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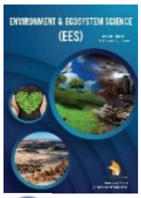

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RESEARCH ARTICLE

RESTORATION OF MANGROVE: EVALUATING ECOLOGICAL, SOCIAL, AND ECONOMIC INTEGRATION FOR PROJECT SUCCESS - A CASE STUDY IN THE PHILIPPINES

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ABSTRACT

The ecological restoration of mangroves is evolving from large monospecific replantation projects to the systemic approaches (hydro-geomorphological rehabilitation and local communities' involvement). To evaluate the effectiveness of these emerging projects to restore mangroves, this paper combines the analysis of 198 restoration project through literature review and the evaluation of a case study in the Philippines, where a restoration project combining replanting mangroves, the construction of infrastructure to limit wave and swell energy, and the development of a sustainable local economy was conducted. The results are mixed, with the failure of most of the reforestation actions (average survival rate of 1.5%), the failure of the maintenance of infrastructure, such as sediment traps, and the unsustainability of four income-generating activities. On the other hand, the installation of breakwaters was a success in terms of sediment accretion, as was the implementation of two income-generating activities. In addition, local communities' perceptions of the project are mostly positive. These results show that there are still important shortcomings in these projects, which are caused by a lack of knowledge regarding the ecology of mangroves' social ecosystems, as well as the governance system.

KEYWORDS

Socio-ecological restoration; mangroves; environmental management; Philippines

1. INTRODUCTION

When studying or restoring mangroves, it is first essential to define mangroves. Mangroves are coastal ecosystems characterized by halophytic trees living in intertidal zones at the confluence of terrestrial and aquatic environments in tropical and subtropical latitudes (Lugo and Snedaker, 1974). Here, they will also be considered as a social–ecological system (SES) (McGinnis and Ostrom, 2014). In other words, a unique and complex system between the ecosystem and the local society with unique properties emerging from their interactions (Dahdouh-Guebas and Cannicci, 2021). Mangroves support many contributions to people, such as material resources, fishery rejuvenation, water quality regulation through nutrient filtration, carbon sequestration, sediment stabilisation and cultural services (Dahdouh-Guebas and Cannicci, 2021; Palacios and Cantera, 2017; Queiroz et al., 2017). The mangroves of Southeast Asia has the highest species richness in the world (Basha, 2018).

Mangroves are sensitive to human activities and, from 1980 to 2000, the earth's mangrove cover diminished by 180,000 ha per year, i.e., there was a worldwide cumulative loss of 35%, which corresponded to a 1.5% annual decrease in overall cover (FAO, 2007). From 2000 to 2005, the rate of decreasing cover dropped to 0.66%, but it remained alarming (Feller et al., 2017; Friess et al., 2020). The annual decreased dropped down even more to 10 200 ha per year (5,6% of the 1980-2000 rate). The main driver for the loss in mangroves is conversion to aquaculture farms worldwide (UNEP, 2014) and in Southeast Asia (Richards and Friess, 2016). In 1982, 1958 km^2 of mangroves of east Asia had already been destroyed for the development of 3300 shrimp farms (Fortes, 1988). More specifically, for the Philippines, the rate of mangrove deforestation between 2000 and 2012 is estimated at 0.11% per year (Friess et al., 2019). The construction of these ponds started in the 1950s with fish farming, followed by a second wave in the 1980s with shrimp farms (Primavera, 1995). Landscape changes due to these ponds have been rapid and massive (Mialhe et al., 2016).

Faced with this rapid degradation, many mangrove restoration projects have emerged, and the need to manage and protect these ecosystems has been highlighted by many studies (UNEP, 2014; Ostling et al., 2009; Queiroz et al., 2017; Suding, 2011). In this paper we define restoration as the act of bringing an ecosystem back to its original condition, as far as possible (Field, 1999). The reforestation is intended as renewing forest cover following losses in forest area, be it through human-driven habitat degradation (e.g., forestry extraction, land-use change) or through natural processes (Zimmer et al., 2022). It includes both replantation and rehabilitation. Replantation means taking plant propagules or seedlings from another area to artificially increase the vegetation cover, which may or may not be a former mangrove (afforestation). Rehabilitation is defined as the re-establishment of the conditions and ecological processes in a degraded ecosystem or its habitat to initiate a trajectory toward the near recovery of its former state (recognizing that complete restoration may be impossible within the short or medium term) (Zimmer et al., 2022). And natural recovery is used about the process of an ecosystem regaining its former status without human interventions (Zimmer et al., 2022).

Mangrove management is evolving from forest management to systemic approaches, with restoration projects becoming more complex.

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Restoration projects exclusively based on replantation are becoming less common, while systemic projects involving the integrated management of the coastal zone are multiplying (Hai et al., 2020; Kamali and Hashim, 2011). Similarly, projects with little or no involvement of indigenous people and local communities (IPLCs) are becoming less common, and IPLCs are earlier invested in project management (Valenzuela et al., 2020; Biswas et al., 2009; Stone et al., 2008). Current initiatives regularly propose 'nature-based', 'soft', and 'passive' methods that support the natural resilience of ecosystems, minimizing human impact (Kamali and Hashim, 2011). By encouraging local communities to participate in the management of the environment, these solutions are intended to be more sustainable.

The initial efforts of this kind were undertaken on an experimental basis, but some of these projects have already demonstrated significant success rates (Babo and Froehlich, 1998; Chotthong and Aksornkoae, 2006; Sidik, 2008). These initiatives marked a significant milestone by being the pioneers in involving local partners such as NGOs and research institutes in project setups. Additionally, they were the trailblazers in integrating agroforestry and landscape engineering concepts into their projects. These initial successes have encouraged project leader to adopt this type of approach in their projects throughout the world (Brown et al., 2014; Damastuti et al., 2022; Lhosupasirirat et al., 2023; Wickramasinghe, 2017).

However, to make these new restoration methods reproducible and sustainable, it is necessary to identify their success and failure factors. Therefore, we combine in this paper a systematic review of 198 restoration project through academic and grey literature and a critical analysis of a case study from the Philippines, which combines mangrove replanting (green infrastructure), the building of infrastructure to reduce wave energy (grey infrastructure), and support to local communities.

The question being addressed here is as follows: *to what extent do mangrove restoration methods effectively incorporate ecological, social, and economic dimensions, and how do these factors influence project success?* A case study in the Philippines will assess the concrete implementation of these methods, analyse the participation of local communities, and provide critical perspectives on the successes and limitations of mangrove restoration initiatives.

2. From Mangrove Replantation to Mangrove Rehabilitation: A Review

In order to compile a comprehensive overview of knowledge, a database on mangrove restoration projects was established globally using data from scientific publications and grey literature. Bibliographic research was conducted using the PRISMA protocol (Moher et al., 2010), employing Elsevier's SCOPUS database, Web of Science (WOS) databases, data from physical university libraries, as well as grey literature from feasibility, activity, and evaluation reports of mangrove restoration projects obtained from seven reliable sources: the French Global Environment Facility (FFEM), the consulting firm Créocéan, open archives from IUCN, FAO, SER (Society for Ecological Restoration), UNEP, and Wetlands International. The distribution of source types used for data collection is 39% of articles, 26% of conference proceedings, 11% activity reports, 9% mangrove restoration guides, 9% Theses, 5% project evaluations and 1% book chapter. Regarding SCOPUS and WOS databases, the keywords utilized were: "Mangrove(s)," "project(s)," "restoration," "rehabilitation," "plantation," and "community management." The steps of bibliographic analysis in accordance with the PRISMA protocol are detailed in Figure 1. The studies projects range from 1955 to 2021 with the higher numbers between 2005 and 2010.

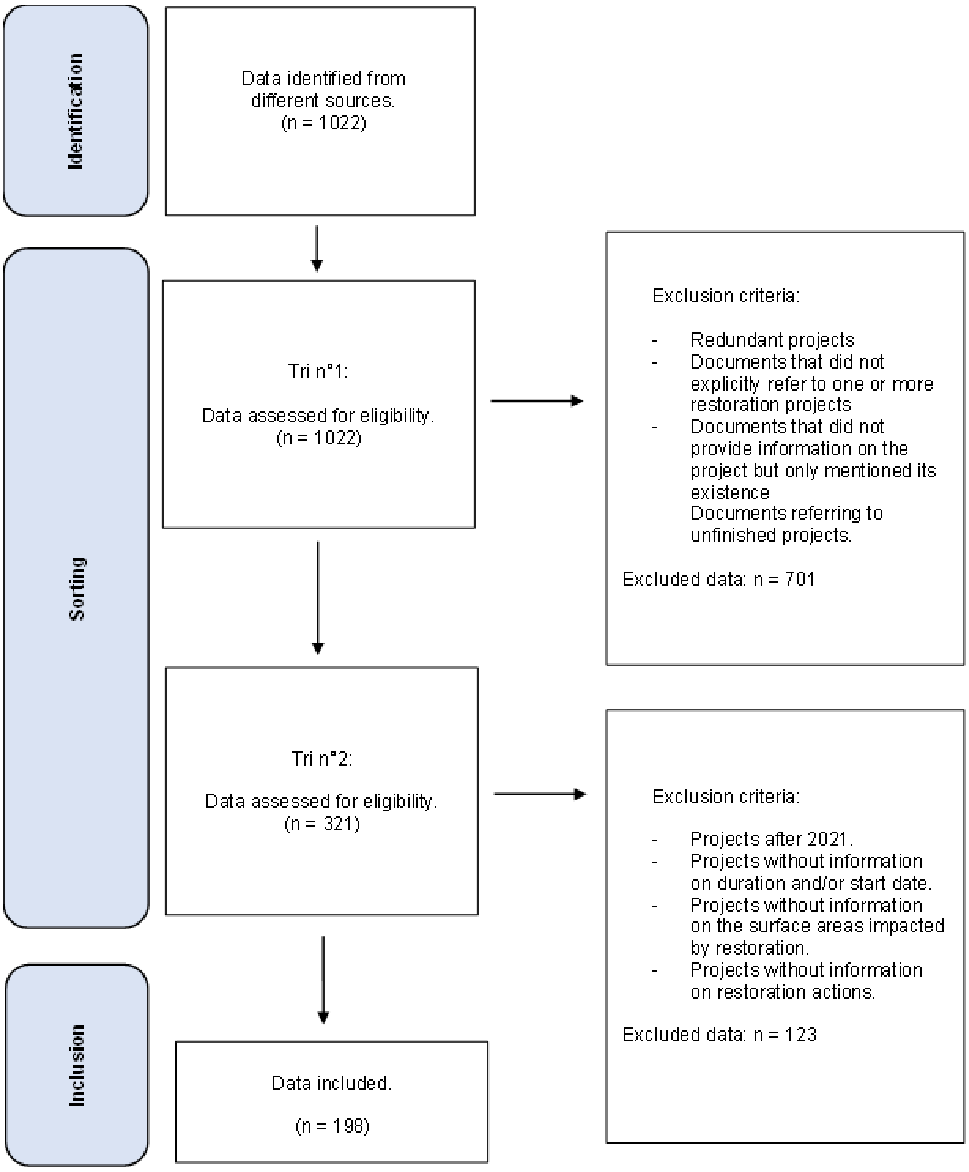

Figure 1: PRISMA flow chart for literature review

2.2 How Does Society Restore Mangroves?

Two major types of restoration method were identified: replantation projects, representing 87% of the studied bibliography, and rehabilitation projects which represent 13% of the studied restoration projects. They include modulating the physico-chemical parameters of the environment, reducing, or even stopping anthropic pressures, raising the local community's awareness of the sustainable use of the environment, or taking management measures for the environment (marine protected areas, natural parks, etc.).

Replantation

Replantation projects account for the majority of our database, with over 170 entries. To focus on the effectiveness of replantation projects, the survival rate of propagules, is used as a measure of replantation success. It is indeed, the indicator most often proposed by project reports. Of the 170 replantation projects, 50% did not specify the propagule survival rate. Of the remaining 50%, the average survival rate was 38%. Looking at the data in more detail (Figure 2), we see that more than a quarter of the projects reporting on this rate are between 0 and 10%. Furthermore, fewer than 15% of the projects have propagule survival rates above 80%. It is important to note that the monitoring to obtain these results was conducted between 1 and 15 years after the end of the replantation. In summary, we found that propagule survival rates are generally low, indicating a tendency for replantation projects to fail, as has been demonstrated by many authors (Brown et al., 2014; Elster, 2000; Kentula, 2000; Lewis, 2005; Nguyen et al., 2017; Primavera and Esteban, 2008; Rey et al., 2012; Wingard and Lorenz, 2014).

For example, the findings of the literature review on mangrove restoration projects in Sri Lanka reveal an overall failure of measures by (Kodikara et al., 2017).

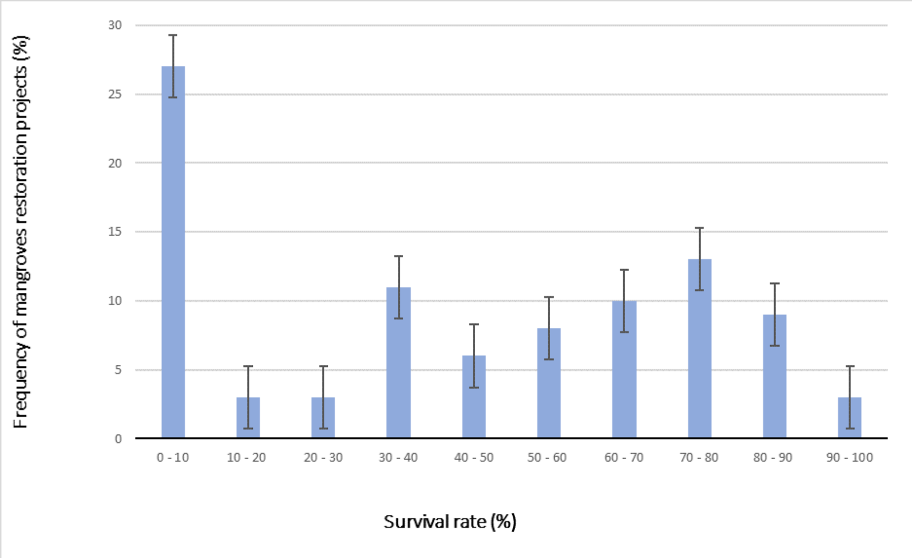

Figure 2: Propagule survival rate as a function of the frequency of restoration projects from our database (the error bars represent the standard error).

Concerning the reasons for this high failure rate, 73% of the articles in the database do not give any reasons, or else only make assumptions. The few data available, coupled with bibliographic syntheses on the subject (Elster, 2000; Hai et al., 2020; Kentula, 2000), allow to propose three main categories of reasons for failure:

- Natural hazards: climatic hazards, animal grazing, diseases, sea level rise.
- Inappropriate choices made by the project managers: unsuitable location for the replantation site on the foreshore (e.g., unfit granulometry of the soil or unfit hydro-ecological conditions), poor choice of replanted species (species and number of replanted species), unsuitable age of the propagules, unsuitable water supply (too much or too little fresh or saltwater causing droughts, floods, and hypo- or hyper salinity).
- Anthropic disturbances: pollution, fishing, boat traffic, cutting.

More specifically, for the Philippines, the reasons for failure are climatic hazards (typhoons, waves, floods); pests and diseases; animal grazing; and anthropic disturbance (pollution, fishing, and boat traffic) (Primavera and Esteban, 2008).

The genus *Rhizophora* is replanted 80% of the studied reports. It is the easiest genus to replant, with high propagule survival rates compared to other, without the need for nurseries. This means that the genus *Rhizophora* can be chosen for the wrong reasons in replantation projects (Cormier-Salem and Panfili, 2016). As a result, this choice can lead to the low survival rate of propagules and can also resulted in monospecific forests, thus reducing biodiversity, as is observed in some studies (Primavera, 2004; Walters, 2000; Walton et al., 2006).

Despite the high failure rates for replantation projects, some are successful. This is the case, for example, in a project carried out in the Philippines on a former degraded mangrove (Walton et al., 2006). It increased the mangrove area from 0 ha to 75.5 ha in 15 years. *Rhizophora spp.* and *Nypa fructicans* were originally replanted. Over time, natural recovery has increased the mangrove area by an additional 25.5 hectares and increased the species richness of two species (*Avicennia marina* and *Sonnetaria alba*). Moreover, the economic value generated by the reforested mangroves is equal or superior to that generated by natural mangroves. In addition, for 95% of fishers, the reforested mangrove increased the barrier effect against climatic hazards and largely contributed to the increase in fish stocks.

A series of environmental parameters were recorded on five mangrove sites located in the Sundarbans (Chowdhury et al., 2023). In 2012, *Rhizophora mucronata* was used to replant the mangroves in an abandoned salt basin. In this restoration project, the mangroves were replanted behind an existing population of *Avicennia marina*. This natural barrier provided protection to the newly planted mangroves against strong swells and waves. The results indicate that the restored site not only exhibits the highest carbon stock but also showcases greater biodiversity compared to the natural sites.

Those studies allow us to say that, when replantation projects are well designed and include important monitoring work, they allow for a significant increase in the socio-ecosystemic value of an area.

Rehabilitation

Mangrove rehabilitation projects are much less numerous than replantation (13% of the database) and are often more recent. As a result, the state of the art is less robust. These projects appeared later than replanting projects following the definition of the Ecological Mangrove Restoration (EMR) approach, first described by (Lewis, 2005). This approach centres hydrology and topography in mangrove restoration projects.

Unlike replantation, projects that foreground the survival rate of propagules, there are no common indicators of the effectiveness of rehabilitation projects. As a result, it is difficult to obtain average success rates for these projects. The lack of feedback for this type of project can also be explained by the fact that, in the case of mangrove rehabilitation, it takes around three to five years to observe effects on the ecosystem (Hai et al., 2020). However, the monitoring period of rehabilitation projects is generally too short. The total duration of mangrove rehabilitation projects in our database is, on average, 50 months, i.e., about 4 years, from the initiation of the project to the last monitoring point. Moreover, 54% of the projects last less than 4 years and 72% less than 5 years.

The two most common rehabilitation methods are 1) modulating sediment dynamics with infrastructure to stabilise or increase sedimentation and 2) restoring hydraulic connections when they have been degraded, as in the case of former aquaculture ponds or the construction of infrastructure such as dams or dikes (Kamali and Hashim, 2011; Van Loon et al., 2016). Very little projects only rely on stopping or reducing anthropogenic pressures, raising awareness in local communities, and implementing environmental management measures: natural parks, marine protected areas (MPAs), etc. However, these methods tend to be added to the main method.

An example of a rehabilitation project that targets both hydrology and sedimentology can be found in a project in Malaysia in 2008 (Kamali and Hashim, 2011). The lack of mangroves was explained by wave exposure. A wave breaker was installed to limit wave energy and erosion and promote sediment deposition. Eight months later, a beginning of natural regeneration was observed. No planting was required. However, a monitoring carried out for a longer period would have allowed to determine whether the natural regeneration observed was long lasting.

2.3 Management of The Projects

The state of the art allowed to identify three main types of actors involved in a restoration project:

- There may be one funding organisation, but there are usually several, each funding a part of the project. They may be government agencies, an NGO, a bank, or a private company.
- The main contractor is the organisation responsible for carrying out the restoration work and for monitoring. It can be an NGO, a research institute and/or a university, members of local communities, tourists, or a private company.
- The project owner is the organisation responsible for developing and managing the project. It can be a government agency, an NGO, a research institute and/or university, a private company, or members of local communities.

Regarding the level of involvement of local communities in restoration projects, in 60% of the database, they were invested in the project. However, the majority of investment is exclusively a payment for planting (80%). Only 20% of the projects involving local communities, gave them an active role in managing, while only 7% involved them in determining restoration strategies based on their requests and needs. More recently, local communities have taken on a central role in the management of some restoration projects, as recommended by the Community-Based Ecological Mangrove Restoration (CBEMR) method (Brown et al., 2014). In Colombia the community-managed projects are the most successful in terms of seedling survival, increased natural regeneration, and increase in mangrove cover (Rodríguez-Rodríguez et al., 2021).

To conclude this section, about 50 % of the data in our database are missing. The lack of data, from feedback from the projects, prevents lessons being learned from experiences and condemns mangrove restoration project to repeat the mistakes (Bash and Ryan, 2002; Block et al., 2001; McDonald and Williams, 2009; Miller and Hobbs, 2007; Parkes et al., 2012; Suding, 2011).

2.4 What Are the Recommendations for Mangrove Restoration in The Literature?

2.4.1 Replanting or Rehabilitation?

The decision to to replant or rehabilitate involves understanding whether the degradation identified during the initial diagnosis (when it took place) was anthropogenic and if the degradation factors are still present in the environment (Bosire et al., 2008; Hai et al., 2020). Often, in the case of human-induced degradation, the cessation of pressure is sufficient to return an ecosystem to its initial pre-impact state (Dutrieux, 1989). If anthropogenic pressures cease and the hydrology and morphology of the habitat have not been affected, it is likely that the mangrove will recover (Martinuzzi et al., 2009). This is also the case following a climate fluctuation where the return to normal rainfall conditions is followed by spontaneous regeneration of the mangrove (Andrieu et al., 2020). If this is not the case, it is important to consider the most appropriate restoration method. Very often, replanting is chosen as the first option; even more widely, mangrove restoration is often equated with replanting (Kamali and Hashim, 2011). However, replanting is useless if the habitat has not been rehabilitated beforehand (Hidayati et al., 2020; Kamali and Hashim, 2011; Van Loon et al., 2016). It is essential that the parameters of mangrove habitat are assessed in the area of interest prior to any restoration. This involves a preliminary study describing the forest structure of the area, as well as the main environmental conditions.

In short, it is necessary to understand the reasons why natural regeneration has not already taken place (Kamali and Hashim, 2011). Replanting should only be considered in cases where environmental conditions have already been rehabilitated or are not degraded, but where little or no plant material is available in the area and in adjacent areas, preventing natural regeneration (Kamali and Hashim, 2011). In addition, the notion of a time lag between rehabilitation actions and effects on mangroves must be considered. For example, in the case of former shrimp farms, it is estimated that it takes around five years to give the ecosystem a chance to regenerate naturally, provided that hydrological conditions have been restored and anthropogenic pressures on the ecosystem have been halted (Lieth et al., 2008). It is therefore not necessary to replant mangroves during this period.

In cases where replanting is necessary and in order to maximise the chances of success, a series of recommendations can be found in the literature: the choice of species should be based on local specific diversity and zonation along the foreshore. The choice of replanted species or restoration site should never be made solely on the basis of ease of replanting or ease of access to the area (Cormier-Salem and Panfili, 2016). This is because the different mangrove species evolve in specific hydroperiod and salinity conditions corresponding to their position on the foreshore. Furthermore, if the information is available, the species initially present before degradation should be replanted (Wu et al., 2020). A distance must be maintained between each propagule/seed; this distance varies according to the species considered. Furthermore, random planting in space is preferred to aligned planting, in order to generate a state closer to that of the original system and to promote biodiversity (UNEP, 2020). Some mangrove species achieve higher survival rates when grown in nurseries before being planted on site, for example *Avicennia sp* (Ravishankar and Ramasubramanian, 2004). Finally, it is also important to determine the best season for replanting mangroves depending on the species and the geographical area. The age of the propagules replanted is also important. Plants older than 12 months are thought to have a very low survival rate (Stubbs and Saenger, 2002).

2.4.2 Recommendations for The Socio-Economic Aspects of Restoration

A successful restoration project is one that integrates ecological functions as well as social, economic and cultural aspects (Alexander et al., 2011). Such projects bring many co-benefits. These co-benefits enable both the preservation of the environment and the maintenance or development of sustainable uses of the ecosystem by human societies.

This is why many authors recommend co-management (Albers and Schmitt, 2015; Begum et al., 2021;Glaser et al., 2010; Mollick et al., 2022). Schmitt and Duke (2016) define co-management of mangrove ecosystems as an approach that engages local communities in long-term mangrove restoration projects. In this approach, government agencies share decision-making, responsibility, and accountability with local communities whose livelihoods depend on the ecosystem services provided by mangroves. To achieve this, local communities must be consulted prior to any restoration action. Ideally, restoration actions should be based on the needs, desires, and concerns of local communities in relation to the environment in which they live (Datta et al., 2012).

It may also be appropriate to involve local communities in the implementation of restoration measures. This can help to generate interest in the restoration project, but also increase the likelihood that restoration sites will be regularly monitored by local communities. If this approach is successful, the benefits of restoration will be sustained over time.

However, paying local people for restoration work is controversial. Cormier-Salem and Panfili (2016) describe the weaknesses of these practices. They may in fact restrict local communities' understanding of how mangrove restoration can increase nature's contributions to people over the long term, thus generating more significant economic benefits rather than immediate and less significant short-term gains. Finally, many human communities have income-generating activities linked to mangroves. If these activities exploit the mangrove sustainably, they should be preserved (Bosire et al., 2008). If these activities are not sustainable in their use of mangroves, it will be necessary to explore other alternative sources of income, depending on local resources and know-how (Valenzuela et al., 2020; Datta et al., 2012; Stone et al., 2008; Sudtongkong and Webb, 2008).

3. Background of the Case Study

3.1 Study Area

This research was carried out in the municipality of Concepción, Ilo-Ilo, the Philippines. Restoration actions were undertaken at five sites in five areas: Tambaliza, Lo-Ong, Bacjawan Norte, Bagongon, and Polopina (Figure 3).

3.2 Actions Implemented and General Information.

The main objective of this project is to increase the resilience of communities to climatic hazards by combing grey infrastructure and by increased surface of mangroves (green infrastructure) while supporting the local economy through income-generating activities aimed at preventing the over-exploitation of mangroves. The restoration actions undertaken on each site are detailed in table 1. It includes most of the recommendations of literature (rehabilitation and participative management). The project started in November 2015 and ended in June 2022.

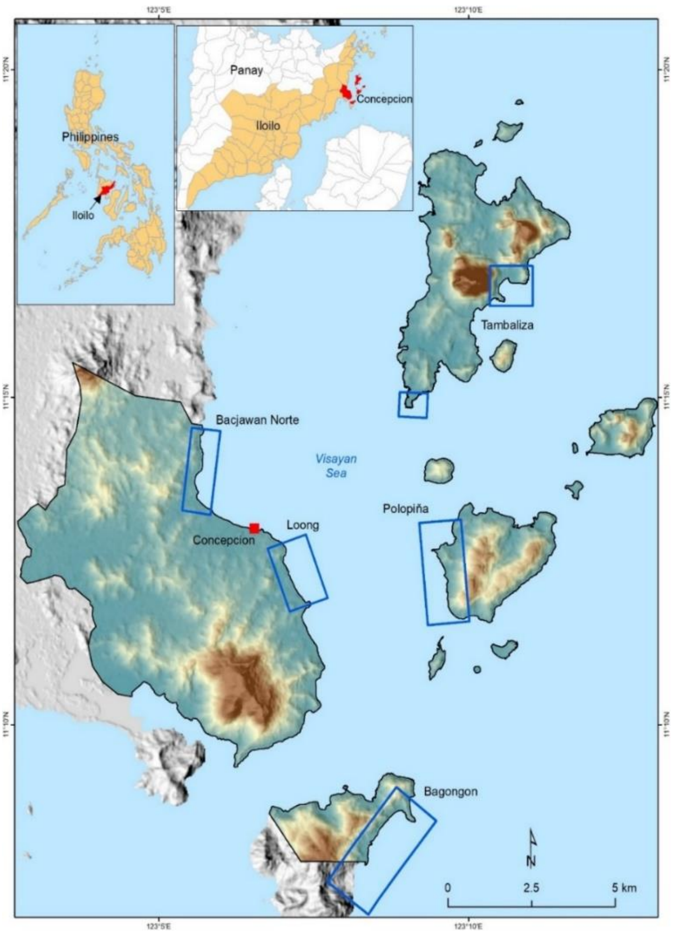

Figure 3: Location of the restoration sites in the municipality of Concepcion, the Philippines.

Table 1: Information on the actions undertaken for each site.

Sites	Bagongon	Tambaliza	Lo-Ong	Bacjawan Norte	Polopina
Replanted area (Ha)	11	2	2	2.55	2.84
Number of plants	110363	36000	20000	25000	30050
Spacing between plants (m)	1x1	0.5x0.5	1x1	n/a	1x1
Replanted species	Avicennia sp. Sonneratiasp. Rhizophora stylosa Rhizophora apiculata	Avicennia sp. Rhizophora sp.	Avicennia sp. Sonneratiasp. Rhizophora apiculata Rhizophora mucronata Ceriopssp.	Avicennia sp. Rhizophora apiculata Rhizophora mucronata Ceriopssp.	n/a
Grey Infrastructure	Installation of two breakers and sediment traps and wave attenuation fence	Removal of a berm impeding the circulation of water	Installation of two breakers.	Installation of a blade breaker.	No grey infrastructure.
Socio-economic actions	Development of the production of coconuts and coconut products.	Establishment of a natural farming system; Establishment of an ecopark for the development of ecotourism	Establishment of an infrastructure for squid processing and production of squid products.	Establishment of organic chicken production	Establishment of a clothing production.

4. MATERIAL AND METHODS

4.1 Social-Ecosystemic Framework

This study is based on the social-ecosystem systems framework (SESF) (McGinnis and Ostrom, 2014) widely used nevertheless, few studies have fully applied it to the analysis of mangroves (Lacroix and Richards, 2015; Partelow et al., 2021; Pollnac et al., 2010). This framework allows the complex concepts of socio-ecosystems to be described: actors involved and interactions between them following a universal language within the scientific community (McGinnis and Ostrom, 2014). In addition, it helps ensuring that no element is missed or overlooked (Partelow et al., 2019). The main elements of the SES framework for our case study in the Philippines are developed and presented in Table 2.

Table 2: Components and variables of the SES mangrove ecosystem of the municipality of Concepcion, Philippines

Components	Variables	
Resource Systems (RS)	RS1	Mangrove ecosystem
	RS2	Mudflats
	RS3	Sandy area
	RS4	Sea grass bed
	RS5	Aquaculture ponds
	RS6	Cropland
	RS7	Livestock farming
	RS8	Sea
Resource Units (RU)	RU1	Mangroves trees
	RU2	Fishes
	RU3	Crabs
	RU4	Shellfishes
	RU5	Cereals and vegetables
	RU6	Livestock
Governance System (GS)	GS1	National government of Philippines
	GS2	Municipal local government of Concepcion
	GS3	Village councils
Actors (A)	A1—Co-funders	Taisei, LGU, DRR-CCA fund, PDRF, DENR/ERDB, DENR/BMB, CIGEF-MKBA, CI-BWISER, CI Turing, IKI-BMUB, MoE Netherlands, FFEM.
	A2—Member institution carrying of the project	MAEDI—French Ministry of Foreign Affairs and International Development, MEDDE – French Ministry of Ecology, Sustainable Development and Energy.
	A3—NGOs	Conservation International (CI)
	A4—Local Communities	Local fishers
Outcomes (O)	O1	Increase in the area of mangroves.
	O2	Reduction in waves and the effects of climatic hazards.
	O3	Increased sediment supply.
	O4	Improving the local economy by diversifying livelihood activities.
	O5	Increased resilience of communities

4.2 Satellites Images Analysis

To map the extent of the mangrove [RS1] before and after the project, satellite imagery was utilised. It is easier to distinguish between mangroves and other (continental) vegetation when the satellites cover wavelengths larger than near infrared. Therefore, satellites as LANDSAT and SENTINEL-II are the best options. SENTINEL-II has a finer spatial resolution (10 m after pan sharpening) but is recent. If the project is recent, this satellite is the best possible option. Both images are from the tile "R103_T51"; the respective dates are 2016/08/03 and 2022/03/30. The climate is very cloudy, drastically reducing the choice of images.

The method is an unsupervised classification, more precisely, a series of stacked classifications with the Kmeans algorithm (Andrieu and Mering, 2008; Valdez-Achucarro et al., 2022). It has proven more efficient than a simple classification (Andrieu et al., 2019).

The first classification divides the pixels into many classes (12) to be sure that all the classes of typology (water RS8, mangrove RS2, mudflat RS3, and all continental surfaces: urban, forests, cropland RS6, RS7) appear at the first step. The radiometric mean values of each class are interpreted to attribute each class to the typology. A first draft map is obtained for four classes. All four classes are separated using a Boolean approach and each one is applied as a mask to the multispectral data in the same unsupervised classification (Kmeans), here at six classes. The same radiometric mean values are studied to verify whether the six subclasses belong to the correct land cover type. If one class or more exhibit a radiometric curve corresponding to another land cover type, is it reclassified accordingly. Finally, a land cover map is produced. The same image processing is realised for both images (before and after the project). A pixel-based cross tabulation reveals all the land cover changes, notably mangrove stability, mangrove increase (over previous water bodies or mudflats), and mangrove loss (replaced by water or mudflats).

Field observations led to a control site dataset. An error matrix was produced by cross tabulation of the map and the image of the control sites. The kappa index is 0.92; therefore, the mapping is acceptable, with some inaccuracy to be expected.

4.3 Vegetation Surveys and Sediment Observations

The second component of the method is a series of field observation, conducted in May 2022.

First, the sediment and bathymetry were observed around six breakwaters and one bamboo sediment trap. For each one, the bathymetry, texture, and colour of sediments comparing the sides exposed to the waves and the protected side were noted. If ecological indicators of habitat restoration were visible, they were noted.

Then, 14 transect lines were laid in the mangrove restoration sites to describe vegetation cover. The species, height, length, and any observations related to the health of individuals found along the line were noted. The length of the transects was variable because they extended from the grey infrastructure to the upper tidal zone.

4.4 Interviews

Three different types of interviews were combined. The first one was with the project managers. Then, in the 5 localities, a questionnaire of 26 questions was submitted to 16 people. The answers were coded for transformation into percentage for answers as yes/no or dates. Several questions led to a list (eg. a list of threats). Scores from 4 for the first cited element to 1 for the fourth one was implemented. Then, the scores were added. At least, the sums were ranked from the most cited element to the least. A researcher stayed in Tambaliza for five days to conduct additional semi-structured interviews with the help of a native interpreter. This third interview aimed to better understand the local socio-ecosystem, governance, perceptions of the mangrove, and perceptions of the project.

5. Results

5.1 Remote Sensing

5.1.1 Mangrove Cover Change in Concepcion Derived From SENTINEL-II

Over the 1125 ha mapped in the municipality of Concepcion, the mangrove [RS1] occupied 55 ha in 2016 and 69 ha in 2022 (Figure 4). In total, 80 % of the 14 ha increase in surface area was found in abandoned aquaculture ponds [RS5] in Lo-Ong and Tambaliza. Polopina also showed a high increase rate.

Bagongon showed very little mangrove coverage [O1] and no change in mangrove cover (less than 0.5 ha) resulting from the compensation of increase and decrease surfaces. Bacjawan Norte was the only site with a mangrove loss (less than 0.5 ha). The scale of the restoration sites is too small to fully rely on 10m resolution remote-sensing imagery; however, as a complement to the field data, the changes in mangrove cover were extracted at this scale. Polopina shows an increase of 0.6 ha; Tambaliza shows an increase of 0.2 ha such dynamics are consistent with field observation. However, both sites also show important progression outside of the restoration sites, indicating that the increase might not be only explained by the project. The three other sites show a decrease of less than 0.2 ha each. The overall increase (0.1 ha) corresponds to 2.4 % of the area.

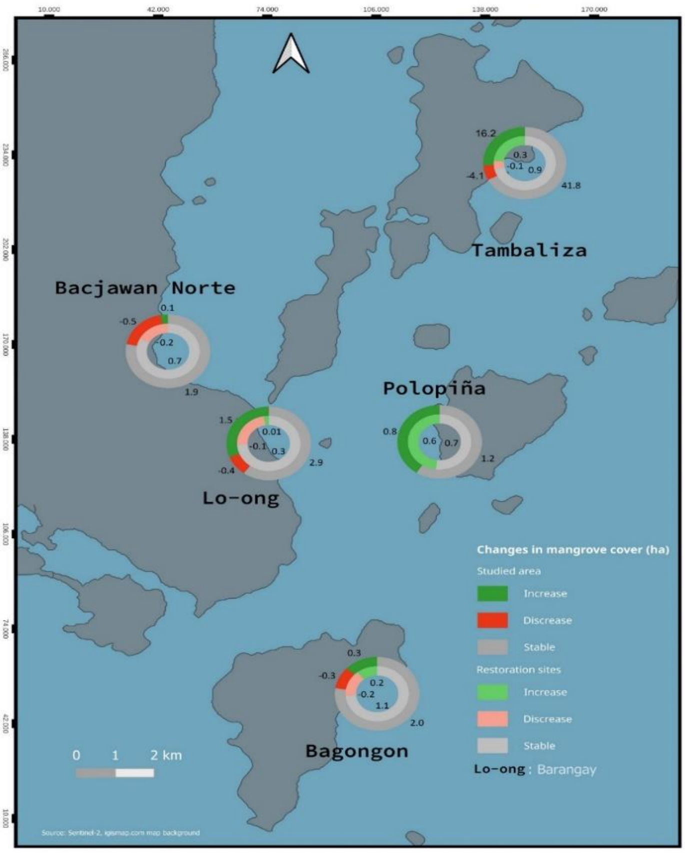

Figure 4: Mangrove cover observed before and after the project

5.2 Field Observations

5.2.1 Grey Infrastructure Impact on Mangrove Habitats

The grey infrastructure aimed to reduce wave energy [O2] and increase fine texture sedimentation [O3]. These are two important elements of mangrove habitats, and they formed part of the plan to facilitate mangrove restoration [O1]. Which are expected to enhance the wave reduction later on.

In the shelter of all the studied breakwaters, a layer of fine sediments was observed. In most cases, it was associated with visible deposits in terms of bathymetry, and, in some cases, it was associated with indicators of ecological restoration (denser seagrass [RS4], and a fiddler crab population present only on this mud bank [RS2]. The direct and local effects of these grey infrastructures are therefore in line with expectations. On the other hand, they are highly localised (effects of a few square meters or, at best, a few dozen square meters). They do not generate adverse lateral effects. Most of the bamboo sediment traps were partially destroyed and the one studied showed no effect. The grey infrastructure in stone may have generated a local positive effect on the mangrove habitat.

5.2.2 Survival Rates Deduced from Vegetation Transects

The 14 transects of vegetation exhibited fractions of replanted vegetation cover ranging from 0 % (no mangrove observed) to 8.21 % in Tambaliza. Most of the sites have rates of replanted vegetation cover under 2.5% (all the sites of Lo-Ong, Bacjawan Norte, and Bagongon, and 3 sites in Polopina). It is important to note that the highest rate observed in Tambaliza is explained by the inclusion, within the transect, of an abandoned mangrove nursery of this project. The density in this nursery is not representative of the restoration protocol, where young mangrove trees from the nursery are being replanted with less density somewhere else. Therefore, the rates of replanted sites according to the protocol vary from 0 to 4%. It is important to remember that a change in vegetation cover of 4% (with very low plants) is not expected to be detected by remote sensing at a 10m resolution.

Despite the positive effect on habitats in the direct shelter of the break water [O2; O3], the restoration [O1] failed. For a few transects, the survival rates could be estimated by comparing the numbers of propagules planted in 2021 (according to the reports from the project manager) and the living and dead observed plants (and, eventually, dead propagules) in 2022 (table 3). The ratio ranges between 8 % in Bacjawan Norte and 0.4 % in Polopiňa. The low fraction of replanted vegetation from transects (0 to 8.21 %) can therefore be explained by the survival rates (ranging from 0.4 to 8 %).

Table 3: Estimated number of living propagules in June 2020

	Replanted surface according to the reports (ha)	Surface where the replantation has been verified in 2022 (ha)	Number of planted propagules (reports)	Number of planted propagules (observed in 2022)	Ratio (%)
Polopiňa 1	0.31	0.04	2929	210	7.2
Polopiňa 2	0.55	0.25	5197	200	3.8
Polopiňa 3	1.61	0.1	15214	68	0.4
Polopiňa 4	0.41	0.08	3874	182	4.7
Total Polopiňa	2.88	0.47	30050	660	**2.2**
Bacjawan Norte	2.55	1.13	25000	1990	**8.0**

5.3 Interviews on the Project's Implementation, Effects, And Sustainability.

5.3.1 Project Implementation in Terms of The Community Management of Mangroves

As stated in the background section, the project was implemented with significant efforts to involve local stakeholders: both local administrations (municipalities Barangays) [GS2, GS3] and people [A4]. The interviews confirmed that people were informed and invited to participate at meetings, and received grants for their participation (e.g., for works on the grey infrastructures, replantation).

In total, 87% of respondents knew about the project; however, this is according to the survey that mainly focused on people who were invested or directly interviewed. Moreover, 100% of the rare respondents who did not know about the project were aware of at least one of the project's achievements (e.g., a breakwater, some mangrove replanting, or a livelihood program). They were mostly informed by the meetings (or at least the invitations to the meetings).

The interviews also revealed the importance of grants for the work. This "effect" of the project ranked fifth when people were asked about the main effects of the project and accounted for a substantial part of the semi-structured interviews. As the grants for daily work in the project are so frequently cited, it is possible to surmise that work would not have been completed without such compensation. The local community does not desire mangrove restoration to the point where they would restore it without being paid for it. Negative side effects of such grants have been studied in other restoration contexts (Cormier-Salem and Panfili, 2016).

The answers about the negative effects of the project shed light on its acceptance. First, most respondents did not comment on the negative effects (offering answers of either "I don't know" or "no negative effect"). This shows that the language used in front of the research team was not too critical toward the project. However, one respondent mentioned that the restriction of boat traffic was a negative effect resulting from reforestation. In addition to this answer in the questionnaire, this topic also occupied several discussions during the semi-structured interviews. Several stakeholders involved in the project evoked it as an explanation of the low survival rates. This also reveals that the acceptance of the project stops where the interests of the main economic activity (fisheries) begin. In Lo-Ong, Bagongon, where houses are situated immediately in front of the sand beach (with boats parked right in front of houses), the replantation was wholly situated in places without houses to avoid conflicts between boat circulation/parking and mangrove restoration. This means that the houses would not have been directly protected [O2, O5] by the mangrove, even if the restoration had been more successful.

5.3.2 Perceptions of The Mangrove Restoration And Its Effect On Resilience

When asked about the main effects of the project, mangrove growth [O1] had an average ranking (after the protection of the coast [O2], alternative incomes [O4], protection from soil erosion [O3], capacity enhancement in the face of disasters [O5], and even the pay for workers during the project). The protection of the coast and the protection from soil erosion might, however, include perceptions of the positive effects of mangrove restoration. Indeed, when asked about the reasons for perceived improvements in security, mangroves ranked second, right after the wave reduction due to breakwaters. We met one family who decided to move from the seafront to a house situated behind the mangroves after a typhoon, but this remains an individual trajectory.

5.3.3 Sustainability of the project

The field observations raise concerns about sustainability of the mangrove restoration. Mangrove reforestation is indeed characterised by a very high overall mortality rate, with high variability from one site to another depending on the suitability of the reforestation to the environment. It is therefore to be expected that a fairly large proportion of the reforestations will not be viable. However, the survey was able to poll local communities on the future of the project, its activities, and its effects. After "don't know", the growth of replanted mangroves was the most common response, showing some discrepancy between our projection of survival rates and the public discourse.

The project had initially foreseen that alternative activities would finance the continuity of reforestation, but the surveys did not reveal any concrete intention to carry out such reforestation-supporting activities where they had failed. Finally, the alternative activity programs themselves have already partially collapsed.

In 2022, only two of these activities are fully active and seem to show that the business plan was relevant with a robust value chain. These are the chicken farm in Bacjawan Norte and the squid product manufacturing centre in Lo-Ong. Both activities are located on the main island. In contrast, the three programs installed on the minor islands have either completely collapsed or show minimal operation, revealing that the business plan was overly optimistic.

6. Discussion

First, in order to synthesise our results, Table 4 shows the level of achievement of the initial objectives from the SES framework using a simplified scale. For each initial objective, we will discuss the potential reasons for their success and/or failure and the recommendations that can be drawn from them.

Table 4: Level of achievement of the initial project objectives.

Initial outcomes	Level of achievement
O1—increase in mangroves area	
O2—reduction in waves and effects of climatic hazards	
O3—increased sediment supply	
O4—improving local economy by diversifying livelihood activities	
O5—increased resilience of communities	

Not reached 0-25% 0-25%	Partially reached 25-50%	Partially reached 50-75%	Reached 75-100%

6.1 Increase in Mangrove Area (O1)

Overall, the reforestation project has failed. First, the preliminary ecological study concerning the mangroves was weak, leading the project leaders to choose inappropriate reforestation sites. Indeed, for all sites except Tambaliza, the areas are not former mangrove areas and showed no potential for afforestation. Second, between the time of reforestation and the time of the evaluation, the young mangroves had already been partially destroyed by climatic hazards. The site of Tambaliza is an exception, with a higher survival rate. Tambaliza is the only former aquaculture farm close to mature mangrove patch and was already showing signs of natural regeneration before restoration. The restoration actions seem to have facilitated and accelerated this natural process.

To summarise, the two reasons for failures are managers' poor choices and natural hazards. These are common reasons for restoration project failures that are noted by many other studies (Elster, 2000; Hai et al., 2020; Primavera and Esteban, 2008).

6.2 Reduction in Waves and Effects of Climatic Hazards (O2)

On the one hand, the breakwaters that were set up seem to be functional; however, they act in a highly localised way. If they are maintained in the long term, they can indeed act on the effects of climatic hazards. On the other hand, part of this objective depended on the mangroves, which function as a natural barrier against the waves. Given that the restoration of the mangroves failed, this aspect also failed.

6.3 Increased Sediment Supply (O3)

Even though the bamboo sediment traps were destroyed, the breakwaters showed their efficiency and allowed increased sedimentation.

The progressive destruction of the bamboo sediment traps leads to two recommendations for this type of project: first, the need to anticipate solid infrastructures by choosing the best material according to the environmental context, while selecting only non-polluting materials; second, the planning of regular maintenance work on these infrastructures to perpetuate their positive effects.

6.4 Improving the Local Economy by Diversifying Livelihood Activities (O4)

Of the five alternative income programs, only two are economically viable in the long term; the other three were no longer functioning at the time of the evaluation. Those that did work resulted in a significant increase in family income while preserving the mangroves. The reasons given for the failures are, first, a poorly constructed business plan from the outset, which was too optimistic. In addition, among the programs that did not work, a significant difference was observed between what was initially planned and what was actually carried out. This highlights that the successive delegation process in this type of project can alter the quality of the final result.

6.5 Increase Resilience of Communities (O5)

This outcome, which is the main outcome of the project, resulting from the synergy of all the previous outcomes, cannot be assessed after so little time. It is only in the long term that we can really evaluate the effects of the project concerning this objective. After several major climatic events, it will be possible to determine whether these actions have had a positive effect (De Dominicis et al., 2023).

7. Conclusion

The main conclusions drawn from the review are to prioritize habitat restauration and community managements. The case study followed these two recommendations. However, this project was not successful and lead us to the following conclusion: the ecological and social context of the area must be studied in detail before undertaking a mangrove restoration project. The choice of restoration site is of great importance (Chowdhury et al., 2023; Ellison, 2000; Flores-Verdugo et al., 2007), which indicate that old mangrove areas degraded have the highest success rates (as in Tambaliza) and should be preferred. The role of each actor must be strictly identified, and constant attention must be paid throughout the delegation process when implementing the measures. It is crucial to think carefully about the durability of the materials used in the construction of infrastructures. It is also essential to clearly define infrastructure maintenance from the outset of the project, as these processes require considerable human, technical and financial resources. Replanting work has very high failure rates; on the other hand, environmental rehabilitation work is showing promising results, although the effects need to be observed over the longer term. Finally, the involvement of local communities is essential to ensure the smooth implementation of restoration measures, and this process must be at the heart of the project leaders' concerns at every stage. In summary, this project stands out as an example of systemic restoration, emphasising integrated coastal zone management with the active participation of local communities. However, the results are mixed. Some recommendations from the state of the art have been considered, including the integration of socio-economic aspects, co-management and the rehabilitation of hydro-sedimentary conditions (in line with the EMR and CEMBR approaches). Nevertheless, our analysis revealed new challenges requiring additional recommendations.

Comprehensive, scientifically analysed feedback is extremely valuable, but it is also extremely rare. It is only through this approach that practices can be improved. Our work, combining a literature review and a case study, has effectively targeted the shortcomings in the implementation phase of restoration actions, while proposing concrete recommendations to remedy them. Combining the case studies with the general recommendations is essential for placing the results of the project in a wider context, allowing us to understand its strengths and weaknesses, but also to test the hypotheses put forward by the scientists by means of concrete cases.

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