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The mangrove's contribution to people: Interdisciplinary pilot study of the Can Gio Mangrove Biosphere Reserve in Viet Nam

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ABSTRACT

The main objective of this pilot study, conducted in June 2015 in the Can Gio Mangrove Biosphere Reserve (Can Gio MBR, Viet Nam), was to develop an interdisciplinary approach to assess some key services provided by reforested mangroves subject to external pressures and varying management policies. We focused on the abundance of viruses, bacteria, endo- and epi- and macrofauna and the diversity of crabs in the mangrove and the exploitation of its resources. The main social finding was that the local inhabitants are aware of the levels of protection of the different zones within the Can Gio MBR and respect them. The core and the buffer zones seem to present a similar ecological status. Genotyping showed a low level of crab diversity although there were many different morphotypes. In the future, we need to understand the stakeholders' general perception of the biodiversity and environment changes by developing an integrated, multi-scale approach.

1. Introduction

In the name of the principles of intra- and trans-generational equity and environmental justice (Millennium Ecosystem Assessment, 2005), the need for ensuring the preservation of biodiversity to maintain or improve the well-being of people has led to a popularization of the notion of ecosystem services (ES), which may be divided into four categories: regulation, support, provision, and socio-cultural aspects. This approach presents many problems, such as our anthropocentric vision of nature, with the attendant risks of commoditization, and the shortcomings of the evaluation methods, which tend to be strictly economic. Approaches taking into account both intrinsic and instrumental values, or a system of values (Maitre

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d'Hôtel and Pelegrin, 2012), and mapping the dynamics of (and interactions between) services are still rare. IPBES (the Intergovernmental Platform of Biodiversity and Ecosystem Services) now prefers the concept of Nature's Contributions to People (NCP), which falls into three categories: regulation, material and immaterial (Pascual et al., 2017). Nevertheless, the relationships (or trade-offs) between these categories are not well defined and lead to inequitable or/and inadequate measures, such as payments for ecosystem services (PES), biodiversity offsets, reduced emissions from deforestation and degradation (REDD+) (cf. PES, biodiversity offset, REDD+, etc., Angelsen et al., 2011). Policy-makers face many critical questions. Can they maintain all services and benefits for all stakeholders? To what extent is the priority given to one service detrimental to another? Who are the winners and the losers? Who are the most vulnerable people affected by the policies? (Arsel and Büscher, 2012; Leach and Scoones, 2015).

Coastal areas are multipurpose systems and environments with some of the most diverse sets of ecological functions and services and some of the most valuable resources in the world. Losses of ecosystem services in coastal systems have been especially high in recent years (Costanza et al., 2014). Policies for coastal environmental management have been diverse, leading to widely different uses ranging from radical conversion into intensive monocultures to access restrictions protecting flagship species or sanctuaries. Mangroves play a predominant role in sub-tropical and tropical coastal areas around the world, providing a wide range of ecological and social services (Moberg and Rönnbäck, 2003; Walters et al., 2008). However, mangroves are threatened by multiple local and global pressures. According to FAO (2007), 20% of the total mangrove area has been lost since 1980, while, according to Valiela et al. (2001), at least 35% of the area was lost between 1980 and 2000. These losses were due to various anthropogenic pressures, such as growing populations, large-scale conversion of mangroves to fish or shrimp farming, agricultural side-effects, sewage effluent, construction, tourism and pollution, climatic pressure, including rising sea levels, and tsunamis (Alongi, 2008). With these changes (Steffen et al., 2005), and rising awareness of the multiple goods and services from the mangroves and of their rapid decline (Valiela et al., 2001), many programs have been led to restore and protect the mangroves. Mangroves are suitable environments for studying coastal vulnerability and, notably, the effects of changes on a particular socio-ecosystem. One of the main challenges of studying the mangrove environment is addressing interdisciplinary objectives, combining social, environmental and ecological sciences, that are linked by the services provided by the mangrove socio-ecosystem: reforestation and restoration, biodiversity, physical flows, uses and benefits for the local inhabitants.

The main objective of this study was to undertake a pilot survey using an interdisciplinary approach (collecting social and biological data) in a protected mangrove to highlight the links between some ecosystem services. The production of seafood and microorganisms was the main service we targeted. Ultimately, the aim was to give a general indication of how the services may be altered by human activities given a combination of external pressures and varying management policies. Mangrove reforestation has spread throughout the world (Walton et al., 2006) to rebuild the services associated with mangrove ecosystems (McNally et al., 2011). The success of mangrove restoration projects can only be improved if there are clear criteria for evaluating the success of the projects, if there is greater accessibility of information for managers and if the relevant ecological and socio-economic theories are applied (Ellison, 2000). Currently, there are few scientific studies evaluating the social and ecological effects of reforestation. This pilot study was carried out in the Can Gio Mangrove Biosphere Reserve (Can Gio MBR, Viet Nam) in June 2015. The MBR is near the Mekong Delta, where the mangrove has been heavily affected by human activities (including war) and climatic events, but has benefited from extensive reforestation campaigns for over 30 years (Kuenzer and Tuan, 2013). The study builds an interdisciplinary methodology to be applied in the field for assessing the contributions of the Can Gio mangrove to the local inhabitants. This socio-ecosystem was viewed as a unique "open experiment" and as an original case study. The main social and scientific questions were at first general and included various aspects of (i) the characterisation of mangrove seafood and microorganisms, (ii) the exploitation of the mangrove seafood, (iii) the stakeholders' knowledge of the Can Gio MBR governance and their values and rights of access and exploitation, and (iv) a view of the benefits from the conservation and exploitation of the mangrove.

In this study, the integration of social (geographers, political ecologists, anthropologists, ethno-malacologists), biological (biologists and micro- and macro- biologists), and environmental sciences (geographers, political ecologists) was used as the basis for a first step to draw up a methodological framework for studying such environments in coastal areas and to evaluate the risks and gaps when using interdisciplinary approaches. For the biological study, two major compartments of the ecosystem affecting the local population were selected: microorganisms (viruses, bacteria) and macro-organisms (mainly crustaceans). The taxa were preselected, but future studies should extend it to a wider list of organisms (pathogens, molluscs, fish). For the social sciences, the first aim was to identify the stakeholders involved in the dynamics of the Can Gio MBR and classify them to organise in-depth interviews with the different types of stakeholders in the area (knowledge and knowhow, practices, and strategies for dealing with environmental changes, etc.). The social interviews and biological sampling campaigns were carried out in parallel, in similar places.

2. Materials and methods

2.1. Study area

The Can Gio mangrove, in the Mekong Delta area, was designated as a coastal protection forest by a Vietnamese Ministerial Council Decision in 1991. In 1993, the State Forestry Enterprise was replaced by the Environmental Protection Forest (EPF) Management Board under the Department of Agriculture and Rural Development

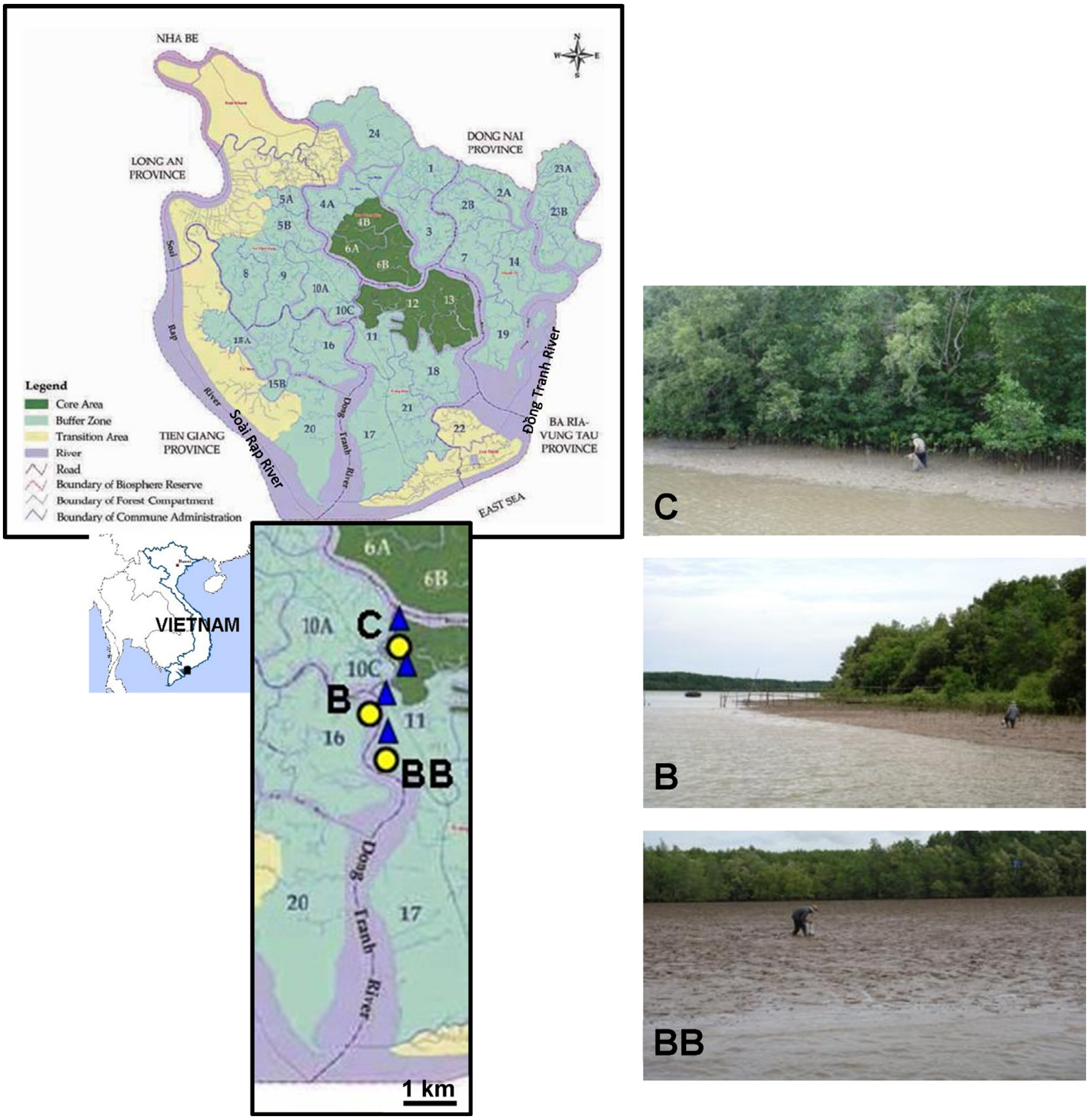

Fig. 1. Sampling sites in the Can Gio Mangrove Biosphere Reserve (water in violet): core zone (dark green) and buffer zone (light green), with numbers indicating the different managed zones within the Reserve. Yellow circles: biological samplings in the core (C), the buffer (B), and the buffer-bis (BB) zones. Blue triangles: sites of interviews onboard boats for the social survey (2 in the core and 2 in the buffer zones). The photos illustrate the different sampling zones (core, buffer and buffer-bis).
International Society for Mangrove Ecosystems (Nam et al., 2014), photos @ Panfili IRD.

(DARD). In 2000, the EPF went under the jurisdiction of Can Gio District People's Committee, and Can Gio became the first Mangrove Biosphere Reserve in Viet Nam. The management was transferred from DARD to the Can Gio People's Committee and the Can Gio Forest Management Board (FMB). From various reports (grey literature in 2014) and our recent observations, the mangrove forest is in very good state in Can Gio, dense and diversified: 21,100 ha of *Rhizophora apiculata* were planted between 1978 and 2000 together with 715 ha of *Eucalyptus* spp. and 281 ha of *Nypa fructicans* (Miyagi et al., 2014). The Can Gio Reserve is divided into 24 forest compartments, each of which are divided into several sub-compartments (Fig. 1). The core zone (4,720 ha) hosts the Can Gio FMB and is reserved for scientific activities. Only a few households live there. In the buffer zone (37,340 ha), forest exploitation is prohibited, while traditional exploitation of the rivers and tidal channels is unregulated. The transition zone (29,310 ha) is densely populated and hosts aquaculture farms (oysters, shrimps, etc.). Can Gio is unusual in that it relies on "protected forest concessionaires" (households under contract to protect the forest) in the core and buffer zones. In 1990, the government of Viet Nam invited new residents to come to settle down in the Reserve. Can Gio FMB signed contracts with 141 households, offering them land, a relocation grant and a small income for 30 years, in exchange for which they made a commitment to watch and protect the mangrove forest. Today, there are 160 protected forest concessionaires who are responsible for 80 ha on average (the smallest protected area is 25 ha and the largest is 300 ha).

2.2. Sampling and data collection

The use of the mangrove was assessed through an interdisciplinary approach with a common sampling design for social and biological data. A field survey was carried out in June 2015 in 3 main zones of the Can Gio Mangrove Biosphere Reserve (Can Gio MBR) with local replicates (Fig. 1). The zones were (i) the core zone (C), a strictly protected ecosystem with restricted human activity, (ii) the buffer zone (B) nearby the core zone used for activities compatible with sound ecological practices, and (iii) the buffer-bis zone (BB), which is a part of the buffer zone where resource management, such as shellfish farming, is promoted. Bioabundance and biodiversity in the various zones were quantified using multiple indicators based on samples of two major compartments of the ecosystem affected by local population: microorganisms (mostly viruses and bacteria) and macro-organisms (polychaetes, molluscs and crustaceans), with the addition of genomic taxonomy for crabs and an investigation of the relationship between shellfish and humans. The rights of access and use of this diverse biological community by the local population were studied in the same zones at the same time to understand the system of values and cultural ecosystem services in this area (Fig. 1). To tie the social and biological data together, it was necessary to select sampling points along a transect in the Can Gio MBR coordinating spatial and temporal scales. This was the main problem to be solved when carrying out both social and biological surveys over two days, as the time for interviews for social data was longer than the duration of biological sampling, while biological sampling required replicates.

2.3. Social data sampling and interviews

Interviews were conducted in the core and buffer zones of the Can Gio MBR (Fig. 1) with interviews of the main stakeholders within these areas, including fishermen, middlemen, seafood retailers, and oyster farmers. Two fishermen on fishing boats were interviewed on the Đông Tranh River in the core zone. One fisherman, one cockle farmer and one middleman were interviewed on the Đông Tranh River in the buffer zone. The buffer-bis zone had many oyster farms and two markets (Hàng Duong Market and Cân Thanh Market). A female seafood retailer in the Hàng Duong Market and an oyster farmer in the buffer-bis zone were interviewed. The questions addressed views and knowledge on the diversity of seafood products collected in the area, accessibility to resources, daily working life, exploiting mangrove products and forest conservation policies. Bivalves and gastropods, either sold in the market or found in the mangrove, were collected, and species were identified by local and scientific names and categorized according to provenance (sea mudflats or mangrove) and price.

2.4. Biological sampling

For quantification of the aquatic and benthic viral and bacterial abundance, triplicate samples of 1.8 mL of surface water and 1.8 mL of sediment were collected in the core (C), the buffer (B), and the buffer-bis (BB) zones. The samples were transferred to cryotubes, fixed with formaldehyde (final concentration 3%) and stored in liquid nitrogen until analysis. The aquatic community was enumerated by taking a subsample of 300 μL from each water sample, filtering it onto 0.02-μm-pore-size membranes (Anodisc), and staining it with SYBR Gold. Benthic viruses and bacteria were enumerated as recommended by Danovaro et al. (2001). Aliquots of the fixed sediment samples (1 mL) were diluted with tetrasodium pyrophosphate (4 mL, final concentration, 10 mM), and incubated for 20 min at 4 °C. The samples were then sonicated three times (100 W for 1 min) and diluted 200-fold with filtered (0.02 μm) formaldehyde (final concentration, 2%). This procedure has been shown to extract the majority of viruses and bacteria from sediment (Glud and Middelboe, 2004). Samples were mounted on microscopic slides (Bettarel et al., 2006). On each slide, 500 to 600 bacteria and viruses were counted.

The abundance of macro-organisms in the mangrove infauna and the epifauna on the mangrove trees and the sediment surface was assessed at three sites on the intertidal mudflats in front of the mangrove stands of both the core (C) and buffer zones (B). Six replicate sediment cores, 10 cm in diameter and 10 cm in-depth were collected from each site. The cores were washed with filtered seawater through a 500-μm sieve and preserved in 4% formaldehyde seawater. Macrofauna species – polychaetes, molluscs and crustaceans – were identified and counted in the laboratory with the aid of a microscope and identification keys. A nested two-factor analysis of variance was carried out on the abundance data of the various macrofauna groups (factor 1 was the zone C/B, factor 2 was the site within the zone). A permutational analysis of variance (PERMANOVA) was used to detect potential differences in assemblage structure. Multidimensional scaling plots were used for graphical representation (Primer Statistical Package). All statistical analyses were performed using R statistical software (R Development Core Team).

For the analysis of crab diversity, the crabs present at each site (Fig. 1) were caught by a fisherman during a 30-min fishing period. Three replicate samples were taken at each site successively (three times 30 min of fishing). The samples were then processed on board or frozen for subsequent laboratory processing. Each individual was photographed, sexed, measured (shell width) and weighed, then, a sample of leg muscle was taken and stored in 96% ethanol in a microtube vial for genotyping. Some individuals were frozen as specimens. All individuals were counted per species (or morphotype). Of the 390 crabs collected, a subsample of 62 individuals was used for genotyping to determine the species or at least the number of putative species. These samples corresponded to the different morphotypes identified and photographed at each sampling station. Genomic DNA was extracted from the muscle tissue using PureLink® Genomic DNA kit (Invitrogen). A portion of each *cytochrome oxydase I* gene (*COI*) was amplified by polymerase-chain reaction (PCR) using the primers LCO1490 (ggtcaacaaatcataaagatattgg) and HC02198 (taaacttcagggtgaccaaaaaatca) (Folmer et al., 1994). PCR was carried in a 40-μL reaction volume comprising 20 μL of FastStart PCR Master Mix (Roche), 0.6 μL of each primer (10 μM), 0.8 μL of BSA, 16 μL of ultra-pure H_2O, and 2 μL of DNA template. The PCR amplification process comprised a preliminary denaturation step at 92 °C for 5 min followed by 35 cycles of strand denaturation at 92 °C for 1 min, primer annealing at 40 °C for 45 s and primer extension at 72 °C for 1.5 min, followed by final extension at 72 °C for 5 min. Sequencing was performed by Macrogen Inc. (Seoul, South Korea; http://dna.macrogen.com). The sequences were edited using 4Peaks version 1.7 by A. Griekspoor and Tom Groothuis (mekentosj.com) and then aligned visually with Mega 5.0 (Tamura et al., 2011). The phylogenetic relationships between the crabs' haplotypes were determined using a phylogenetic analysis based on a maximum-likelihood (ML) method implemented in Mega 5 (Tamura et al., 2011) with the heurist method set to nearest-neighbour interchange, a NJ/BioNJ initial tree, and a very strong branch swap filter. The support for the nodes was assessed by bootstrapping with 1000 pseudo-replicates.

3. Results

3.1. Social science survey

The three protected zones of the Can Gio MBR are characterised by large differences in conservation policy that shape the exploitation and economy. Although mangrove tree harvesting is strictly forbidden in the Can Gio MBR, seafood fishing is less restricted. The main difference between the core zone and the buffer zone is the equipment used for fishing, which depends on the seafood targeted (fish, crustaceans, or molluscs). Permits from the Can Gio Mangrove Protection Forest Management Board are required for aquaculture. These permits are not restricted to the local inhabitants. Local inhabitants seem to have a good knowledge of the conservation rules for the different zones within the Can Gio MBR. In the buffer zones, they manage both the use of the mudflats for shellfish aquaculture, with resting periods of a few years for recovery, and the reforestation of the mangroves near the areas used for aquaculture.

The policies are focused on the management of the mangrove trees. The main objective of the Can Gio MBR management board is the protection of the mangrove forest by extending the area, diversifying the species planted, and prohibiting tree harvesting. The other resources, such as seafood, are not controlled and there seems to be no official limits to fishing, gathering shellfish, or aquaculture. Tourism and fishery are promoted ways of improving the local economy. Tenure is negotiated by the stakeholders.

Can Gio MBR is bounded by two rivers, the Soài Rap River (West side) and the Đông Tranh River (North-East side), emptying into the sea. It is divided into compartments, each with a different management and tenure system. The survey revealed a wide range of players involved in or affected by the Can Gio MBR (Fig. 2). There are three main groups: the representatives of the central and provincial governments, the protected forest concessionaires and the out-of-area or migrant users. There were many different categories of out-of-area users: men and women who gather wild crabs and molluscs from the mudflats on foot, seasonal fishermen who are natives of other provinces and use various fishing gear (diverse nets, baskets, pots and small artisanal dams), black cockle

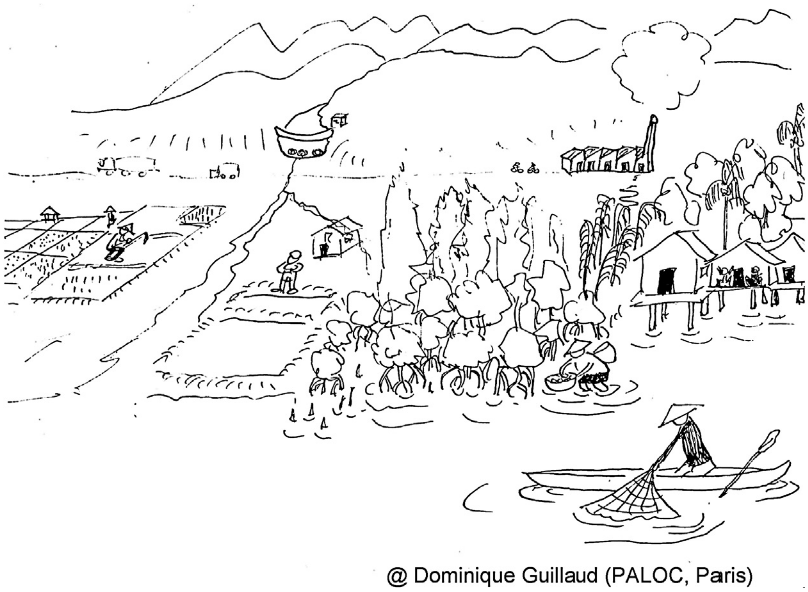

Fig. 2. Mangrove, a complex socio-ecosystem with multiple stakeholders, from local to global scales, which needs an interdisciplinary approach. Original drawing is courtesy of Dominique Guillaud, PALOC, Paris, December 2016.

(*Tegillarca granosa*) farmers along the banks of the channels within the MBR who use netting to create non-permanent, more or less open, beds that are checked from boats, and those who farm oysters, shrimps and cockles in closed beds and who live in houses outside the MBR. In addition, some of the protected forest concessionaires also operate saltpans.

According to previous in-depth surveys (unpublished) and the life stories collected during this survey, some stakeholders were identified as becoming richer, with a comfortable socio-economic status, such as new traders in Can Gio and protected forest concessionaires. On the other hand, some stakeholders, who used to be protected forest concessionaires, lost this status and became poorer and less privileged. A similar imbalance in access to finance and markets and differences in privilege between two groups of players, farmers and public forestry companies, was found in the Ca Mau mangroves close by (Ha et al., 2012). This reflects the inequality between the indigenous population and immigrants, as well as between farmers and more privileged government officers.

3.2. Biological abundance and diversity

The benthic viruses and bacteria were much more abundant than the aquatic viruses and bacteria but, in all cases, there were no significant differences in abundance between the sampling sites (Fig. 3). Seven macrofauna groups were identified in the mudflat samples: polychaetes, small crabs, nematodes, mysidacea, copepods, stomatopods, and isopods (in order of decreasing abundance). Polychaetes were largely dominant. Epifauna on the mangrove trees and the sediment surface was very scarce at all sampling sites. No snails or bivalves were found in any of the samples. The analysis of variance did not detect any significant differences in the total abundance of macrofauna organisms between the buffer and the core zone or between sites (Fig. 4A; $P > 0.05$). Six out of the

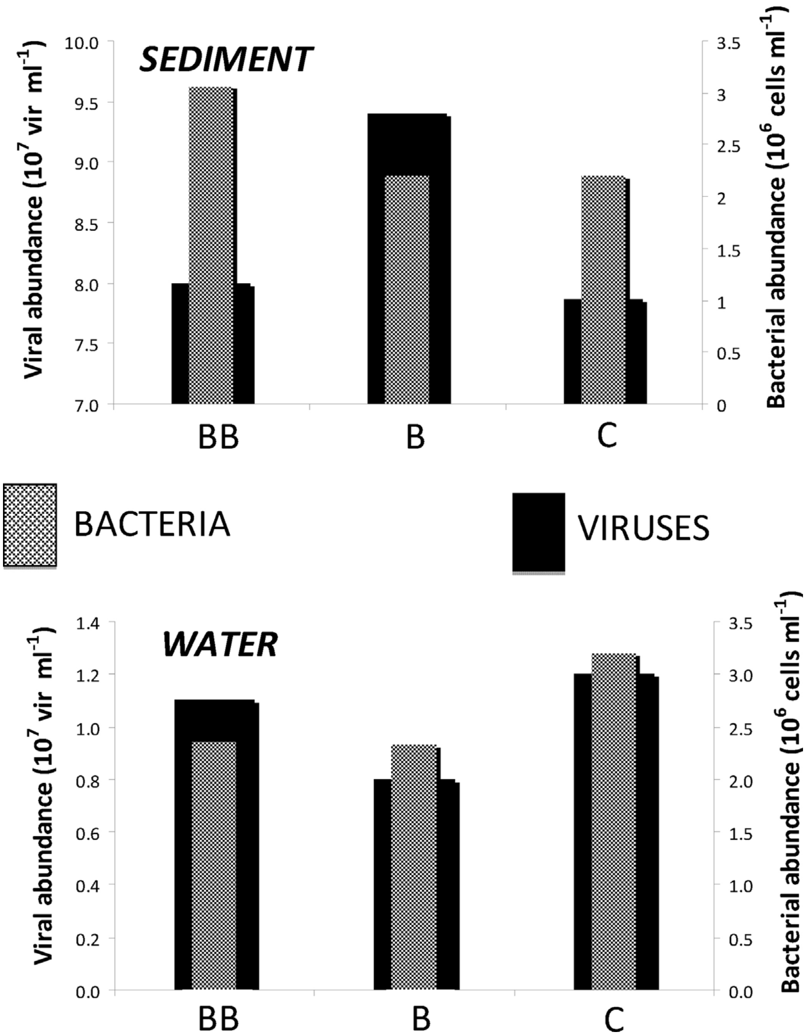

Fig. 3. Bacterial and viral abundance in the sediment and water in three zones in the Can Gio Mangrove Biosphere Reserve: buffer-bis zone (BB), buffer zone (B), and core zone (C).

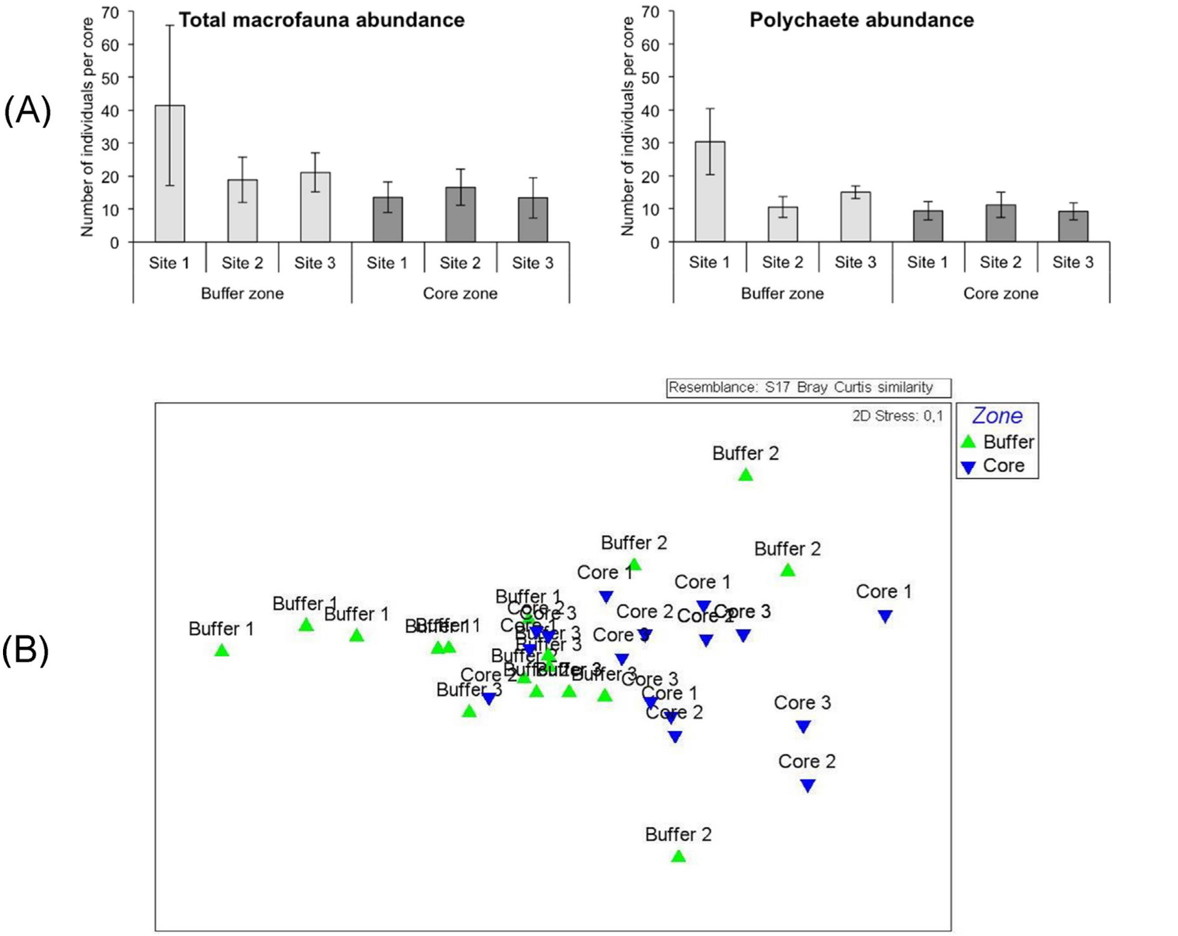

Fig. 4. A. Abundance (mean number of individuals ± SE) of total macrofauna and polychaetes in the six replicates at the three sampling sites in the buffer and the core zones. B. Multidimensional scaling plot on the abundance data of each macrofauna group at the three sites (1–3) in the buffer zone (green triangles) and the core zone (blue inverted triangles). $V = 6$.

seven macrofauna groups – crabs, nematodes, mysidacea, copepods, stomatopods, and isopods – did not show any significant differences between zones or sites. The abundance of polychaetes was not significantly different between zones, although there were differences between certain sites in the buffer zone (Fig. 4A).

PERMANOVA did not show any pattern in macrofauna assemblage as a function of zones or sites (Fig. 4B). In the buffer zone, however, site 1 was significantly different from sites 2 and 3 (P(perm) = 0.002). The macrofauna assemblages were thus not affected by the different protection levels inside the Can Gio MBR and, in general, there were no clear differences between sites.

The biodiversity assessment was limited to the crab species as only a few mollusc and bivalve species were collected in the three zones. The three replicate samples in each of the three zones created a collection of 390 crabs. At first, looking at the morphology in the field, the crab diversity seemed very high, but genotyping showed that only four species were present (Fig. 5): two *Uca* species, *U. annulipes*, and *U. paradussumieri*, and two *Metaplax* species, *M. elegans*, and *M. longipes*. A precise description of the morphology of each species was created using the genotypes. Males are easily recognisable using morphology, but it is much more complicated for females. *U. annulipes* male has asymmetric claws (but the larger claw can be left or right), the larger claw is bicoloured (orange and white) and the shell is mottled. *U. annulipes* female has a mottled shell and hairy claws. *U. paradussumieri* male has asymmetric claws (the larger claw can be left or right), the larger claw has a uniform colour (from brown to dark yellow) and the shell is dark sometimes with dark yellow bands. *U. paradussumieri* female has a dark shell and hairy claws. *M. elegans* male has long thick orange claws and long legs. *M. longipes* male has small, thin orange claws and long legs. *Metaplax* females are very difficult (or impossible) to separate between species.

Uca were the most abundant in the total sample (70% *vs.* 30% *Metaplax*) and this ratio distinguished between the buffer-bis zone with intensive aquaculture (90% *Uca vs.* 10% *Metaplax*) and the core and buffer zones with a higher level of protection (around 50% of each genus). This result should be treated with caution, however, as natural environmental differences that might interact with the human activities were not measured here.

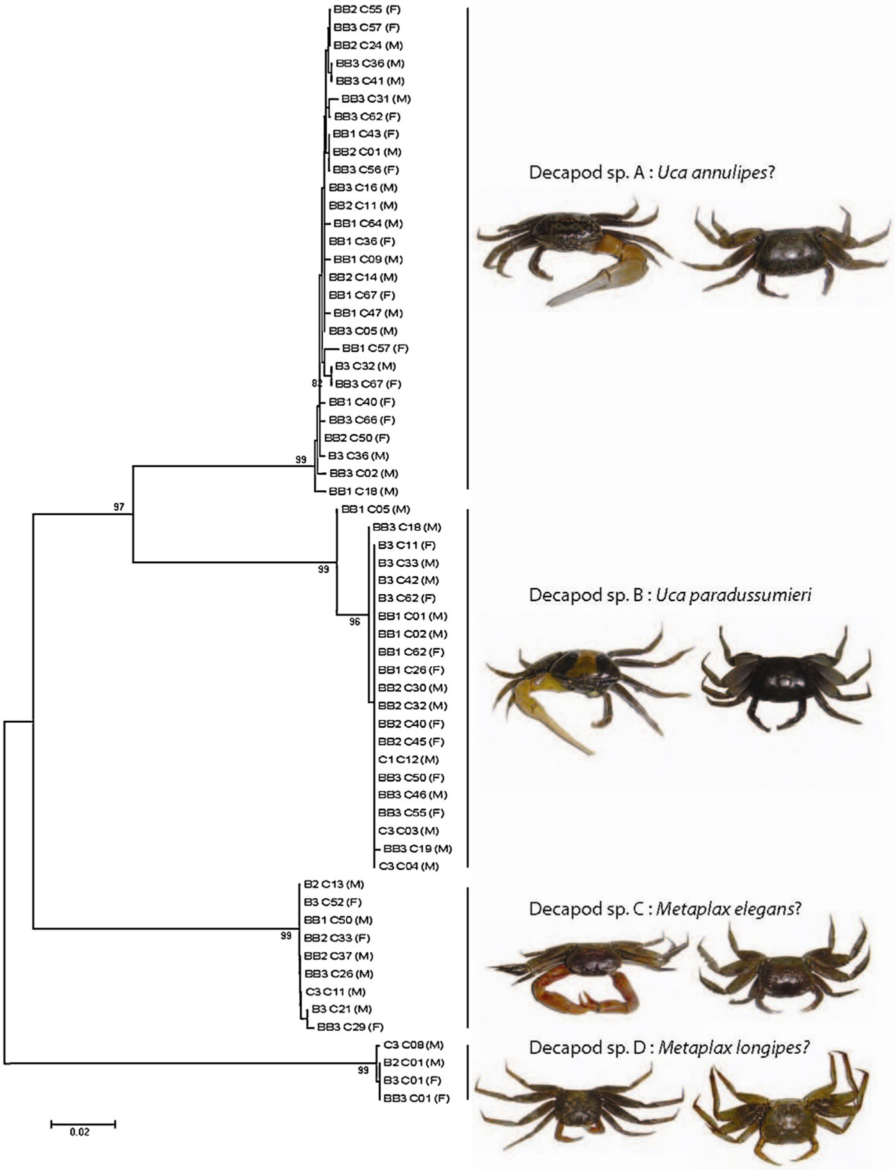

Fig. 5. Phylogenetic tree of the crabs sampled in the Can Gio Mangrove Biosphere Reserve in June 2015. Four species only were identified: *Uca annulipes*, *U. paradussumieri*, *Metaplax elegans*, and *M. longipes*.

4. Discussion

4.1. Insights from our results

The study successfully undertook a preliminary interdisciplinary survey of the Can Gio MBR. One of the main conclusions, shared by the scientists and the stakeholders, was the ecological and social relevance of the reserve management strategy. From a social point of view, local users not only are aware that they are living within a reserve, knowing its limits and rules, but they also participate in its sustainable management and take benefits from its goods and services.

Although biological sampling was limited both spatially and in terms of taxa, the viral, bacterial and infauna abundance and the crab diversity were similar in the core and buffer zones, even if the buffer-bis zone with its more intensive aquaculture showed differences in terms of crab diversity. Does this mean that the management and exploitation of the mangrove have a relatively low effect on abundance and diversity? The question cannot be answered yet. The results should indeed be interpreted with caution, as environmental differences not measured here (variations in mangrove vegetation structure, sediments and hydrodynamic conditions, physical and chemical gradients in the waters) can also affect the assemblages.

The most notable finding is the low level of crab genotype diversity, even though there were strong differences between morphotypes and sizes (results not presented). Our knowledge of crab diversity in the Can Gio

MBR relies mostly on grey literature, as there is very little published data in international journals. A study of the crab diversity and its resilience to a typhoon indicated that only 12 species were present in Can Gio (Diele et al., 2013). In the area sampled in the present study, the even lower level of diversity could be a result of the limited area sampled (part of the core and buffer). An additional aspect of the social survey could be to determine whether people give different names for crabs of the same species (genetically identified) presenting different morphologies. This could give an idea for the general perception of the biodiversity by the stakeholders.

4.2. Interdisciplinary approaches for studying the mangrove

An "interdisciplinary" approach is a close coordination between disciplines, from the joint development of a conceptual and methodological framework up to the integrated analysis of the results. This approach is to be distinguished from the "multidisciplinary" one, which can be a simple juxtaposition of various disciplines and from the "transdisciplinary" one, which combines disciplines so as to achieve a single objective using various methods. Many "transdisciplinary" researchers (Bouamrane et al., 2013; Weber, 1996) have argued that interdisciplinarity cannot be decreed, but is a question of practice, particularly in the field. Social studies can be undertaken from the local level (e.g., exploitation of mangrove crabs) to the global (e.g., impact of international conventions and mechanisms such as REDD+). Biological studies can be undertaken from the individual scale to the community or the meta-community scale over a very wide range of time scales. Both methodological and ontological issues affect the spatial scales of data collection (see also Johnston et al., 2000; see Sayre, 2005). The geographical scale is important for both ecology and human geography, and processes and interactions rather than scale per se should be the object of research, with particular attention to non-linearities and thresholds of change (Sayre, 2005).

Further empirical studies are required for in-depth characterization of the stakeholders and for understanding of the socio-economic and political contexts. We must refine the stakeholder categories (indigenous *vs*. migrant, beneficiaries and protected forest concessionaires *vs*. excluded or marginalized households) and determine their knowledge and practices, their traditional rights of access and exploitation, the individual and institutional development paths and public policies. It is necessary to describe and analyse the systems of mangrove tenure and enclosure. During this first survey, which should be considered as a test, the accent was put on the food uses of molluscs and bivalves, but it is necessary to include the use of other seafoods (e.g., crabs) and forest products. It is also necessary to investigate the seasonality of resource use and exploitation and the distribution of resources within the MBR. Furthermore, further investigation is required concerning synergies and competition (for instance between fishing and intensive aquaculture) and conflicts between incompatible tenures, as well as the sources of conflicts and the processes of conflict resolution. It is also necessary to analyse the environmental policies and private activities (both endogenous and exogenous) in favour of mangrove services and determine their effects on the local dynamics.

Research in social sciences requires a long immersion in the field. In many cases, in-depth investigations are preceded by a first introductory visit to take the measure of the study site and introduce the research team to the stakeholders. Then, the interviews themselves may last several hours and may be spread over several days or even months. For example, the mangrove uses vary with the tide and the seasons. In addition to the seasonal calendar of activities, life histories or biographies, retrospective surveys, personal plans and links between families are useful for understanding the stakeholders' strategies and timing for adapting to change.

A simple visit to one of the Can Gio markets and the Binh Điên grocery market in Ho Chi Minh City showed the wide diversity and the large quantity of products from the rivers and the sea, the mass of stakeholders in these networks, and their economic and social weight. It also raised questions about the durability of the sector and the need for organising the value chains for the products from the sea and from the mangrove. This requires studies of the production sites, local markets, regional markets and other distribution centres, outlets (restaurants, Ho Chi Minh City markets), and the food and culinary heritage. Comparative studies of the quality of products from or associated with the mangrove (wild *vs*. farmed shellfish, from the mangrove itself, the channels or the foreshore) are required to determine the relevance of the protected food designations. The certification of the products could be considered as a mean for increasing biodiversity (increasing value to decrease pressure on the resources). Other forms of exploitation, such as tourism and ecotourism, also need to be studied. Finally, the flows and exchanges between the mangrove and other socio-ecosystems must be determined and analysed.

5. Conclusions

There was little in the way of direct links between social and biological data in our study. For example, the crabs that were analysed for diversity are present in all areas because they are detritivores and use the mangrove and tidal areas for feeding, but are not really consumed by the local inhabitants. The effect of aquatic and benthic viruses and bacteria on human well-being is not yet demonstrated. Long-term immersion and talking to people is an effective way of understanding the socio-ecosystem, but the questions need to be concrete. The methodologies and tools used in the different disciplines need to be combined, but the results still need to be compared, classified, and the scales rationalised to get a global picture. Interdisciplinarity could be a very good way to highlight the main issues in terms of research and actions for the management of environments, such as mangrove socio-ecosystems.

The key issue consists of understanding the complexity of the mangrove, considering all variables, all agents and linking various spatial and temporal scales. In the future, we intend to apply an inclusive and interdisciplinary approach and implement various tools for collating the data, from participatory mapping to multi-agent modelling. Studies of the functional ecology and diversity should be added, to improve our understanding of the structure of the different zones in the Can Gio MBR, together with a study of the trophic chain, up to human consumption, to reveal the ecosystem's functioning. Understanding the local stakeholders' perceptions of the changes in their environment and the factors influencing them could be a bonus. Studies should also focus on quantitative and/or qualitative indicators that could lead to direct management of the Can Gio MBR and to evaluation of development scenarios.

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