Environmental governance of mangrove ecological restoration projects: definition of socio-ecosystemic efficiency indicators

Mangroves are forest formations found in the intertidal zone of tropical and subtropical regions in areas sheltered from the energy of swells and currents. According to the FAO (2007), between 1980 and 2000 it is estimated that mangroves declined by 180,000 ha per year, a cumulative loss of 35% of the ecosystem's surface area. Although during the 21st century the rate of decline has slowed down, mangrove forests are still considered threatened ecosystems due to their conversion to fish farms, urbanisation, and pollution, even though they are highly productive ecosystems.

In fact, they are important coastal ecosystems for humans because of the multitude of services they provide: among others, the supply of timber and firewood; the renewal of fish stocks; or the regulation of water quality through the process of nutrient filtration and contaminant storage. Mangrove forests also play an important role in mitigating the effects of climate change by protecting the coast from coastal vagaries and storing carbon. Mangroves provide natural coastal barriers against erosion. They promote sediment accumulation and attenuate the mechanical impact of waves.

In view of this record, scientists have been calling for consideration of the ecological and socio-economic importance of mangroves since the 1970s. In response, since the 2000s, studies on their restoration and conservation have grown exponentially. However, although a large number of restoration measures have been carried out around the world, these have largely failed in their objective of restoring resilient ecosystems. Research on these objectives includes an increasing amount of Social and Human Sciences.

The research project aims to propose an integrative and multidisciplinary approach to the ecological restoration of mangroves, considering ecological, biophysical, and socio-economic factors. **In view of the effectiveness of mangrove preservation, which is still unsatisfactory in the face of the ecological emergency, what operational responses can be proposed to improve the design of projects aimed to protect and restore mangroves?**

The interest of the subject is threefold: it is on the one hand (1) **ecological**, as the adaptation of measures to environmental conditions must allow the return of the degraded ecosystem to a desirable trajectory and no longer require assistance in the regeneration of the ecosystem; (2) **economic**, as a well-designed measure offers better results and thus limits economic losses ; and finally (3) **social**, as improving the ecological conditions of mangroves makes it possible (a) to reduce the vulnerability of coastal populations to the impacts of climate change, (b) to better redistribute the benefits of restoration among the various stakeholders and (c) to sustain the resources resulting from the presence

of mangroves. This scientific contribution finds its originality in the comparison of projects located on several continents (Central America, West Africa and South Asia), allowing the ecological diversity of mangrove forests to be taken into account, as well as the cultural and institutional diversity of each country studied. Three sub-questions arise from the initial problem:

(1) What are the scientific and technical developments relating to restoration techniques applied to mangroves?

The issue linked to the question is first of all that of providing knowledge on scientific and technical developments on actions to maintain and/or improve the ecological functioning of mangroves, as well as on initiatives and projects in progress. This world state of the art will deal with the pilot sites of the FFEM projects (Togo, Benin, Senegal, Costa Rica, Philippines), the sites of Creole interest (New Caledonia, Mauritania), but more widely with any mangrove coast in the world where protection/prevention or restoration actions have been carried out. The aim is to participate in the FGEF's capitalisation effort within the framework of its project by including research work in the development of a scientific monitoring platform compiling innovative experiments carried out on mangroves. The answers to this first question will be obtained through networking with local experts, accompanied by a literature review.

(2) To what extent does environmental governance constitute a brake or a lever for the sustainable management of mangroves?

The issue related to this question is the analysis of the influence of Environmental Governance on mangrove management, firstly by means of a network analysis. This has several advantages: (1) First of all, it allows us to free ourselves from the divide between "micro-structures" and "macro-structures" by favouring circulation from one to the other. The second advantage of the notion is (2) that it questions the notion of power through the analysis of power relations until a consensus is reached. The third advantage of network analysis (3) is that it provides information on institutional locks by identifying the holders of power in the definition of consensus.

The analysis should cover a sample of sites where, on the one hand, ecological engineering techniques adapted to mangroves have been implemented, and then targeted with regard to the difference in terms of Governance in order to allow the elaboration of typical profiles of the stakeholder network. We propose to analyse here at least four modes of governance targeted on FFEM and Creocean sites of interest. In each of these sites, the stakes and the relationship with the mangrove differ.

In practical terms, the analysis of the networks will first be based on a targeting of national and international actors and institutional tools, then on a contact facilitated by the local NGO partners of

the FFEM and the professional network of Creocean, and finally on meetings on the spot by carrying out short missions (±15 days per country) with the actors of each of the selected sites.

(3) How can restoration projects be better selected and monitored?

The issue at stake is to adapt a rapid ecological performance assessment technique to the mangrove ecosystem, inspired by the UMAM method and its French adaptation to the MERCI-Cor coral reefs. The research work will be based on the standards recommended by the EMR guide, developed by Lewis and Brown (2014). The guide provides the tools needed to assess the resilience of mangroves. It provides information on the parameters to be included in the analysis, their collection or calculation methods and their capacity to qualify the environment. A review of the specific literature will also be carried out to explore the notion of resilience and tipping points to explore the extent to which mangrove resilience can be modelled. We propose to call the ecological performance tool the "MaREM" tool (Mangrove Rapid Evaluation Method).

For the Costa Rican projects, the EPOMEX Institute (Institute of Ecology, Fisheries and Oceanography of the Gulf of Mexico) of the Autonomous University of Campeche in Mexico is in charge of carrying out environmental diagnostics and scientific monitoring of the different sites of the "Mangroves Costa Rica - Benin" project. The following criteria will be studied and tested for their integration into the MaREM tool.

A second approach will be studied, which is to be able to follow the evolution of restoration thanks to remote sensing. Satellite images of the different project sites over periods of time from the time of degradation to post-restoration monitoring will be analysed. The aim will be to develop a monitoring method that can be replicated on a large scale to be able to monitor restoration projects without the constraint of geographical displacement and in a simple and rapid manner. This method will firstly allow to establish the context of degradation before restoration and secondly to evaluate the impact of the restoration. This type of method is well known, but its innovative character lies in the finesse of the detection, where 90% of remote sensing works in a binary way (Presence of mangroves/no mangroves), here we will go further in the characterization of the mangrove (Degradation levels, mangrove density, etc.). This work will also lead to the publication of a literature review.