Humans in social-ecological systems: A novel indicator-based approach to assess social resilience in mangroves

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Abstract

Assessing the resilience of social or ecological system in isolation differs significantly from evaluating the resilience of a social-ecological system. While numerous frameworks exist for resilience assessment, most are tailored to standalone systems. Applying them on social-ecological systems often leads poor decision-making. Principles well-suited for analysing the resilience of both social and ecological components in social-ecological systems exist in the literature. However, these principles present challenges due to the limited availability of appropriate indicators and variables. Through an extension of the principles, we provide a more refined set of indicators and variables applicable first on the social segment of mangroves, with the aim to extend the approach to the ecological dimension of the system. Two rounds of literature review were conducted: one focusing on threats to mangroves, and the other on indicators and variables aligned with the seven principles. Qualitative and quantitative data collection took place in the Republic of Benin; West Africa aims to operationalize this novel approach. This research represents one of the few efforts to empirically test and apply indicators and variables to operationalize the principles of resilience, offering a novel framework designed to assess the resilience of the social and ecological components within a social-ecological system.

1. Introduction

The concept of resilience has rapidly risen to the top of development agenda over the past decades (Capdevila et al., 2021). It is one of the most important research topics in the current path of achieving sustainability (Brand & Jax, 2007). Following its emergence, the term resilience has been used with a lot of disparities (Capdevila et al., 2021). As a result, Holling proposed in 1996 two main approaches to assess resilience: *engineering resilience* and *social-ecological resilience (*Brand & Jax, 2007). The social-ecological resilience which is the aim of this study refers to the amount of disturbance a system can absorb before shifting to another state (Capdevila et al., 2021). In a more comprehensive way, it refers to the capacity of a social-ecological system to withstand disturbances and maintain its key ecological functions (Capdevila et al., 2021). Mangroves represent an important social-ecological system divided into two major components: the social part and the ecological dimensions (Glaser et al., 2018). The social dimension represents human population who live around mangroves, and who partially or totally depends on the ecosystem for their livelihoods and well-being. The ecological dimension represents mangrove habitat. It is composed of the biotic and abiotic factors that interact to sustain the habitat (Glaser et al., 2018). Despite the abundance of frameworks and indicators to

assess resilience, there remains a gap in the literature regarding the specific indicators and variables necessary to evaluate the resilience within social-ecological systems. Most studies examining resilience in key social-ecological systems, such as mangroves, have relied on generic indicators related to socioeconomic characteristics and various form of capital (human, material, and physical) (DasGupta & Shaw, 2015). While these indicators are recognized for resilience assessment, they are more suited to evaluating the resilience of local communities or ecosystems as standalone systems rather than capturing the resilience of the components in social-ecological systems. The application of these indicators to the social or ecological dimension of complex social-ecological systems like mangroves leads to flawed decision-making, with severe implications for people's livelihoods and the environment. To address this issue, Biggs et al. (2012) and Sterk et al. (2017) laid important groundwork by proposing seven principles to evaluate the resilience of both the social and ecological elements in social-ecological systems. However, the absence of empirically tested indicators necessary to operationalize these principles leaves the framework incomplete and challenging to implement. To bridge this gap, we propose a new set of indicators and variables aligned with these principles, specifically designed to assess the resilience of the social and ecological dimensions of social-ecological systems. We focus on mangroves which represent critical coastal social-ecological systems and developed indicators and variables tailored to the social component of this ecosystem, with the plan to extend this effort to the ecological component. Mangroves are fragile coastal forests which occur in the intertidal zones of many tropical and subtropical countries. They are noted for their capacity to grow in highly challenging saline environments and provide many goods and services to the local environment and people worldwide. Mukherjee et al. (2014) defines mangroves as tidal habitats predominantly composed of a particular set of species. The difference between mangrove species and those occurring in inland forests lies in their ability of withstanding hard or difficult conditions such as saturated soils, high salt level and regular tidal floods (Alongi 2015). Studies that focus on mangrove development largely associated their growth with some specific conditions including the toposequence, the climate, the hydrography and manmade interference (Kairo et al., 2001; Dahdouh-Guebas et al., 2004; Walters et al., 2008; Srivastava et al., 2014). This work is essential to contribute to the development of accurate and reliable indicators and variables that are specifically adapted to mangroves as social-ecological systems, allowing more comprehensive and empirical assessment of mangrove resilience. Ongoing data collection in the mangroves of the Republic of Benin aims to operationalize these proposed indicators and variables, providing an opportunity to evaluate the strengths and limitations of this novel approach.

Conceptual framework: The principles of resilience

Numerous frameworks have been developed to evaluate resilience, yet only a limited number focus explicitly on social-ecological resilience. A prominent conceptual model addressing this gap was introduced by Biggs et al. (2012) and later expanded upon by Sterk et al. (2017) (Figure 1). This framework outlines seven overarching, policy-relevant principles essential for strengthening the resilience of social-ecological systems (Figure 1). These are:

- ✓ preserving diversity and redundancy,
- ✓ regulating connectivity,
- ✓ managing slow-changing variables and feedback mechanisms,

- ✓ promoting an understanding of social-ecological systems as complex and adaptive,
- ✓ supporting learning and adaptive experimentation,
- ✓ encouraging inclusive participation, and
- ✓ advancing polycentric governance structures.

The initial three principles relate to the fundamental characteristics of the system, while the remaining four pertain to governance mechanisms. In this study, we based on the seven principles, to propose and operationalize first and second order indicators essential to evaluate the resilience of human components in mangroves. The principle of "*diversity and redundancy*" was linked to livelihood diversity. It is largely reported that the diversity of economic activities at community level enhance the resilience of mangrove-dependent communities (Biggs et al., 2012). The second principle, "connectivity," refers to how different people within the social-ecological system interact, move, or disperse. The third principle addresses "slow variables," distinguishing them from fast-changing elements. These slow variables operate across extended timescales and include demographic characteristics that change slowly across years (Dahdouh-Guebas et al., 2021). Regarding the governance principles, the fourth— "fostering the understanding of social-ecological systems as complex adaptive systems (CAS)"—emphasizes the importance of how well stakeholders, especially managers, grasp ecosystem dynamics such as those of mangroves (Chen et al., 2020; Evangelista et al., 2024). This comprehension is often deepened through education, capacity-building efforts, public awareness, and effective science communication (Rim-Rukeh et al., 2013). The fifth principle, "learning and experimentation," underlines the adaptive nature of knowledge, where continuous learning and innovation are essential for dealing with uncertainties in complex systems like mangroves [12]. This process can be supported through targeted research efforts (Walker et al., 2004). The sixth principle, "participation," stresses the need for inclusive stakeholder involvement in both project management and decision-making (Sterk et al., 2017). Finally, "polycentric governance" advocates for the involvement of multiple overlapping authorities or institutions operating at different levels—national, regional, and local—all with shared responsibilities (Biggs et al., 2012).

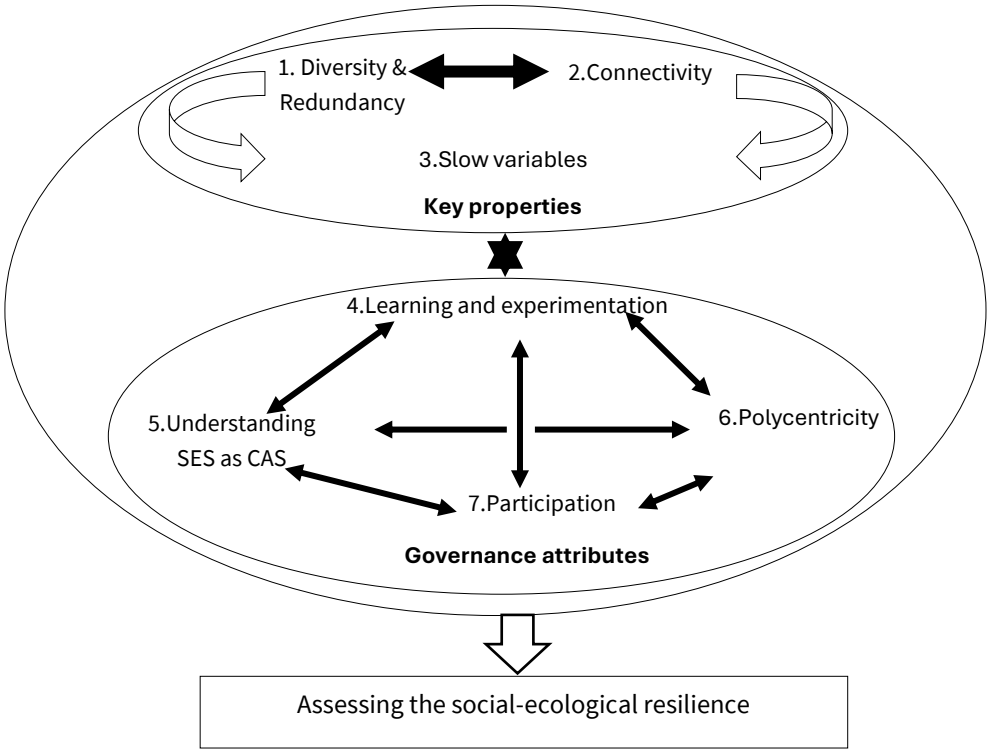

Figure 1. The principles of resilience. Source: Biggs et al. (2012)

2. Material and Methods

2.1. The study area

The case study area is the Ramsar site 1017 located in Benin Republic, West Africa. Ramsar sites are wetlands of international importance under the Ramsar convention (Bridgewater & Kim, 2021). Three communities — Adounko, Houakpè-Daho, and Avlo — were selected for data collection (See Figure 2). These communities were chosen during preliminary fieldwork conducted in 2023, based on the following criteria: accessibility, willingness of local authorities to support data collection, and availability of local guides to assist enumerators. Adounko, the first community, located in the municipality of Abomey-calavi, is easily accessible, but has had limited conservation and community-based project interventions. The second community, Houakpè-Daho, in the municipality of Ouidah, is moderately accessible and has experienced moderate conservation and community-based project interventions. In contrast, Avlo, the third community, is a remote island in the municipality of Grand-Popo, surrounded by the Mono river, coastal lagoon and their tributaries. It is difficult to access but has benefited from extensive conservation and community-based interventions due to its rich coastal biodiversity, which surpasses that of the other two communities. These communities, with their contrasting levels of accessibility and project interventions, were selected to explore the primary driver of social resilience within a mangrove community, specifically by comparing the influence of accessibility versus project interventions. The dominant ethnic groups found in the selected communities include Fon, Plah and Pédah. Other ethnic groups such as Adja, Mina, Yoruba and Ouatchi can also be found in minority. Fishing, salt production and vegetable growing are the main occupations of coastal dwellers in the selected communities (Teka et al., 2018).

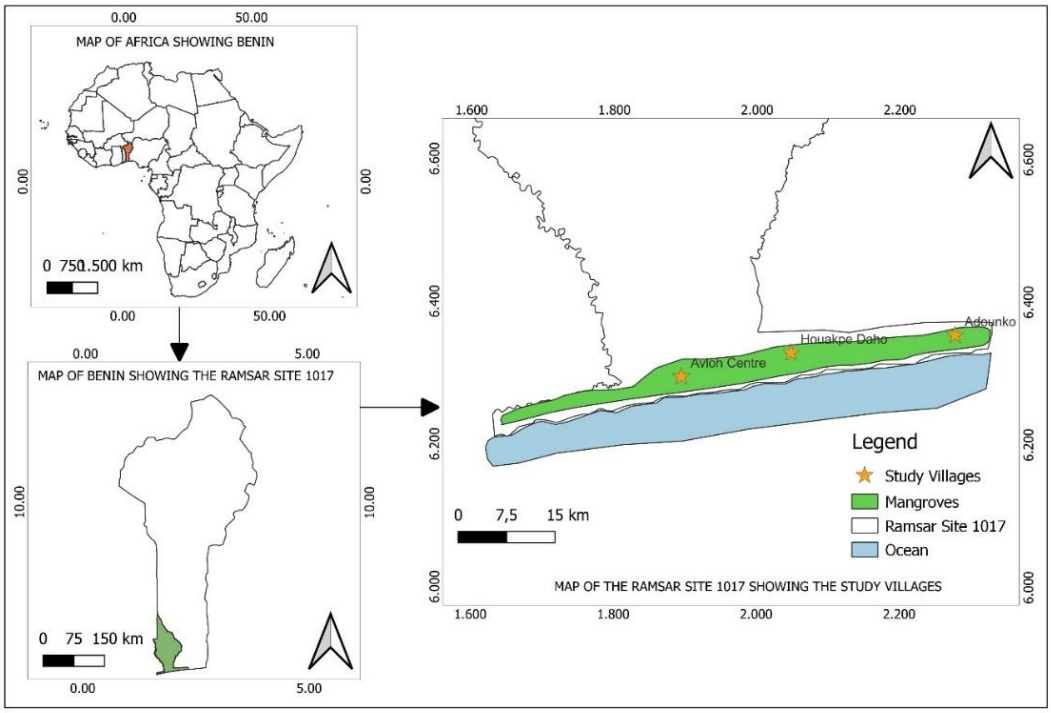

Figure 2. Study communities

2.2. Data collection

This study on the development of new indicators focuses initially on the social dimension of mangroves as a social-ecological system, with the aim of extending the effort to the ecological component in the future. The methodology is divided into two parts: first, the development of indicators and variables that can be applied to the seven principles at the community level to effectively assess the resilience of the social component within mangroves, and second, the operationalization of this newly proposed approach in coastal Benin.

2.2.1. Indicators and variables development

The initial phase of identifying appropriate indicators involved an extensive literature review. Two types of reviews were conducted for this study: the first aimed at identifying human-induced and climate-related threats to mangroves globally, while the second focused on identifying key indicators and variables to assess the resilience of the social component of mangroves to these threats, based on the seven principles of resilience. Resilience-focused articles for the literature review were sourced from databases and search engines such as ScienceDirect, Google Scholar and Scopus. The final list of key indicators and variables was developed after broad consultations of academics specializing in resilience, mangroves, social sciences, social-ecological systems, as well as local stakeholders involved in mangrove conservation.

2.2.2. Operationalization of the newly proposed indicator-based approach in Benin

This phase involves both qualitative and quantitative data collection (Figure 3). We collected data on the three coastal communities mentioned in the study area section in Benin to operationalize the proposed indicators. The first round of data collection involves the use of focus group discussions and in-depth interviews to gain insights into the preliminary threats affecting mangroves and their social components in the study communities. The quantitative phase then followed, aiming to assess the resilience of the communities to these identified threats, based on our proposed indicators and variables. In total, five informal interviews, ten in-depth interviews, three focus group discussions involving 30 participants and 300 respondents (quantitative survey) were included in the study. Variables were be transformed into measurable questions and were rated using a 5-point Likert scale and binomial questions (Yes/No). This approach ensures a comprehensive understanding of the social resilience of mangroves at community level. The qualitative data collected will be transcribed, coded, and analysed with NVivo to explore the threats encountered by coastal communities and their spatial variations at local level. Percentages were calculated to evaluate the score attributed to each indicator.

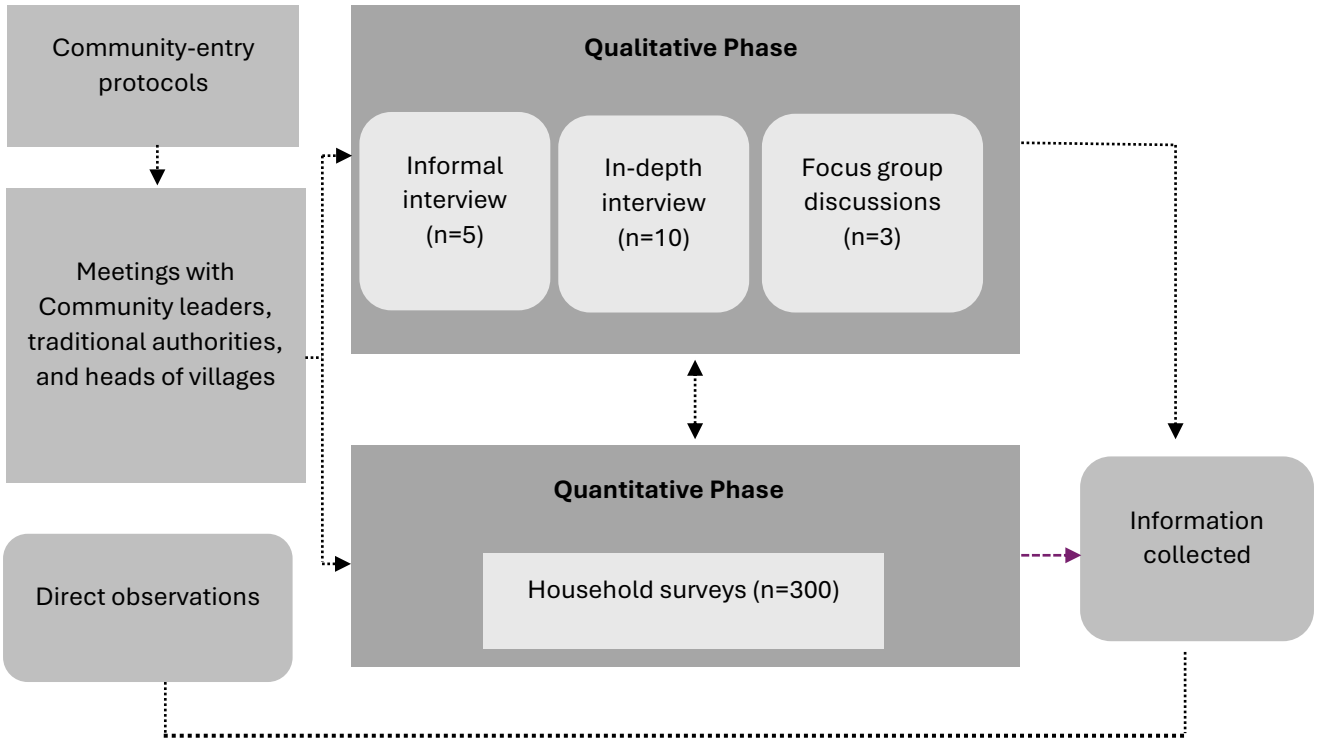

Figure 3. Flowchart of the methodological approach adopted for the study

3. Results and discussions

3.1. Proposed indicators and variables to assess social resilience in mangroves

This study is a part of a broader attempt to propose indicators to assess the social ecological resilience of mangroves based on plants, fish and humans. We introduce two types of indicators to assess the resilience of mangroves: specific indicators and systemic indicators based on the principles outlined in Figure 1. Specific indicators are linked to individual components and are drawn from the first three dimensions of our framework (diversity & Redundancy, connectivity and slow variables). Systemic indicators on the other hand, transcend individual components and connect at least two elements of the system. In this paper, we only present specific indicators for humans (Table 1), with the aim to extent to the other components in another chapter. Among the proposed indicators, livelihood diversity stands out as a key measure that aligns with the principle of maintaining diversity and redundancy. This concept refers to the variety of income-generating activities undertaken by community members, rather than dependence on a single economic source (Quandt, 2018). Livelihood diversification plays a vital role in resilience thinking, as it reduces susceptibility to shocks, enhances the community's adaptive potential, promotes economic steadiness, supports sustainable resource use, and strengthens social fabric (Hanazaki et al., 2013). When people in mangrove areas rely on multiple income streams, they are more likely to recover from disturbances.

The degree of connection between mangrove-dependent communities is another important factor in resilience and can be assessed through indicators such as social networks, communication systems, and transportation networks. In our study, we consider these elements as fundamental to measuring connectivity. Social network analysis (SNA) offers a valuable approach to assess how communities are linked internally and to others. This method helps to map relationships and understand how information, resources, or assistance are shared, revealing both strengths and gaps in social structures (Bertoni et al., 2022). Such analysis is

beneficial for resilience planning because it identifies influential figures who can disseminate critical information quickly, uncovers marginalized groups needing better integration, and facilitates improved coordination among stakeholders (Yao et al., 2023). Beyond social network, access to reliable communication tools (e.g., internet, mobile networks) and adequate transport systems enables faster emergency responses, strengthens access to external aid, and contributes to overall community resilience (Wang et al., 2022; Therrien et al., 2019).

Slow variables—those that evolve over extended periods—are also pivotal in influencing the long-term resilience of mangrove-related communities. These include demographic trends, economic conditions such as inflation, political instability such as coups d'état, and global geopolitical dynamics. Demographic indicators like age composition and household size are particularly important. A community with a mix of age groups benefits from both physical labour and the retention of traditional knowledge, both of which are necessary for sustainable resource use and resilience. Meanwhile, household size can have both positive and negative effects: larger families may offer more labour and diversified income potential, but they also require more resources, which can strain households during crises.

Other slow variables, such as rising inflation, can deeply affect the resilience of these communities. Inflation increases the cost of essential goods and equipment, placing additional strain on already vulnerable populations and making recovery from environmental stressors more difficult (Halim et al., 2022). Moreover, decisions made at the international level can significantly influence the well-being of these communities. For example, a decision by the Trump administration in January 2025 to halt USAID funding—a major source of international development aid—led to the suspension of numerous mangrove and fishery conservation initiatives across coastal African countries that were designed to enhance resilience.

Political upheavals like coups d'état are another crucial indicator of resilience. The consequences of such events can be measured through variables like the number of coups, the length of ensuing instability, policy reversals, changes in leadership, and the imposition of international sanctions (Powell & Chacha, 2016; Powell, 2012; Thyne & Powell, 2016; Ukaoka et al., 2024). For example, instability duration refers to the time during which community activities remain disrupted following a coup. Policy reversals look at whether community-oriented environmental regulations are weakened or rescinded. Leadership turnover examines how changes in officials—such as environmental ministers or protected area managers—affect conservation programs. Lastly, sanctions imposed by the global community may restrict funding or resources, further impacting the livelihoods of those in mangrove-dependent areas.

Table 1. Indicators proposed to assess the resilience of humans in mangroves

Dimensions	Indicators (First-order variables)	Metrics (Second-order variables)	Data to be collected	Source of data	Link with resilience	References
Diversity & Redundancy	Livelihood diversity	Diversity of economic activities	Data on people's livelihood and economic activities in mangrove communities	Primary data through survey	When local communities have multiple sources of income, they are better equipped to withstand disruption	Hanazaki et al. (2013) Quandt (2018) Liu et al. (2020)
Connectivity	Social network	-Relationships among individuals, and groups within and between communities -Involvement in local organizations (churches, local associations, *etc*.) -Information, aid and resource flow within communities	Data on people's social interconnection in mangrove communities	Primary data through survey	This supports resilience efforts by identifying key leaders who can quickly disseminate information during emergencies, highlighting disconnected or vulnerable groups in need of better support, and improving collaboration and resource flow between communities	Bertoni et al. (2022)
	Communication facilities	-Quality of internet connexion in the community -Access to smartphones by community members	Data on existing communication facilities in mangrove communities	Primary data through survey	Easy access to smartphones in mangrove-dependent communities, and quality internet connexion increases awareness about hazards and enhances resilience	Wang et al. (2022)
	Transportation infrastructures	-Types of transportation facilities in the -Quality and access to roads in the communities	Data on transportation facilities in mangrove communities	Primary data through survey	Better road network and transportation infrastructures facilitates the movement of goods and people and enhances resilience in mangrove communities	Therrien et al. (2019)
Slow variables	Key demographic variables	Age distribution and household size	Data on age distribution among mangrove dependent communities	Primary data through survey	A balanced age structure and household size supports resilience by ensuring a mix of physical capacity and knowledge retention.	

	Inflation rate	Cost of essential goods and living conditions	Data on inflation rate following currency depreciation	Economic data	Inflation increases the cost of essential goods, fishing equipment, and materials, pushing communities into economic hardship, and making it difficult for them to recover from environmental shocks	Halim et al. (2022)
	Impacts of coup d'etats	number of coups, duration of instability after the coup, policy changes or reversals, leadership turnover and international sanctions	Data on the impact of coup d'etats on people's lives in mangrove dependent communities	Primary data through survey	They can diversely affect mangrove-dependent communities ranging from curfew to restrictions, and reduce their resilience	Powell (2012) Powell & Chacha (2016) Ukoaka et al. (22024)
	Geopolitical decision	Number of mangrove projects or initiatives cancelled due to geopolitical decisions	Data on the extent to which geopolitical decisions impact on the mangrove-dependent communities			

3.2. Operationalizing the newly proposed indicators and variables in Benin

3.2.1. Descriptive statistics of the survey communities

The sociodemographic characteristics of the respondents investigated for the household surveys are presented in Table 2. The proportion of male in the selected communities accounted for 65% while 35% of female were interviewed. Ethnic groups which participated in this study included Fon (14.33%), Pedah (41.66%), Plah (35.33%) and Mina (8.66%). Respondents in their majority have no formal educational background (70%), and practice traditional religion (78.33%). Their main occupations included fishing (40%), fish processing (31.33%), farming (15.66%) and salt production (12.66%). Most of them are married (58.33%).

Table 2. Sociodemographic characteristics of respondents.

Socio-demographic characteristics	Adounko	Houakpè-Daho	Avlo	Total N= 300
	N= 100	N= 90	N= 110	
Gender				
Male	61 (61)	57(63.33)	77 (60)	195 (65)
Female	39 (39)	33 (36.67)	33 (30)	105 (35)
Ethnicity				
Fon	20 (20)	15 (16.66)	8 (7.27)	43 (14.33)
Pedah	35 (35)	30 (33.33)	60 (54.54)	125 (41.66)
Plah	40 (40)	34 (37.77)	32 (29.09)	106 (35.33)
Mina	5 (5)	11 (12.22)	10 (9.09)	26 (8.66)
Education				
No education	70 (70)	60 (66.66)	80 (72.72)	210 (70)
Primary	15 (15)	18 (20)	10 (9.09)	43 (14.33)
Secondary	15 (15)	12 (13.33)	20 (18.18)	47 (15.66)
Activity				
Farmers	25 (25)	17 (18.88)	5 (4.54)	47 (15.66)
Fishers	30 (30)	27 (30)	63 (57.27)	120 (40)
Fishmongers	44 (44)	30 (33.33)	20 (18.18)	94 (31.33)
Salt producers	1 (1)	15 (16.66)	22 (20)	38 (12.66)
Religion				
No religion	15 (15)	7 (7.77)	5 (4.54)	27 (9)
Christian	10 (10)	18 (20)	10 (9.09)	38 (12.66)
Traditional religion	75 (75)	65 (72.22)	95 (86.36)	235 (78.33)
Marital status				
Married	80 (80)	40 (44.44)	55 (50)	175 (58.33)
Widow/widower	10 (10)	28 (31.11)	25 (22.72)	63 (21)
Single/Bachelor	10 (10)	22 (24.44)	30 (27.27)	62 (20.66)

Values in parentheses represent the percentages while those which are not in parentheses are the absolute frequencies.

3.2.2. Operationalization of the proposed indicators

Indicators proposed in the first section were operationalized in the three selected communities in Benin (Adounko, Houakpè-Daho and Avlo), a coastal country located in West Africa (Table 3). Below is the detailed analysis of the proposed indicators across the study sites. Results presented in this section represent a portion of one of the first author's PhD chapter that investigates the social-ecological resilience of mangroves based on fish, plant and local populations.

3.2.2.1. Diversity & Redundancy

- ✓ Livelihood Diversity

The number of income-generating activities is a strong indicator of economic flexibility and adaptive capacity. Avlo, with 21 distinct activities, exhibits the highest livelihood diversity, followed by Houakpè-Daho (16), and Adounko (10), which lags considerably. In Avlo, the broad range of livelihoods—including fishing, harvesting *Cyperus articulatus*, salt production, agriculture, and oil extraction—allows households to shift between economic activities in response to seasonal, market, or environmental changes. This diversity cushions against specific sectoral shocks and provides fallback options, enhancing resilience. Houakpè-Daho, while moderately diversified, remains somewhat vulnerable if dominant activities are affected by shocks (e.g., climate events or overexploitation). In Adounko, the limited livelihood base restricts households' capacity to adapt. With fewer options to fall back on, a disruption in any one income stream can have cascading effects, undermining resilience. Increasing livelihood options through vocational training, microfinance support, and value chain strengthening—especially in Adounko—would build redundancy and reduce vulnerability to economic shocks.

3.2.2.2. Connectivity

- ✓ Social Networks (Communication Patterns)

Social connectivity is a critical element of social resilience. Houakpè-Daho has the highest percentage of respondents (75%) who maintain regular communication with both parents and friends. Avlo follows (60%), while Adounko, though having higher individual communication with parents (38%), scores lowest in combined communication (55%). Houakpè-Daho's strong communication ties suggest good information flow, emotional support, and potential access to informal help during crises. These networks can facilitate early warnings, shared resources, and collective coping. Avlo, while slightly less connected, still maintains sufficient interpersonal links to enable resilience through support networks. Adounko, with weaker overall communication, may face delayed information flow, limited social support, and isolation during crises—undermining its adaptive and absorptive capacities.

- ✓ Involvement in Local Organizations

Community participation in is strongest in Avlo (40%) and weakest in Adounko (22%). Engagement in groups such as churches, women's associations, or cooperatives often enhances collective action and social capital. In Avlo, strong organizational engagement supports cooperative responses, resource sharing, and access to collective resources or decision-making structures. In Adounko, low participation reflects social fragmentation or disengagement, eroding social capital and limiting the community's ability to organize effectively in times of need.

- ✓ Help & Assistance in Emergencies

Avlo shows the most balanced emergency support network, with 50% receiving help. In contrast, Houakpè-Daho and Adounko report higher percentages of individuals (77% and 65%, respectively) with no help in emergencies. Avlo's relatively broad access to informal support systems increases its capacity to absorb and recover from shocks. The high rate of self-reliance in Houakpè-Daho and Adounko suggests social safety nets are weak or absent. Without dependable help, households face compounded stress during emergencies, eroding their resilience over time. Notably, no respondents across any site reported receiving help from local authorities or formal institutions. This indicates an institutional gap in disaster risk management and response.

- ✓ Smartphone Access

Smartphone ownership is exceptionally low—Avlo (5%), Houakpè-Daho (7%), Adounko (3%). Limited smartphone access hinders real-time communication, access to early warnings, online education, digital financial services, and broader networks of support. All three communities are disadvantaged, but Adounko is particularly isolated. This severely limits its capacity for adaptive learning and digital engagement, crucial in modern risk contexts.

3.2.2.3. Transportation Infrastructure

- ✓ Modes of Transport

Walking is the most common mode of transport in all areas, especially Adounko (85%). Canoe usage is significant in Houakpè-Daho and Avlo. Heavy reliance on walking and canoes limits mobility, especially in emergencies (e.g., needing medical care, evacuation during floods). This restricts access to markets, services, and response systems. In Adounko, poor transport diversity increases isolation and reduces the ability to respond quickly to shocks or to engage economically.

- ✓ Road Quality

Houakpè-Daho is considered more accessible (35% highly accessible), while Avlo and Adounko are less so. Better road access in Houakpè-Daho facilitates access to markets, healthcare, and educational services, strengthening adaptive capacity. Adounko's

moderate to poor road conditions hinder movement and logistics during normal times and emergencies, thereby undermining both individual and community resilience

3.2.2.4. Slow Variables (Demographics)

- ✓ Age Distribution

All communities have similar age structures, with a significant number of children and babies, and large average household sizes in Avlo. A younger population offers a long-term resilience dividend if adequately educated and healthy. However, in the short term, it increases the burden on households for food, education, and care. Large households, like those in Avlo, may provide more labour for economic activities but also require more resources and coordination.

- ✓ Education Levels

Avlo has higher levels of education, including secondary representation, while Adounko has higher illiteracy rates. Higher education levels in Avlo increase access to information, improve income opportunities, and facilitate problem-solving, directly supporting adaptive capacity. Low educational attainment in Adounko reduces awareness of risks, limits job opportunities, and weakens community organization and leadership, all of which erode resilience.

- ✓ Household Size

Avlo's larger household size may be a strength or a liability depending on the household's internal dynamics and economic base. Larger households can mean more working-age individuals to engage in livelihoods or respond to crises. However, they also imply more dependents, which can strain resources, especially where income diversity is lacking. In Houakpè-Daho and Adounko, smaller households may be easier to support but could lack internal redundancy in labor and income generation.

Table 3. Operationalization of the indicators in Benin. Source quantitative survey (N=300)

Dimensions	Indicators (First-order variables)	Metrics (Second-order variables)	Questions asked	Avlo	Houakpè-Daho	Adounko
Diversity & Redundancy	Livelihood diversity	Diversity of economic activities	How many income generating activities exist in your communities?	21	16	10
Connectivity	Social network	Relationships among people	With whom do you frequently communicate?	Parents: 25% Friends: 15% Both: 60%	Parents: 20% Friends: 5% Both: 75%	Parents: 38% Friends: 7% Both:55%
		Involvement in local organizations	Do you belong to a local association	Yes: 40% No: 60%	Yes: 30% No:70%	Yes:22% No:78%
		Help and assistance	From whom do you receive assistance in case of emergency?	Nobody: 50% Parents: 30% Friends: 20%	Nobody:77% Parents: 13% Friends:10%	Nobody:65% Parents: 5% Friends:30%
	Communication facilities	Access to communication	Is the phone a smartphone?	Yes: 5% No: 95%	Yes: 7% No: 93%	Yes: 3% No: 98%
	Transportation infrastructures	Types of transportation facilities	What is your mean of transportation?	Foot: 55% Car:0% Motorbike:0% Canoe:45%	Foot: 35% Car:0% Motorbike:10% Canoe:55%	Foot: 85% Car:0% Motorbike:5% Canoe:10%
		Quality of roads	Rate the quality the road network of your communities	Not accessible: 12% Moderately accessible: 60% Highly accessible: 28%	Not accessible: 15% Moderately accessible: 50% Highly accessible:35%	Not accessible: 9% Moderately accessible: Highly accessible:25%
Slow variables	Key demographic variables	Age distribution	How many people of these categories are there in your house: Male>18, Female>18, Children<18, Baby	Male>18: 7 Female>18: 5 Children<18: 3 Baby: 2	Male>18: 6 Female>18: 5 Children<18: 4 Baby: 3	Male>18: 7 Female>18: 5 Children<18: 4 Baby: 4
		Education level	How many people of these educational categories are there in your household: no education, primary, secondary, tertiary	No education: 8 Primary: 7 Secondary: 7 Tertiary: 0	No education: 6 Primary: 5 Secondary: 5 Tertiary: 0	No education: 5 Primary: 3 Secondary: 5 Tertiary:0
		Household size	How many people are there in your house?	9	7	7

4. Conclusion

This study extended the principles of resilience, tailored specifically to social-ecological systems, to propose a new approach to assess the resilience of the social component of mangroves, with the aim of extending the approach to the ecological dimension of the ecosystem. The operationalization of this approach in coastal Benin shed light on a novel way of assessing social-ecological resilience. This approach aims the complement the existing ones for an effective assessment of mangroves as social-ecological systems. The analysis of diversity, connectivity, infrastructure, and demographic variables across Avlo, Houakpè-Daho, and Adounko reveals significant disparities in resilience capacities. Avlo emerges as the most resilient community, driven by high livelihood diversity, stronger local organizational engagement, and relatively better educational attainment. However, limited access to technology and formal support systems still constrains its adaptive potential. Houakpè-Daho demonstrates robust social connectivity and moderately accessible infrastructure, yet its resilience is weakened by poor emergency support and limited digital inclusion. Adounko shows the greatest vulnerability, marked by low livelihood diversity, weak institutional and social engagement, poor educational levels, and inadequate access to both information and transport. Overall, resilience is not evenly distributed. Strengthening resilience in these communities will require targeted interventions—diversifying livelihoods, fostering community-based organizations, improving digital and transport infrastructure, and investing in education. Tailored strategies that build on local strengths while addressing specific weaknesses are essential to ensure that all three communities are better equipped to withstand and adapt to future shocks.

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