience at the community scale. Applied Geography 42, 95–107. https://doi.org/10.1016/j.apgeog.2013.05.004

Fu, X., Wang, X., 2018. Developing an integrative urban resilience capacity index for plan making. Environ Syst Decis 38, 367–378. https://doi.org/10.1007/s10669-018-9693-6

Gabrié, C., Planes, S., Baldwin, J., Bonvallot, J., Chauvet, C., Vernaudon, Y., Payri, C., Galzin, R., 1994. Study of the coral reefs of Bora-Bora (society archipelago, French Polynesia) for the development of a conservation and management plan. Ocean & Coastal Management 25, 189–216. https://doi.org/10.1016/0964-5691(94)90056-6

Gallopin, G. C. (1997) - “Indicators and Their Use: Information for Decision-making. Part One-Introduction”. Sustainability Indicators. A Report on the Project on Indicators of Sustainable Development:13–27

Gairin, E., Collin, A., James, D., Maueau, T., Roncin, Y., Lefort, L., Dolique, F., Jeanson, M., Lecchini, D., 2021. Spatiotemporal Trends of Bora Bora’s Shoreline Classification and Movement Using High-Resolution Imagery from 1955 to 2019. Remote Sensing 13, 4692. https://doi.org/10.3390/rs13224692

Gemenne, F., Alex, B., Baillat, A., 2019. Implications of Climate Change on Defence and Security in the South Pacific by 2030 May 2019. Observatoire Defense & Climat.

Giardino, A., Schrijvershof, R., Nederhoff, C.M., de Vroeg, H., Brière, C., Tonnon, P.-K., Caires, S., Walstra, D.J., Sosa, J., van Verseveld, W., Schellekens, J., Sloff, C.J., 2018. A quantitative assessment of human interventions and climate change on the West African sediment budget. Ocean & Coastal Management, SI: MSforCEP 156, 249–265. https://doi.org/10.1016/j.ocecoaman.2017.11.008

Gonçalves, J.A., Henriques, R., 2015. UAV photogrammetry for topographic monitoring of coastal areas. ISPRS Journal of Photogrammetry and Remote Sensing 104, 101–111. https://doi.org/10.1016/j.isprsjprs.2015.02.009

Haunschild, R., Bornmann, L. & Marx, W. Climate change research in view of bibliometrics. PLoS ONE 11, e0160393 (2016).

Heinzlef, C., Barroca, B., Leone, M., Serre, D., 2022. Urban resilience operationalization issues in climate risk management: A review. International Journal of Disaster Risk Reduction 75, 102974. https://doi.org/10.1016/j.ijdrr.2022.102974

Heinzlef, C., Becue, V., Serre, D., 2019. Operationalizing urban resilience to floods in embanked territories – Application in Avignon, Provence Alpes Côte d’azur region. Safety Science 118, 181–193. https://doi.org/10.1016/j.ssci.2019.05.003

Heinzlef, C., Serre, D., 2020. Urban resilience: From a limited urban engineering vision to a more global comprehensive and long-term implementation. Water Security 11, 100075. https://doi.org/10.1016/j.wasec.2020.100075

Heinzlef, C., Serre, D., 2022. Understanding and Implementing Urban Resilience for Comprehensive and Local Risk Management, in: Eslamian, S., Eslamian, F. (Eds.), Disaster Risk Reduction for Resilience: Disaster Risk Management Strategies. Springer International Publishing, Cham, pp. 103–128. https://doi.org/10.1007/978-3-030-72196-1_5

Hoeke, R.K., McInnes, K.L., Kruger, J.C., McNaught, R.J., Hunter, J.R., Smithers, S.G., 2013. Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global and Planetary Change 108, 128–138. https://doi.org/10.1016/j.gloplacha.2013.06.006

Holand, I.S., Lujala, P., Rød, J.K., 2011. Social vulnerability assessment for Norway: A quantitative approach. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 65, 1–17. https://doi.org/10.1080/00291951.2010.550167

Holling, C.S., 1973. Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics 1–23.

Horton, B.P., Kopp, R.E., Garner, A.J., Hay, C.C., Khan, N.S., Roy, K., Shaw, T.A., 2018. Mapping Sea-Level Change in Time, Space, and Probability. Annual Review of Environment and Resources 43, 481–521. https://doi.org/10.1146/annurev-environ-102017-025826

Hu, M., Zhang, J., Huang, J., 2018. Assessing Social-Ecological System Resilience in Mainland China. Pol. J. Environ. Stud. 27, 1085–1096. https://doi.org/10.15244/pjoes/76242

Hung, H.-C., Yang, C.-Y., Chien, C.-Y., Liu, Y.-C., 2016. Building resilience: Mainstreaming community participation into integrated assessment of resilience to climatic hazards in metropolitan land use management. Land Use Policy 50, 48–58. https://doi.org/10.1016/j.landusepol.2015.08.029

Intergovernmental Panel On Climate Change (Ipcc), 2022. The Ocean and Cryosphere in a Changing Climate: Special Report of the Intergovernmental Panel on Climate Change, 1st ed. Cambridge University Press. https://doi.org/10.1017/9781009157964

ISPF, AND INSEE. (2017) - "Le recensement de la population en Polynésie française en 2017". Institut de la Statistique de la Polynésie-française

Jessin, J., Charlotte, H., Long, N., Serre, D., 2023. A Systematic Review of UAVs for Island Coastal Environment and Risk Monitoring: Towards a Resilience Assessment. Drones 7, 206. https://doi.org/10.3390/drones7030206

Jessin, J., Charlotte, H., Long, N., Serre, D., 2022. Supporting a Resilience Observatory to Climate Risks in French Polynesia: From Valorization of Preexisting Data to Low-Cost Data Acquisition. Water 14, 359. https://doi.org/10.3390/w14030359

Juigner, M., Robin, M., Debaine, F., Hélen, F., 2017. A generic index to assess the building exposure to shoreline retreat using box segmentation: Case study of the Pays de la Loire sandy coast (west of France). Ocean & Coastal Management 148, 40–52. https://doi.org/10.1016/j.ocecoaman.2017.07.014

Kammouh, O., Zamani Noori, A., Cimellaro, G.P., Mahin, S.A., 2019. Resilience Assessment of Urban Communities. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering 5, 04019002. https://doi.org/10.1061/AJRUA6.0001004

Kardel, I., Chormanski, J., Miroslaw-Swiatek, D., Okruszko, T., Grygoruk, M., J., M., 2011. Decision Support System for Biebrza National Park, in: Jao, C. (Ed.), Efficient Decision Support Systems - Practice and Challenges From Current to Future. InTech. https://doi.org/10.5772/17070

Kaye-Blake, W., Stirrat, K., Smith, M., Fielke, S., 2019. Testing indicators of resilience for rural communities. Rural Society 28, 161–179. https://doi.org/10.1080/10371656.2019.1658285

Kim, E., Park, H., 2018. Two-stage approach to quantify the resilience of maritime hazardous and noxious substance spill accidents. International Journal of Disaster Risk Reduction 28, 595–601. https://doi.org/10.1016/j.ijdrr.2018.01.009

Kotzee, I., Reyers, B., 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. Ecological Indicators 60, 45–53. https://doi.org/10.1016/j.ecolind.2015.06.018

Lam, N.S.-N., Qiang, Y., Arenas, H., Brito, P., Liu, K., 2015. Mapping and assessing coastal resilience in the Caribbean region. Cartography and Geographic Information Science 42, 315–322. https://doi.org/10.1080/15230406.2015.1040999

Lamaury, Y., Jessin, J., Charlotte, H., Serre, D., 2021. Operationalizing Urban Resilience to Floods in Island Territories—Application in sPunaauia, French Polynesia. Water 13, 337. https://doi.org/10.3390/w13030337

Lei, Y., Wang, J., Yue, Y., Zhou, H., Yin, W., 2014. Rethinking the relationships of vulnerability, resilience, and adaptation from a disaster risk perspective. Natural Hazards 70. https://doi.org/10.1007/s11069-013-0831-7

Lhomme, S., Serre, D., Diab, Y., Laganier, R., 2010. Les réseaux techniques face aux inondations, ou comment définir des indicateurs de performance de ces réseaux pour évaluer la résilience urbaine (Urban networks and floods : how to define performance indicators to evaluate urban resiliency). Bulletin de l'Association de Géographes Français 87, 487–502. https://doi.org/10.3406/bagf.2010.8193

Maby, J. « Approche conceptuelle et pratique des indicateurs en géographie ». In Objets et indicateurs géographiques, A.Barthelemy., 316. UMR Espace, Université d'Avignon, 2003.

Macaskill, K., Guthrie, P., 2014. Multiple Interpretations of Resilience in Disaster Risk Management. Procedia Economics and Finance 18. https://doi.org/10.1016/S2212-5671(14)00989-7

Magnan, A.K., Viriamu, T., Moatty, A., Duvat, V.K.E., Le Cozannet, G., Stahl, L., Anisimov, A., 2022. The climate change policy integration challenge in French Polynesia, Central Pacific Ocean. Reg Environ Change 22, 76. https://doi.org/10.1007/s10113-022-01933-z

Manyena, B., Machingura, F., O'Keefe, P., 2019. Disaster Resilience Integrated Framework for Transformation (DRIFT): A new approach to theorising and operationalising resilience. World Development 123, 104587. https://doi.org/10.1016/j.worlddev.2019.06.011

Masselink, G., Lazarus, E.D., 2020. Erratum: Masselink, G.; Lazarus, E.D. Defining Coastal Resilience. Water 2019, 11, 2587. Water 12, 1368. https://doi.org/10.3390/w12051368

Meerow, S., Newell, J.P., Stults, M., 2016. Defining urban resilience: A review. Landscape and Urban Planning 147, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Méheux, K., Dominey-Howes, D., Lloyd, K., 2007. Natural Hazard Impacts in Small Island Developing States: A Review of Current Knowledge and Future Research Needs. Natural Hazards 40, 429–446. https://doi.org/10.1007/s11069-006-9001-5

Merkle, A., Kaupenjohann, M., 2000. Derivation of ecosystemic effect indicators — method. Ecological Modelling 130, 39–46. https://doi.org/10.1016/S0304-3800(00)00213-1

Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., Kötter, T., 2019. A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. International Journal of Disaster Risk Reduction 35, 101069. https://doi.org/10.1016/j.ijdrr.2019.101069

Muthusankar, G., Jonathan, M.P., Lakshumanan, C., Roy, P.D., Srinivasa-Raju, K., 2017. Coastal erosion vs man-made protective structures: evaluating a two-decade history from southeastern India. Nat Hazards 85, 637–647. https://doi.org/10.1007/s11069-016-2583-7

Nalau, J. & Verrall, B. Mapping the evolution and current trends in climate change adaptation science. Clim. Risk Manag. 32, 100290 (2021).

Nurse, L., Mclean, R., Agard, J., Briguglio, L., Duvat, V., Pelesikoti, N., Tompkins, E., 2014. Chapter 29: Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Oppenheimer, M.; Glavovic, B.C.; Hinkel, J.; Van de Wal, R.; Magnan, A.K.; Abd-Elgawad, A.; Cai, R.; Cifuentes-Jara, M.; DeConto, R.M.; Ghosh, T.; et al. Sea level rise and implications for low-lying islands, coasts and communities. In IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; World Meteorological Organization: Geneva, Switzerland, 2019; p. 169.

Peacock, W., 2010. Advancing the Resilience of Coastal Localities: Developing, Implementing and Sustaining the Use of Coastal Resilience Indicators: A Final Report. https://doi.org/10.13140/RG.2.2.35146.80324

Pimm, S., Donohue, I., Montoya, J., Loreau, M., 2019. Measuring resilience is essential to understand it. Nature Sustainability 2, 895–897. https://doi.org/10.1038/s41893-019-0399-7

Pörtner, H.-O., Roberts, D.C., n.d. Climate Change 2022: Impacts, Adaptation and Vulnerability.

Rus, K., Kilar, V., Koren, D., 2018. Resilience assessment of complex urban systems to natural disasters: A new literature review. International Journal of Disaster Risk Reduction 31, 311–330. https://doi.org/10.1016/j.ijdrr.2018.05.015

Santos, P.P., Pereira, S., Zêzere, J.L., Tavares, A.O., Reis, E., Garcia, R.A.C., Oliveira, S.C., 2020. A comprehensive approach to understanding flood risk drivers at the municipal level. Journal of Environmental Management 260, 110127. https://doi.org/10.1016/j.jenvman.2020.110127

Satour, N., Raji, O., El Moçayd, N., Kacimi, I., Kassou, N., 2021. Spatialized flood resilience measurement in rapidly urbanized coastal areas with a complex semi-arid environment in northern Morocco. Natural Hazards and Earth System Sciences 21, 1101–1118. https://doi.org/10.5194/nhess-21-1101-2021

Schönthaler, K., von Andrian-Werburg, S., Wulfert, K., Luthardt, V., Kreinsen, B., Schultz-Sternberg, R., Hommel, R., 2010. Establishment of an Indicator Concept for the German Strategy on Adaptation to Climate Change.

Serre, D., Barroca, B., Balsells, M., Becue, V., 2018. Contributing to urban resilience to floods with neighbourhood design: the case of Am Sandtorkai/Dalmannkai in Hamburg. Journal of Flood Risk Management 11, S69–S83. https://doi.org/10.1111/jfr3.12253

Serre, D., Heinzlef, C., 2018. Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. International Journal of Disaster Risk Reduction, Understanding and mitigating cascading crises in the global interconnected system 30, 235–243. https://doi.org/10.1016/j.ijdrr.2018.02.018

Serre, D., Heinzlef, C., 2021. Long-Term Resilience to Climate Change Risks in French Polynesian Community, in: The Palgrave Handbook of Climate Resilient Societies. Springer International Publishing, Cham, pp. 1–28. https://doi.org/10.1007/978-3-030-32811-5_129-2

Serre, D., 2016. Advanced methodology for risk and vulnerability assessment of interdependency of critical infrastructure in respect to urban floods. E3S Web Conf. 7, 07002. https://doi.org/10.1051/e3sconf/20160707002

Song, J., Huang, B., Li, R., 2018. Assessing local resilience to typhoon disasters: A case study in Nansha, Guangzhou. PLOS ONE 13, e0190701. https://doi.org/10.1371/journal.pone.0190701

Taylor, S., Kumar, L., 2016. Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review. Tropical Conservation Science 9, 203–223. https://doi.org/10.1177/194008291600900111

Toubes, D.R., Gössling, S., Hall, C.M., Scott, D., 2017. Vulnerability of Coastal Beach Tourism to Flooding: A Case Study of Galicia, Spain. Environments 4, 83. https://doi.org/10.3390/environments4040083

Toubin, M., 2014. Améliorer la résilience urbaine par un diagnostic collaboratif : l’exemple des services urbains parisiens face à l’inondation (2014). Droit et gestion des collectivités territoriales 35. https://doi.org/10.3406/coloc.2015.2945

Tumini, I., Villagra-Islas, P., Herrmann-Lunecke, G., 2017. Evaluating reconstruction effects on urban resilience: a comparison between two Chilean tsunami-prone cities. Nat Hazards 85, 1363–1392. https://doi.org/10.1007/s11069-016-2630-4

Twigg, J., 2009. Characteristics of a disaster-resilient community: a guidance note (version 2).

Wheater, H., Evans, E., 2009. Land use, water management and future flood risk. Land Use Policy, Land Use Futures 26, S251–S264. https://doi.org/10.1016/j.landusepol.2009.08.019

Williams, A.T., Giardino, A., Pranzini, E., 2016. Canons of Coastal Engineering in the United Kingdom: Seawalls/Groynes, a Century of Change? Journal of Coastal Research 32, 1196–1211. https://doi.org/10.2112/JCOASTRES-D-15-00213.1

Zheng, Y., Xie, X.-L., Lin, C.-Z., Wang, M., He, X.-J., 2018. Development as adaptation: Framing and measuring urban resilience in Beijing. Advances in Climate Change Research 9, 234–242. https://doi.org/10.1016/j.accre.2018.12.002