frontiers in Forests and Global Change

ORIGINAL RESEARCH
published: 12 January 2022
doi: 10.3389/ffgc.2021.769182

Ecosystem Services Assessment for the Conservation of Mangroves in French Guiana Using Fuzzy Cognitive Mapping

Pierre Scemama[1]*, Esther Regnier[2], Fabian Blanchard[3] and Olivier Thébaud[1]

[1] Ifremer, Univ Brest, CNRS, UMR 6308, AMURE, Unité d'Economie Maritime, IUEM, Plouzané, France, [2] Univ Brest, Ifremer, CNRS, UMR 6308, AMURE, IUEM, Plouzané, France, [3] Ifremer, USR 3456, LEEISA, CNRS, Universite de Guyane, Cayenne, French Guiana

In 2016, the French government adopted a law for biodiversity, setting an objective of protecting 55,000 hectares of mangroves. This objective is particularly important to French Guiana, which shelters almost 60% of French mangrove ecosystems, and where mangroves occupy three quarters of the coastline. The coast of French Guiana is also where issues associated with demographic and economic dynamics concentrate. There is thus a need to plan for an economic development that is compatible with the objective of protecting mangrove ecosystems. Ecosystem services (ES) assessment can support such decision-making, informing on the costs and benefits associated with alternative mangrove conservation strategies. While the many services provided by mangrove ecosystems are well documented worldwide, the extent to which these can be encountered in the specific case of French Guiana is currently only very partially known. Relying on the Fuzzy cognitive mapping (FCM) approach, we collected and compared the perception of multiple and heterogeneous groups of stakeholders, of the functioning of the mangrove social-ecological system at the scale of French Guiana. Results, allow to identify mangroves ES and threats particularly influenced by the high sedimentary dynamism of the shoreline. This generates two distinct components of the mangrove social-ecological system: mud banks where ecosystem services are spatially and temporally unstable, and associated with perceived constraints for key coastal activities, and estuarine mangroves where the ecosystem services usually described in the literature on mangroves can be found. Disservices associated with mangrove ecosystems were also identified as a key interaction. This can inform the research needs that should support sustainable development trajectories, fully accounting for the protection of French Guianese mangrove ecosystems.

Keywords: French Guiana, stakeholders perceptions, marine ecosystem services, mangrove forest, socio-ecosystem sustainability

OPEN ACCESS

Edited by:
Sigit Sasmito,
National University of Singapore,
Singapore

Reviewed by:
Clare Duncan,
Zoological Society of London,
United Kingdom
Jahson Alemu I,
Northeastern University, United States

Correspondence:
Pierre Scemama
pierre.scemama@ifremer.fr

Specialty section:
This article was submitted to Tropical Forests, a section of the journal Frontiers in Forests and Global Change

Received: *01 September 2021*
Accepted: *14 December 2021*
Published: *12 January 2022*

Citation:
Scemama P, Regnier E, Blanchard F and Thébaud O (2022) Ecosystem Services Assessment for the Conservation of Mangroves in French Guiana Using Fuzzy Cognitive Mapping. Front. For. Glob. Change 4:769182. doi: 10.3389/ffgc.2021.769182

INTRODUCTION

Despite their importance, mangroves are disappearing at a global rate of 1–2% per year (Spalding et al., 2010) and 20–35% have been lost in the last 50 years (Polidoro et al., 2010). The main threats to mangroves are climate change (Gilman et al., 2008; Lovelock et al., 2015; Schuerch et al., 2018); land-use conversion to agriculture and aquaculture (Thomas et al., 2017;

Goldberg et al., 2020); and pollution (Maiti and Chowdhury, 2013). These threats have led to the mobilization of the international community for mangrove conservation (Sandilyan and Kathiresan, 2012; Friess et al., 2016).

Within its overseas territories, France shelters more than 80,000 ha of mangrove (Trégarot et al., 2021). In 2016, in line with its international commitments, the French government adopted an ambitious law to protect 55,000 hectares of mangroves, with the mangrove of French Guiana at the forefront of this action.

In French Guiana, mangrove forests, that occupy around 75% of the coastline, are in a relatively good state, largely un-impacted by urbanization and residential development (Trégarot et al., 2021). This situation strongly contrasts with the neighboring countries, notably Suriname and Guyana, where mangroves have been severely impacted by urbanization (Anthony and Gratiot, 2012). However, demographic projections estimate an increase of 75% of population by 2050 (INSEE, 2019). With a population predominantly located on the coast (Zouari, 2015), urbanization pressure is expected to increase as a result of both residential demand and infrastructure development (e.g., recently with the construction of a power plant; Autorité Environnementale, 2019). In addition, there is currently the implementation of a planning strategy for the maritime economy as a development opportunity for economic growth, that will also require the development of dedicated infrastructures, directly on the coast (e.g., port; CEREMA, 2016). In this context, the conservation of mangroves is likely to become a challenge for decision-makers requiring the assessment of associated trade-offs. Understanding the importance of mangroves to society is thus necessary, to support the development and implementation of informed conservation policies.

The concept of ecosystem services (ES) was introduced to account for interdependencies between human societies and ecosystems (Daily, 1997; MEA, 2005). By enabling the identification of these interdependencies, its application can inform on the trade-offs between economic development and biodiversity conservation (Carpenter et al., 2009).

Recently, France conducted a national assessment of the state of marine ecosystem and ES[1] that showed a lack of information regarding ES in its overseas territories, including French Guiana, as compared to mainland France (Mongruel et al., 2018). Regarding mangroves, information remains relatively scarce, and not all ES are equally well documented. In comparison, there is an extensive literature on the ES they provide at the global level, which identifies a range of services provided by these ecosystems, as well as interactions between these services.

Firstly, mangroves worldwide deliver many provisioning services that are essential for local and national economies (Rönnbäck, 1999). They support commercial, recreational and subsistence fisheries (e.g., Manson et al., 2005; Aburto-Oropeza et al., 2008). For example, a positive statistical relationship has been identified between catches of fish or shrimp and mangrove surface area (Carrasquilla-Henao and Juanes, 2017). Shellfish gathering can also occur directly in the mangrove (Treviño and Murillo-Sandoval, 2021). Mangroves have also been shown to sustain shrimp aquaculture (e.g., Truong and Do, 2018). However, the intensive conversion of mangroves into aquaculture farms is currently one of the main threats to mangroves in many countries, and may not be compatible with their importance in sustaining fisheries (Naylor et al., 2000). Among the other products provided by mangroves, the harvesting of wood for construction, combustible or artisanal products has also been highlighted (e.g., Walters, 2005; Bosire et al., 2008).

Secondly, mangroves have been shown to provide cultural services, although the importance of these services is less well documented (Himes-Cornell et al., 2018). Mangroves can support nature-based recreational activities that include diving, bird watching, hiking and recreational fishing (Van Oudenhoven et al., 2015), contributing to tourism development (Spalding and Parrett, 2019). Mangroves can also support the production of knowledge for research and education (Owuor et al., 2019). Mangroves are also associated with more immaterial values, where coastal communities have developed symbolic relationships with the mangrove forest (de Souza Queiroz et al., 2017).

Thirdly, mangroves have been shown to provide regulatory services. Mangroves act as a buffer between the land and the sea, significantly attenuating the energy of wind-generated surface waves (Massel et al., 1999) and protecting the coastline from tropical storms (Ouyang et al., 2018; Hochard et al., 2019). Mangroves can also play a role in regulating the impacts of human activities on water quality, studies showing the ability of mangrove ecosystems to reduce nutrient loads (Xiao et al., 2018; Adame et al., 2019) and chemical concentrations (MacFarlane et al., 2007; Kulkarni et al., 2018) in coastal water. Mangroves have also been shown to support climate regulation, through carbon sequestration (Bouillon, 2011; Duarte et al., 2013; Atwood et al., 2017). Mangroves' stocks of carbon are distributed between aboveground biomass, belowground biomass and soil (Walcker et al., 2015).

When relying on the concept of ES to understand the relationships between societies and ecosystems, studies often fail in addressing the importance of disservices (Blanco et al., 2019). Historically, mangroves were more commonly considered as a reservoir of disease such as malaria by nineteenth century explorers that led to global drainage operations (Friess, 2016). Nowadays, mangroves continue to receive negative press that can severely undermine conservation efforts (Dahdouh-Guebas et al., 2020).

The objective of this project was to begin bridging this gap between the state of knowledge at international and French Guiana levels, by developing a first comprehensive assessment of the ES provided by mangroves in this territory.

There is currently no consensus regarding the way ES assessment should be structured (Schröter et al., 2014). An important body of research has focused on the monetary valuation of the benefits that humans derive from ecosystems. Monetary values reflect the social importance of ES and are considered by many as a prerequisite for better management decision-making (TEEB, 2010; Costanza et al., 2017). However,

[1]The EFESE project for French Assessment of Ecosystem and Ecosystem Services was divided in several reports according to types of ecosystems: agricultural, urban, mountainous, wetlands, forested and marine and coastal. Mangrove ecosystems, as transitional ecosystems, were included in marine and coastal ecosystems.

the monetary valuation of ES is still subject to criticism, due to methodological and theoretical controversies (Farley, 2012; Muradian and Gómez-Baggethun, 2021) or to their operationalization (Marre and Billé, 2019).

In this paper, we rely on another facet of ES assessment which stems directly from the need to support policy-making regarding biodiversity conservation via improved understanding of the potential impacts of alternative conservation strategies (Armsworth et al., 2007). In this perspective, ES assessments take root in the contribution of systems sciences to the understanding of socio-ecological systems (Braat and de Groot, 2012). This approach is also strongly influenced by the concepts of biological conservation, for which the imperative of providing policy answers to the biodiversity crisis imply adopting holistic multidisciplinary approaches, that also include stakeholder knowledge. Following this path, ES assessment constitutes a boundary object allowing various stakeholders to share their representation of the world based on a common framework (Steger et al., 2018).

With this in mind, and given the lack of prior studies of mangrove ES in French Guiana, we relied on the expertise of French Guiana stakeholders to develop the first holistic assessment of ES associated with Guianese mangrove ecosystems. We used fuzzy cognitive mapping (FCM) as an integrated research tool to assess how stakeholders perceive the entire bundle of multiple and interconnected ES within the mangrove socio-ecosystem. FCM is a semi-quantitative modeling tool that is useful to analyze and compare stakeholders' knowledge of a socio-ecosystem (Özesmi and Özesmi, 2004; Gray et al., 2014; Bosma et al., 2017). In addition, FCM are easy to use in participatory research settings (van Vliet et al., 2010). We collected stakeholders' perception using a combination of interviews and workshops.

First, we provide a synthetic description of mangroves in French Guiana and a presentation of the FCM methodology and how this was used to develop a holistic representation of the Guianese mangrove socio-ecological system. This representation is then described, taking into account the qualitative information collected as part of focus groups where it was presented to stakeholders. The article then discusses the implications of this representation for mangrove conservation policy in French Guiana, and concludes.

MATERIALS AND METHODS

Presentation of the Case Study

French Guiana is an overseas department of France, bordered by Brazil in the south and east and by Surinam in the west, with a land area of 83,534 km^2 and a coastline of 320 km in length. Its population of around 275,000 inhabitants in 2016 is mainly concentrated within 10–30 km-wide coastal strip (Zouari, 2015). The main city is Cayenne where the main transport infrastructures of the territory are located (international airport, main commercial port) and which shelters half of the Guianese population. The two other main populated areas are Kourou where the Guianese Spatial Center is located and the estuary of Maroni river that is characterized by the highest population growth.

It is located in a equatorial climate and has all the necessary characteristics for mangrove colonization and growth, with air temperature fluctuating between 26 and 30°C and rainfall ranging from 2,500 to 3,000 mm.yr^{-1} (Marchand, 2017; Walcker et al., 2018). Mangroves in French Guiana occupy almost 75% of the coastline (Walcker et al., 2015).

French Guiana's coastline is characterized by the dynamics of its coastline, that is deeply affected by the Amazon River. Sediments eroded in the Andes are transported along the Amazonian basin down to the river mouth (Martinez et al., 2009). There, under the influence of tides, waves and currents, accumulated sediments form individual mud-banks typically extending 10–60 km along the coastline, 20–30 km offshore and 5 m thick, that move along the coast toward the Orinoco river (Venezuela) at a rate of 1.5–3.5 km/yr (Gardel and Gratiot, 2005). This dynamic geomorphology offers uncommon conditions for coastal mangroves (Walcker et al., 2018). During their formation, mud-banks are colonized by propagules carried by the tides; with the arrival of new seeds the mangrove forest accumulates in successive strips of even-aged stands. During the erosion phase, mangroves are swept away starting with the youngest forest stands, until the erosion stops or until the mangrove locally disappears with its substrate. Coastal mangroves, exposed to mud-banks migration, are mostly dominated by *Avicennia germinens* that are more effective in rapidly colonizing and developing on such an unstable and stressful substrate (Fromard et al., 2004).

Mangrove succession in French Guiana is also well described (Fromard et al., 1998) starting with pioneer mangroves that accumulate biomass while maturing. Mangroves are dominated by *Laguncularia racemosa* and *A. germinens*, and depending on environmental conditions, sediment can accumulate and the landward mangrove forest can turn into savannah. Under stronger riverine influence, mangrove species association also include *Rhizophora* spp. and can evolve into marshy forest, depending on sedimentary conditions. Excess sedimentation can also suffocate mangrove trees, leading to dead mangrove areas, that can enter a new cycle of colonization, if conditions are favorable. Such dead mangrove areas are a characteristic feature of the Guianese coast (Fromard et al., 1998). In a nutshell, mangrove in French Guiana are not homogenous and an important distinction exists, between coastal mangroves that are exposed to mud-bank migration and estuarine mangroves located under riverine influence.

Fuzzy Cognitive Mapping

Presentation of the Method

FCM is an integrated research tool that has been developed to assess and compare expert knowledge (Özesmi and Özesmi, 2004). The approach presents many advantages relevant to our research question, notably the ability to model system relationships where scientific information is limited but expert and stakeholder knowledge is available, and the ability to deal with variables that may not be well-defined. As a consequence, FCM captures all knowledge, including individual misconceptions or biases. However, this can be reduced by the possibility of combining individual answers, thus limiting the uncertainty associated with individual responses (Özesmi and Özesmi, 2004). FCM can either be used to capture the knowledge of experts (e.g., Hobbs et al., 2002) as well as non-experts, including local stakeholders (e.g., Gray et al., 2015). In this perspective, it has successfully been implemented in both social and ecological research (Teixeira et al., 2018).

A cognitive map can be defined as "a qualitative model of how a given system operates" (Özesmi and Özesmi, 2004, p. 44). It offers a graphical representation of the relationships between the key variables of the system. Variables can designate physical quantities that can be measured (e.g., a number or biomass of fish) or more abstract concepts (e.g., heritage value). Drawing a cognitive map thus implies (i) selecting the important variables that affect a system and (ii) establishing the causal relationship among these variables with a number between −1 (negative effect) and 1 (positive effect). It is the application of fuzzy causal functions to measure the connections between variables, relying on real numbers between [−1; 1] rather than integers, that turn cognitive maps into fuzzy cognitive maps (FCMs). Cognitive maps have the advantage of being concise, allowing stakeholders, including decision-makers, to capture the complexity of a system at a single glance.

Once individual FCMs are collected, it is common to aggregate them in order to form a social map (Özesmi and Özesmi, 2004), with the following steps: (1) an augmented matrix including the variables from all the individual maps is created; (2) all the individual FCMs are coded into the augmented matrix; (3) individual maps are aggregated using matrix addition resulting in a social map. It is also possible to normalize the matrix values of this social map by the number of cognitive maps underlying them, to obtain scores between −1 and +1.

After aggregation, the social map contains all the variables that have been identified by individuals. At this stage, it may be necessary to condensate the social map to avoid too many variables and connections (Özesmi and Özesmi, 2004). Condensation is the action of replacing a part of the social map with a single variable. Condensation may follow a quantitative logic—maintaining the strongest relations—or a qualitative logic—merging variables when they can be united under a larger encompassing variable. When replacing a group of variables, connections from merged variables to other variables are maintained.

The construction of social maps is based on the rationale that an assessment by many experts with diverse visions and perspectives will have greater relevance than one relying on a single expert versed in all aspects of the problem. In this work, we refer to two types of social maps: "stakeholder maps" when the social map is obtained from the aggregation of individual FCMs within a particular stakeholder group, and "community maps," when the social map is obtained from the aggregation of all the individual FCMs, across stakeholder groups.

Sampling Design and Fuzzy Cognitive Mapping Construction

There is no constraint regarding the way FCMs should be built: some researchers choose to draw individual FCMs during a face-to-face interview and then combine individual maps in a social map (Bosma et al., 2017) while others prefer drawing single FCMs during a workshop that gathers the targeted experts (Gray et al., 2015). In this research, we implemented an original methodology for developing FCMs by combining both individual interviews, and group workshops as in Gourguet et al. (2021). This process is similar to the logic of the Delphi process, where experts are asked to express their judgment several times on the same subject with the possibility to re-evaluate their judgment at each round, based on the aggregate results of the previous round. Such a process is particularly useful to find consensus on complex matters (Rowe and Wright, 1999), and thus seemed relevant to the objective of our study, which was to mobilize stakeholder knowledge to develop a holistic representation of the functioning of mangrove socio-ecosystems, that can assist in identifying key conservation levers and obstacles.

A stakeholder is usually defined as a person who affects or is affected by a decision or action (Reed et al., 2009). Given the size of the territory studied, the number of stakeholders to consider is very large. We thus narrowed our scope to expert stakeholders, i.e., stakeholders with extensive knowledge or skills on the subject of study, based on research, experience or occupation in a particular field related to mangroves. We followed the Campagne and Roche (2018) approach for expert selection. We first identified key stakeholders closely involved in the conservation of mangroves in French Guiana and followed their recommendations of additional experts to contact, resulting in a list of 29 experts from four categories: scientists, managers, conservationists and economic actors. The steps of the consultation process are presented hereafter and summarized in **Table 1**.

The first step of the work consisted in the face-to-face interviews and creation of individual FCMs. Between March and July 2019, we conducted individual interviews with the 29 experts. Interviews were divided into two parts: (i) firstly, a semi-structured interview questioned experts on their activity and its links with mangroves and (ii) secondly, the drawing of FCMs. We favored face-to-face interviews over workshops in the first phase to avoid the risk of answers based on conformity and group pressures (Woudenberg, 1991). Because of logistical difficulties (remoteness or transport difficulties in French Guiana) some experts were contacted by phone or videoconference. In those cases, it was not possible to draw the FCM, as this requires sharing the visual conception of the map while it is being developed. In the end, 19 FCMs were collected. We then homogenized the terms used across FCMs when there was no ambiguity that experts were speaking of the same variables. We used these homogenized variables to combine the individual FCMs and obtain social maps, merging the variables and summing the connections between the same variables.

TABLE 1 | Steps of the expert consultation process and links with the successive social maps produced.

Step	Activity	Material	Social maps	Number of variables
1	Face to face interviews with experts	29 interviews	Social map #1	89
2	Reduction of the number of variables	19 individual FCMs	Social map #2	29
3	Workshops with experts from each category	4 workshops	Social map #3	30

The second step of our consultation process consisted in the condensation of the community map. To do so, we applied three types of rules following three questions:

(1) Can the variables be grouped under a superior key concept following a qualitative logic? We notably relied on the framework of ecosystem services (e.g., naturalistic observation, hiking and visits by boat were merged under the broader concept of recreational activities) or factors of change from global biophysical assessments (e.g., sea level rise, drought and acceleration of mudflat migration, under the broader concept of climate change). In this case the value of the connection between group variables was divided by the number of grouped variables.
(2) Can a succession of variables be grouped, as they describe a single process? This follows a more quantitative line of reasoning, where logical chains are shortened (e.g., the chain Mangrove - > Wood production - > Handicraft - > Wooden articles is replaced by Mangrove - > Handicraft). In this case the value of the connection from deleted variables with other variables is preserved.
(3) Can we delete isolated variables? Variables that were mentioned by only one expert and that could not be grouped were removed.

All the changes involved in the condensation process were recorded, in order to be able to explain these to stakeholders in the following step.

The third step of our consultation consisted in organizing workshops by groups of stakeholders to discuss their stakeholder FCMs and identify consensual and/or conflicting views on these maps. Given the size of the mangrove socio-ecosystem in French Guiana and the complexity of the question we aimed to address, the number of maps we obtained may be considered low. Combining individual interviews with workshops offered a means to increase consistency in answers (Singh et al., 2017). We organized 4 workshops in February 2021, each workshop was open to every expert that was interviewed, whether they had drawn FCMs or not. Each workshop followed the same procedure: (1) We started by reminding participants about the objective of the project and the methodology of FCM, and explained the method used to build the social maps. (2) We then presented the stakeholder map and asked whether this conformed with their perceptions. (3) We then modified the stakeholder map in real time to account for changes needed to represent a consensual vision among the group of mangrove socio-ecosystems in French Guiana (final variables are described in **Supplementary Table 1**). In addition to the new social maps, we collected interesting qualitative material based on the comments from stakeholders during the workshops. The four modified stakeholders FCMs were then aggregated into a final community map. The final representation of FCMs was done using Mental Modeler software (available at: www.mentalmodeler.com; Gray et al., 2013).

Analysis of Fuzzy Cognitive Mapping

FCMs can be coded into adjacency matrices in the form $A(D) = [a_{ij}]$, where a_{ij} represents the strength of the effect of variable i on variable j. Variables identified in the map are listed both on the vertical axis (v_i) and on the horizontal axis (v_j). a_{ij} take a value between –1 and 1, with 0 meaning no connection.

From these matrices, different metrics can be calculated using graph theory, to help in FCM analysis (Özesmi and Özesmi, 2004; Bosma et al., 2017). Indeed, the adjacency matrix allows the use of algebra tools from graph theory to produce a series of indices characterizing map structure, that can then be compared using statistical analysis, including one-sided ANOVA. Examining the structure of the map allows us to determine how the respondents perceive the system. First, the number of variables $[N]$ and the number of connections $[C]$ are determined and used to calculate density $[D]$. When density is high, respondents perceive more relationships among variables and thus more options to change the system.

$$D = \frac{C}{N(N-1)}$$

The types of variables can also be examined to assess how they will interact. There are three types of variables: (1) transmitter variables [T] that designate forcing functions or endowments, variables that come as given and on which actors in the system have no power; (2) receiver variables [R] that refer to utility variables or ends, and that are the output of the system and; (3) ordinary variables [O] that represent the means by which the system can evolve. The ratio of the number of receiver variables (R) divided by the number of transmitter variables (T) measures its complexity (Özesmi and Özesmi, 2004). A high number of receiver variables illustrate a system with many outcomes or implications. On the other hand, a large number of transmitter variables indicates a system with top-down influences. In the end, complex maps will present larger complexity ratios (R/T), as they present more utility outcomes and less controlling forcing functions.

The contribution of the different variables is based on the calculation of their outdegree $[od(v_i)]$, indegree $[id(v_i)]$ and centrality $[td(v_i)]$ scores. Outdegree score is the row sum of absolute values of a variable in the adjacency matrix. It shows the variable's cumulative strength on other variables.

$$od(v_i) = \sum_{k-1}^{N} \overline{a_{ik}}$$

Indegree score is the column sum of absolute values of a variable in the adjacency matrix. It indicates how much a variable is influenced by other variables through the cumulative strength of variables entering the variable.

$$id(v_i) = \sum_{k-1}^{N} \overline{a_{ki}}$$

The overall contribution of a variable in a cognitive map can be understood by calculating its centrality (or total degree) $[td(v_i)]$ as the summation of its outdegree and indegree scores.

$$td(v_i) = od(v_i) + id(v_i)$$

The last metric that can be used to assess the structure of the map is the hierarchy index (h). When close to 1, a system is called hierarchical while close to 0 it is called democratic. Democratic systems are much more adaptable to local changes because of their high level of integration and dependence.

$$h = \frac{12}{(N-1)N(N+1)} \times \sum_i \left[\frac{od(v_i) - (\sum od(v_i))}{N}\right]^2$$

RESULTS

Individual Fuzzy Cognitive Maps

Table 2 presents the graph theory indices obtained for the 19 FCMs collected after the individual interviews. Interviewees identified a total of 257 variables to characterize French Guiana's mangrove systems, with a mean number (± SD) of 13.53 (± 6.26) variables per map and 15.26 (± 8.39) connections. Note that 5 additional variables were mentioned without any connection to other variables; they are excluded from the following calculations.

A visual analysis of the indices suggests that economic actors identified fewer variables and connections. Moreover, in comparison to other categories, they identified a very low number of transmitters suggesting a high level of complexity with few controlling forcing functions. We ran a one-sided ANOVA on the indices that showed only one statistical difference amongst our stakeholder groups regarding the number of receivers (F = 33,156; df = 18; p = 0.049): economic actors and scientists perceive a below-average number of receivers showing a low number of "outcomes" from the system.

A first homogenization of variables allowed identifying several categories in which they could be grouped. Many variables have a very low number of records: 46 variables were mentioned only once and 20 only twice or thrice. 21 concepts were mentioned between four and eight times. Finally, five variables were mentioned by more than half of respondents, namely "Nurseries" (10 times), "Coastal protection" (11), "Biodiversity" (12), "Fishing" (13), and "Mangrove" (19).

Stakeholders Fuzzy Cognitive Maps

Before presentation of the results during the workshops we condensed the number of variables from 92 to 29. After aggregation of individual maps among stakeholders we obtained four stakeholder FCMs with a mean number (± SD) of 21.5 (± 4.7) variables and 34 (± 13.5) connections.

A descriptive analysis of the graph indices of the different stakeholders FCMs (**Table 3**) shows that the FCM from economic actors presents the highest level of complexity, i.e., stakeholders perceive more outcomes from the system than options to intervene on it to make it change (given the number of identified transmitters). FCMs from conservationists present the highest density meaning that their perception of the system is the most interconnected with many links between variables. The study of the FCMs from scientists shows a more concentrated vision of the system with fewer variables (17) and a relatively high level of complexity. Finally, managers have the most extended perception of the system with many variables and a great majority of ordinary variables.

After the workshops, the mean number of variables across FCMs increased to 24.3 (± 3.3) and the mean number of connections also increased to 40.3 (± 11.7). Standard deviation decreased for all the graph indices, except for the number of receivers.

Community Fuzzy Cognitive Mapping

In this section, we present the community FCMs obtained from the aggregation of our four expert groups FCMs after the workshops. The aggregated community map is presented

TABLE 2 | Graph theory indices of the individual FCMs: mean and standard deviation by stakeholders group.

	Conservationists	Economic actors	Scientists	Managers	All
No. of maps	3	5	3	8	19
No. of variables (N)	15.67 ± 7.51	9.00 ± 2.65	13.33 ± 2.65	15.63 ± 6.95	13.53 ± 6.26
No. of transmitter variables (T)	2.33 ± 1.53	0.80 ± 0.84[a]	2.67 ± 0.84	2.25 ± 1.83[a]	1.95 ± 1.58
No. of receiver variables (R)*	7.33 ± 4.04	3.6 ± 1.95	3.67 ± 1.95	7.38 ± 2.67	5.79 ± 3.05
No. of ordinary variables (O)	6.00 ± 2.00	4.6 ± 2.88	7.00 ± 2.88	6.00 ± 3.63	5.79 ± 3.29
No. of connections (C)	17.67 ± 9.50	9.80 ± 3.96	16.00 ± 3.96	17.50 ± 9.43	15.26 ± 8.39
Complexity (R/T)	3.25 ± 0.66	4.17 ± 2.36[a]	2.22 ± 2.36	4.44 ± 2.82[a]	3.75 ± 2.35
Density (D)	0.08 ± 0.04	0.12 ± 0.03	0.09 ± 0.03	0.08 ± 0.03	0.09 ± 0.03

[a] *Include answers with no transmitter that forbid the calculation of complexity index.*
**Statistically significant differences in indices among stakeholder groups (p < 0.05).*

TABLE 3 | Graph theory indices of social maps obtained at different stage of the consultation process.

	Stakeholder FCMs before workshop				Community map		
	Conservationists	**Economic actors**	**Scientists**	**Managers**	**#1—after interviews**	**#2—after condensation**	**#3—after workshop**
No. of variables	21	20	17	28	92	29	30
No. of transmitter variables	5	3	3	3	11	2	2
No. of receiver variables	8	8	6	3	29	2	3
No. of ordinary variables	8	9	8	22	51	25	25
Number of connections	30	26	26	54	178	79	90
Connection per variable	1.43	1.3	1.52	1.93	1.93	2.72	3
Complexity (R/T)	1.6	2.7	2	1	2.63	1	1.5
Density	0.36	0.031	0.031	0.06	0.02	0.09	0.1
Hierarchy index	0.002	0.002	0.005	0.002	0.0001	0.004	0.02

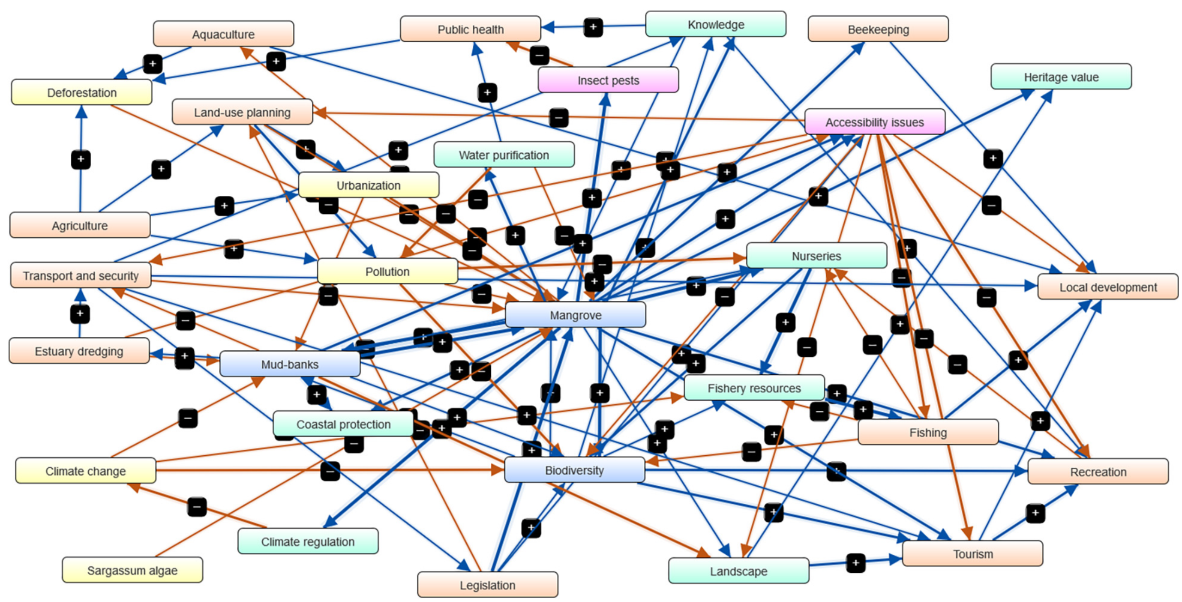

FIGURE 1 | Community map after workshop [Blue arrows (with a "+" sign) indicate a positive relationship, while orange (with a "-" sign) indicate a negative relationship. Thickness of the arrow reflects the strength of the relationship from | 1| (when reported by every group) to | 0.25| (when reported by only one group). Box colors are selected to assist the reading of the FCM: Blue boxes for biological compartments, green boxes for ecosystem services, pink boxes for disservices, orange boxes for anthropic activities and yellow boxes for pressure vectors].

in **Figure 1** and the corresponding graph theory indices are presented in **Table 3**.

The high number of ordinary variables indicates numerous interactions between system components. This outcome corroborates the important number of connections identified, suggesting perceptions of a strongly integrated and interdependent mangrove socio-ecosystem. That is, the system's dynamics result from mutual influences between the French Guiana society and the mangrove ecosystem. The low hierarchical index (close to 0) indicates a relatively "democratic system" with a high level of integration and dependence between the different components of the system. A system perceived as democratic is a sign that experts consider there are various ways to change it. Yet, the rather low density index reports a sparse map, reflecting that few management options are identified as capable of influencing the system's dynamics.

Table 4 ranks the community map variables by order of centrality. Variables with highest centrality scores are influential within the system: i.e., they can either be highly connected to other variables or display few connections with a high weight.

The most influential variables are associated to the biological compartments of the mangrove ecosystem, namely "Mangrove," "Mudflat/Mud-banks," and "Biodiversity," followed by "Nursery," "Accessibility issues" and to a lesser extent, "Recreational activities." Together, these elements come out as key influential dimensions of the socio-ecosystem's functioning. In accordance, the anthropic activities "Tourism" and "Fishing" come next. Tourism is most directly supported by biodiversity and as such, increases demand for recreational services, themselves relying on biodiversity, while fishing rests on mangrove supply of fishery resources, through its habitat support function. In turn, all three anthropic activity types are concerned by accessibility

TABLE 4 | Indices regarding variables of the community map.

Ranking	Variables	Indegree score	Outdegree score	Centrality score	Centrality change[a]	Ranking change[a,b]	Occurance	Occurance change[a]
1	Mangrove	4.75	10.5	15.25	–1.5	=	4	=
2	Biodiversity	4.25	2.5	6.75	0.75	=	4	=
3	Mudflat/Mud-banks	2	3.5	5.5	0.75	=	4	=
4	Accessibility issues	1.75	3	4.75	2.75	↑↑	4	↑
5	Nurseries	2.5	1.75	4.25	0.5	=	4	=
6	Tourism	2.5	1	3.5	1	=	4	=
7	Pollution	1.5	1.75	3.25	1	=	4	=
8	Recreational activities	3	0.25	3.25	0.5	=	4	↑
9	Fishery resources	1.75	1	2.75	1.25	↑	4	=
10	Fishing	1.5	1.25	2.75	–0.5	↓	4	=
11	Land-Use Planning	0.75	1.75	2.5	1	↑	4	=
12	Transport and security	0.75	1.25	2	0.5	↑	2	=
13	Legislation	0.25	1.75	2	0.25	=	4	=
14	Urbanization	1	1	2	2	→	3	=
15	Climate change	0.5	1.25	1.75	0.25	=	3	=
16	Water purification	0.75	1	1.75	0.25	=	3	=
17	Landscape	1	0.75	1.75	0.25	=	4	↑
18	Knowledge production	1	0.75	1.75	0.25	=	3	=
19	Local development	1.75	0	1.75	0	↓	3	=
20	Insect pests	1	0.5	1.5	0.5	↑	4	↑
21	Climate regulation	1	0.5	1.5	0	↓	4	=
22	Public health	1	0.25	1.25	0.25	↑	2	↑
23	Coastal protection	1.25	0	1.25	–0.25	↓	4	=
24	Agriculture	0	1	1	0.25	=	3	↑
25	Heritage values	1	0	1	0	↓	3	=
26	Deforestation	0.75	0.25	1	0	↓	1	=
27	Estuary dredging	0.25	0.75	1	0	↓	3	↑
28	Beekeeping	0.5	0.25	0.75	0.25	=	2	=
29	Aquaculture	0.25	0.5	0.75	0.25	=	1	=
30	Sargassum algae	0	0.25	0.25	0	=	1	=

[a]*Changes materialize a change in the community map following discussions during the workshops: "=" no change; "↑" increase; "↓" decrease; "→" new variable.*
[b]*Change for ranking is taking into account when superior to 2 ranks.*

issues arising from mud-banks and mangrove forest. These latest components can be detrimental to fishing vessels' access needs to the coastline and/or to the amenity value of beach landscapes sought by (certain) tourists. The influence of mangrove on recreational activities is more ambiguous, since these activities are supported by mangrove forest (for kayaking, bird watching, hunting, hinking, etc.), while they can also be negatively affected by the limited access forest and mud-banks impose on coastal areas (preventing watching the laying of turtles on the beach for instance). Pollution is the environmental impact factor displaying the highest centrality score. It is harmful to several benefits derived from the mangrove ecosystem, via its negative impacts on biodiversity and ecological habitats.

The centrality of the subset of variables presented above may owe to the fact that they are mentioned by four stakeholders' groups we surveyed who consider them important to the functioning of the system (**Table 4**). Indeed, looking at the very core of the representation shared by the expert community we interviewed (**Supplementary Figure 1**), it is clear that the mutual interdependence between mud-banks and mangrove forest is acknowledged by all experts, so as the role of the mangrove ecosystem in supporting biodiversity and the problems it causes in terms of accessibility. In relation to society's demands, only fishing activities stand out, through the channel mangroves foster "Nurseries" (support service) and "Fishery resources" (provisioning service).

Other variables emerge in **Supplementary Figure 1** as being mentioned by every category of stakeholders. Because of its relatively high outdegree score but low indegree score (id = 0.25 vs. od = 1.75), "Legislation" does not count as "very" central to the system's dynamics: it is perceived as a lever for mangroves conservation with direct and positive relationship with mangroves and biodiversity. On the other hand, climate regulation is a mangrove ecosystem service with a higher indegree score than outdegree score (id = 1 vs. od = 0.5). While expert groups are not unanimous and clear on the consequences of climate change on the mangrove socio-ecosystem, all agree on the fact that mangrove ecosystems play a role in climate regulation, in particular with respect to the carbon cycle. The variable "Insects issues" presents a similar behavior (id = 1 vs. od = 0.5) showing that all stakeholders have this issue in mind notably regarding the Yellowtail Moth (*Hylesia metabus*) that can provoke severe allergic reactions. Other ES are mentioned by all stakeholders but their connection with other variables of the system is less unanimous (namely "Coastal protection," "Landscape"). Finally, all stakeholders recognize the role of "Agriculture," "Pollution," and "Land-use planning" in the system but there is no consensus regarding the nature of this role. For example, in the case of "Agriculture": conservationists assumed an impact of agriculture on mangroves through territory planning, and an unclear effect of agriculture on mangroves through pollution carried by rainfall runoff; managers perceived a negative impact of agriculture via deforestation; scientists through land conversion; while the overall interaction was unclear for economic actors.

DISCUSSION AND CONCLUSION

Ecosystem Services Provided by French Guiana

All expert groups underline the role of mangroves in sustaining coastal fisheries. Indeed, the most unanimous relationship in the community FCM (**Figure 1**) is the inseparable link between mud-banks and mangroves, owing to "Nursery" functions necessary to maintain "Fishery resources." "Fishing" is thus perceived as the most emblematic activity depending on the mangrove ecosystem within the French Guiana society. In 2019, 2,820 tons of fish were landed in French Guiana, worth €5.4 million (≈ US$ 6.1 million) (IFREMER, 2020). Acoupas (*Cynoscion* spp.) and Crucifix sea catfish (*Arius proops*) that represent the majority of catches of coastal fisheries (76% of total landed volume in 2019; IFREMER, 2020), spend part of their life cycle in mangrove (Rojas-Beltran, 1986; Rousseau et al., 2018). Also, mangrove fluctuation has shown to directly impact shrimp fisheries, that represented an important source of export for French Guiana (Diop et al., 2018). These numbers do not include illegal and subsistence fishing that could represent around 60% of total catches (Levrel, 2012). Mangrove conservation is thus critical for the sustainability of fishing practices, especially in the context of climate change that could lead to a collapse of both biomass of targeted species and fishing activities (Gomes et al., 2021). Meanwhile, fishing was reported by managers and scientists as an extraction activity that puts pressure on the natural environment. Fisheries can modify mangroves fish assemblages and impact their sustainability (Reis-Filho et al., 2019). However, empirically, it is currently unclear whether fishing has any impact on the quality of mangroves or the delivery of other services.

The importance of mangrove in "Climate regulation" is also recognized by all experts. Mangroves are very productive ecosystems that capture carbon from the atmosphere to develop. This carbon is then trapped and stored into the soil (Hamilton and Friess, 2018; Richards et al., 2020). In the case of French Guiana, the migration of mud-banks brings uncertainty to this role. During an accretion phase, the mud-bank is colonized by mangrove and starts to accumulate carbon (Marchand, 2017). When it enters an erosion phase, mangrove is destroyed and important quantities of organic matter are exported to coastal and offshore waters (Mongruel et al., 2018). Nevertheless, the total mangrove carbon stock at the scale of French Guiana is estimated to 23.06 ± 5.03 TgC (Walcker et al., 2018). Mangroves destruction would liberate this sequestrated carbon (Hamilton and Friess, 2018; Richards et al., 2020). As a signing party of the Paris Agreement on climate change, France has a duty in conserving this carbon stock.

There is a common agreement among our experts that mangroves have a potential role to play in the development of "Tourism" and "Recreational activities" (**Supplementary Figure 1**). In their review, Himes-Cornell et al. (2018) found that almost all the studies they selected provided economic values for recreation and tourism services by mangroves, confirming this role at the global level. However, we found no studies in French Guiana and experts during workshops underlined that eco-tourism in mangroves remains relatively marginal. This reflects the perception that mangrove and its biodiversity richness are identified as a potential for the development of the territory (WWF, 2017). Indeed, while only 21% of tourists come to French Guiana for leisure and 28% to discover the forest or the coast (CTG, 2016), there is a political will to increase those numbers relying on the development of eco-tourism (CTG, 2013). The final map provides the vision of a positive effect of mangroves on tourism and recreation that suggest that a development of these activities compatible with mangrove conservation is possible. However, the link between mangroves and the development of tourism and recreation is ambiguous (**Figure 1**). Firstly, because Recreation and Tourism encompass various practices that may be positively or negatively affected by mangroves. Certain activities (e.g., beach activities) can be negatively affected whether because the mangroves prevent access to areas of interest or because they modify the seascape. On the other hand, mangroves can also be attractive for eco-tourism and nature-related activities (e.g., faunistic observation). Secondly, because mangrove is closely related to mud-banks that are perceived as a constraint for the development of these activities. The migration of mud-banks can bring mangroves where they will be considered as a discomfort (e.g., on cities seafronts). In addition, there is currently a lack of infrastructure in French Guiana (e.g., there are only two marinas in French Guiana), developing tourism and recreation will imply new development projects.

Mangrove socio-ecosystems are also involved in the construction of coastal "Landscape" but the nature of this role is not obvious. If some experts consider that mangroves can have a positive impact on landscape, this is also negatively impacted by mud-banks and accessibility issues. Experts underline that urban seafronts are deserted when mangroves obstruct the seaview, while mangrove landscapes are appreciated in rural areas where they contribute to the identity of French Guiana. Aesthetic values of mangrove are understudied (Himes-Cornell et al., 2018). The question of the perception of the aesthetic value of a landscape is complex as it results from the link between the intrinsic characteristics of an object and its perception by an observer which is influenced by human nature, education and society (Tribot et al., 2018). According, to Tribot et al. (2018) there is a disconnection between the landscape aesthetic and the ecological value of ecosystems: mangroves are more likely to trigger negative perceptions than agricultural landscapes. The authors propose a virtuous loop in which, knowledge and experience on the functioning of ecosystems could increase mangroves' aesthetic value that would be more likely to be protected.

The last ES mentioned by every group of experts is "Coastal protection." The role of mangroves in providing coastal protection in French Guiana is closely associated to the dynamics of mud-banks as an alternation of "bank" and "inter-bank" phases. In bank areas, ocean energy is at first dissipated by the mud-banks, closer to the shore, the remaining energy is gently dissipated by mangroves (Anthony and Gratiot, 2012). Moreover, mangroves favor sedimentation (Furukawa et al., 1997) and enhance the resistance of the substrate during erosive inter-bank phases (Fiot and Gratiot, 2006). This process has been effective over the last 5,000 years, resulting in a net coastal progradation (Anthony et al., 2010). In addition, in inter-bank areas where higher energy waves result in mangrove destruction, mangrove trees still dissipate wave energy and thus contribute positively to coastal protection (Anthony and Gratiot, 2012). In French Guiana, coastal erosion and coastal flood are two issues well identified by the natural risk prevention plan (DEAL, 2015), which should advocate for mangrove conservation.

The experts also all pointed two disservices associated to the functioning of the mangrove ecosystem, namely "Accessibility issues" and "Insect Pests." "Accessibility issues" reflect the fact that some coastal facilities (e.g., slipways, fishing docks, touristic seaside infrastructures) may get directly obstructed by mangroves or see their value decrease because of the negative perception of mangrove in the vicinity. "Insect Pests" relate to the fact that mangroves shelter species that can impact public health, notably the moth *Hylesia metabus* that cause skin rashes (Jourdain et al., 2012). According to stakeholders, mangrove deforestation near residential areas occurred for sanitary reason in the recent past. This study shows that mangrove conservation can be exposed to a trade-off with mangrove destruction aimed at reducing such disservices. This trade-off is generally under-estimated in ES assessments of mangroves and comprehensive framework should be implemented (e.g., Knight et al., 2017).

The services mentioned by only some groups were listed (e.g., Knowledge production, Heritage value) and can be used in future discussions with local focus groups to further establish whether these warrant additional investigation, given their perceived importance by French Guianese residents and economic actors.

Threats on Mangroves in French Guiana

In order of importance given the respondent's perception (**Table 4**), the first perceived threat on mangroves in French Guiana is pollution, as mangroves are affected by wastewater near urban areas. Close to Cayenne, the impacts of pollution are visible on the microbial taxa of the mangrove (Fiard et al., 2022). Water pollution is mitigated by the purification ES from the mangrove that benefit society. Mangroves and their associated ecosystems act as natural sinks that trap all kind of anthropogenic pollutants (e.g., heavy metals, MacFarlane et al., 2007; Kulkarni et al., 2018; organic matter, Xiao et al., 2018; Adame et al., 2019). However, the sustainability of this purification role is questionable as high loads of pollutants can considerably modify mangrove ecosystems. Eutrophication in mangrove favor growth of shoots over roots and decrease their resilience (Lovelock et al., 2009), it also modifies the phytoplankton communities (Manna et al., 2010). There is a lack of information to conclude on the threat that chemicals represent for mangroves. Still, some studies has shown the impacts of chemicals on mangrove trees (particularly in early life stages; Lewis et al., 2011) and on the associated trophic network (Kulkarni et al., 2018). The question of water quality in French Guiana is the subject of a dedicated strategy established in 2017 that provides for public support dedicated to wastewater treatment (DEAL, 2017). If this plan is implemented primarily for sanitary reason, the improvement of water quality should benefit to mangrove ecosystems.

The second main threat raising concern among stakeholders is urbanization. Land-use planning, i.e., the extension of human infrastructures to face the increasing needs of society is positively related to this pressure on mangroves in the FCM. As population is concentrated on a 10–30 km wide strip along the littoral (Zouari, 2015), population growth may thus affect primarily this area and thus negatively affect the mangrove. Estuarine mangroves, which thrive on rivers, are considered as more subject to pressure from territorial development near urban areas. Indeed, they offer stable land that can support infrastructure, as is the case of a recent project of power plant construction near Cayenne, that has been criticized for its impact on mangroves and insufficient mitigation requirements (Autorité Environnementale, 2019). Coastal mangroves would be less affected, as they are under influence of mud-banks migration that make the coastline very unstable. The temptation to stabilize this dynamic system for infrastructure, urban and economic development may be associated with high risks (Jolivet, 2019). In neighboring Guyana, mangroves have been replaced, to make space for agriculture and aquaculture, and coastal protection is now provided by coastal dikes. This has considerably modified the sedimentary dynamics and the country is now exposed to erosion that can only be countered by expensive engineering solutions (Anthony and Gratiot, 2012). The integration of mangrove variability in land-use planning is thus necessary, in order to integrate its positive and negative effects in the best possible ways.

Agriculture is actually booming with an increase by nearly 38% of cultivated area between 2010 and 2019, in order to cater for the growing needs linked to the territory's increasing population. To maintain food self-sufficiency, 1,000 hectares should be turned into agricultural land every year (CEREMA, 2016). Total used agricultural land was 33 800 ha in 2019, with more than half concentrated in the west part of the country (DEAAF, 2020). However, there was no consensus on the impacts of such development among our stakeholder groups calling for more investigation. Farming in French Guiana combines traditional manual itinerant agriculture, breeding and mechanized agriculture for commercial purposes. Sorting out the incidence of these different practices and their expansion on mangroves' ecological states calls for further investigation as was pointed out by most of our expert groups.

The third threat on mangrove ecosystems identified by stakeholders is climate change. According to stakeholders, the impact of climate change does not directly affect mangroves but rather elements of the ecosystem, namely "Mud-banks," "Biodiversity," and "Fishery resources" (**Figure 1**). For most stakeholders (excepted one scientist), climate change was considered as a broad variable. However, it is difficult to summarize Climate change interactions with mangroves in a single variable as this corresponds to multiple factors of environmental changes (e.g., sea level rise, drought, change in salinity) that can have different—if not reverse—impacts on mangroves, depending on the context (Alongi, 2015; Lee et al., 2021). For example, in French Guiana, climate change intensifies the swell regime, which accelerates mud bank movements that should impact coastal mangroves. Further investigation is needed in this regard. As for perceived negative effects of climate change on biodiversity, these seemed to corroborate established knowledge on ocean warming and acidification risks, rather than being derived from local evidence.

Fourthly, deforestation has a very low importance in the community map, compared to its importance at the international scale (e.g., Richards and Friess, 2016). This may be explained by the absence of some extraction activities generally associated with mangroves. First, wood harvesting for construction, manufactured goods, firewood or coal is mostly absent in French Guiana. The few extractions of mangrove wood that serve handicraft productions or smoking processes are negligible in the global functioning of the socio-ecosystem as shown by their absence from the FCMs. Second, the expansion of aquaculture remains limited and takes place mainly in freshwater from coastal plains. A small amount of mangrove oyster farming currently takes place in Montsinéry (upstream from Cayenne). The mention of aquaculture in the FCM reflects the several scientific and governmental programs that aim at developing the sectors' potential. Given the threat that aquaculture has applied on mangroves worldwide (Naylor et al., 2000), this may require special attention.

Facing those threats, one main lever of action is identified by stakeholders, namely "Legislation." Legislation is supposed to be able to act directly on the enhancement of state of the ecosystem ("Mangrove" and "Biodiversity") or indirectly in reducing "Land-use planning" (**Figure 1**). A single positive feedback loop is identified from the ES of "Knowledge production," with a positive effect on mangrove. However, stakeholders perceive no variables with the opportunity to reduce the identified threats. This result is surprising as it reflects a command-and-control perception of conservation, rather than a vision developed following socio-ecosystems management principles (Ostrom, 2009). Indeed, solutions based on more flexible institutional arrangement can also increase the ecological outcomes of conservation, as well as its social and economic benefits (Scemama and Levrel, 2019; Bellanger et al., 2021). Nevertheless, imagining effective solutions for mangrove conservation needs to take good consideration of the multiple interactions between mangroves and societies, the associated positive and negative incentives for mangrove conservation, and the numerous sources of variability and uncertainty. In particular, there is a need for innovative solutions to better integrate the dynamism of the coastline in the future development of the territory.

Interest of Fuzzy Cognitive Mapping

FCMs were created by merging variables and connections raised by all experts in each group. Such merging can lead to overly complex system representations that potentially include artifacts associated with individual misconceptions or biases merged into group responses. The combination of individual interviews and workshops allowed to validate and increase the confidence in the credibility and relevance of the results (Teixeira et al., 2018). Moreover, the organization of the workshops allowed to increase consensus regarding the variables and the connections between them, as we can see with the reduction of standard deviation between the stakeholders FCMs. Finally, discussions during the workshops provided qualitative arguments that help understanding the FCMs configuration in light of the variability observed in the territory under consideration. Indeed, the final FCM summarizes the perception of the socio-ecosystem at the scale of the French Guiana. It does not explicitly represent the many sources of variability such as the differences between coastal and estuarine mangrove or the temporal variability associated to the migration of mud-banks, while the functioning of mangrove ecosystems and their ES is closely related to their biogeographic and geomorphological characteristics (Lee et al., 2014). However, the process of generating the map enabled identifying these differences.

Another risk with merging variables under broader concepts is to lose information (see e.g., the discussion on climate change or recreation and tourism). As a result, FCMs may fail to reflect some local variations. The final community map provides the perception of the expert groups consulted regarding such local variation and how they should adequately be captured, at the scale of the entire French Guiana. As a result, it provides a relevant overview of the perception of the functioning of the mangrove socio-ecosystem of French Guiana, and of the actual state of knowledge on this system. The organization of workshops with stakeholders allowed to collect qualitative material that can help to appreciate variability. It would be interesting to realize similar exercises on more restricted areas to focus on local issues.

The use of expert knowledge in ES assessment is considered one of the most popular ES assessment techniques today (Jacobs et al., 2015; Campagne and Roche, 2018). Indeed, it is particularly adapted to face the uncertainty-urgency dilemma that characterizes biodiversity conservation. As such, expert consultation results fit within a post-normal framework for ES assessment (Ainscough et al., 2018). In such a framework, expert knowledge is used to overcome uncertainty issues that can hinder conservation decision-making, to the benefit of a status quo detrimental to biodiversity and ES protection. Moreover, this is particularly interesting where the scientific evidence is not sufficient to support a comprehensive ES assessment as underlined by Mongruel et al. (2018). In such comprehensive assessments, economic analysis generally relies on the use of benefit transfer (e.g., Giry et al., 2017; Trégarot et al., 2021), using values commonly associated to mangroves in the literature and applying them to the studied territory. Our approach enables capturing the originality of the mangroves of French Guiana regarding the ES provided, in comparison to mangroves at the global scale, and shows that the use of benefit transfer without better knowledge of these key ES and disservices along with their variability would be hazardous at best. Based on our results, future research needs regarding mangrove ES in French Guiana, and their interactions with mangrove conservation policy can also be identified.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

PS was the main writer of the manuscript. ER, FB, and OT assisted in writing the manuscript. PS, ER, FB, and OT contributed to the research. All authors contributed to the article and approved the submitted version.

FUNDING

This work was part of the project ESSEM funded by Ifremer.

ACKNOWLEDGMENTS

We want to thank all the stakeholders for their participation in the consultation process. We acknowledge our colleagues from GDR LiGA for their help in the realization of this work. Finally, we particularly thank Lucas Balsan for its contribution to this project during his master internship.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2021.769182/full#supplementary-material

REFERENCES

Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., and Sala, E. (2008). Mangroves in the Gulf of California increase fishery yields. *Proc. Natl. Acad. Sci. U.S.A.* 105, 10456–10459. doi: 10.1073/pnas.0804601105

Adame, M. F., Roberts, M. E., Hamilton, D. P., Ndehedehe, C. E., Reis, V., Lu, J., et al. (2019). Tropical coastal wetlands ameliorate nitrogen export during floods. *Front. Mar. Sci.* 6:671. doi: 10.3389/fmars.2019.00671

Autorité Environnementale (2019). *Avis Délibéré de l'Autorité Environnementale sur la Centrale Électrique du Larivot (973) et mise en Compatibilité des Plans Locaux D'urbanisme de Cayenne, Matoury et Remire-Montjoly, n° 2019-106*. Paris: Autorité Environnementale, 41.

Ainscough, J., Wilson, M., and Kenter, J. O. (2018). Ecosystem services as a post-normal field of science. *Ecosyst. Serv.* 31, 93–101. doi: 10.1016/j.ecoser.2018.03.021

Alongi, D. M. (2015). The impact of climate change on mangrove forests. *Curr. Clim. Chang. Rep.* 1, 30–39.

Anthony, E. J., Gardel, A., Gratiot, N., Proisy, C., Allison, M. A., Dolique, F., et al. (2010). The Amazon-influenced muddy coast of South America: a review of mud-bank–shoreline interactions. *Earth Sci. Rev.* 103, 99–121. doi: 10.1016/j.earscirev.2010.09.008

Anthony, E. J., and Gratiot, N. (2012). Coastal engineering and large-scale mangrove destruction in guyana, South America: averting an environmental catastrophe in the making. *Ecol. Eng.* 47, 268–273. doi: 10.1016/j.ecoleng.2012.07.005

Armsworth, P. R., Chan, K. M. A., Daily, G. C., Ehrlich, P. R., Kremen, C., Ricketts, T. H., et al. (2007). Ecosystem-service science and the way forward for conservation. *Conserv. Biol.* 21, 1383–1384. doi: 10.1111/j.1523-1739.2007.00821.x

Atwood, T. B., Connolly, R. M., Almahasheer, H., Carnell, P. E., Duarte, C. M., Lewis, C. J. E., et al. (2017). Global patterns in mangrove soil carbon stocks and losses. *Nat. Clim. Chang.* 7, 523–528. doi: 10.1111/gcb.15348

Bellanger, M., Fonner, R., Holland, D. S., Libecap, G. D., Lipton, D. W., Scemama, P., et al. (2021). Cross-sectoral externalities related to natural resources and ecosystem services. *Ecol. Econ.* 184:106990. doi: 10.1016/j.ecolecon.2021.106990

Blanco, J., Dendoncker, N., Barnaud, C., and Sirami, C. (2019). Ecosystem disservices matter: towards their systematic integration within ecosystem service research and policy. *Ecosyst. Serv.* 36:100913. doi: 10.1016/j.ecoser.2019.100913

Bosire, J. O., Dahdouh-Guebas, F., Walton, M., Crona, B. I., Lewis Iii, R. R., Field, C., et al. (2008). Functionality of restored mangroves: a review. *Aquat. Bot.* 89, 251–259.

Bosma, C., Glenk, K., and Novo, P. (2017). How do individuals and groups perceive wetland functioning? Fuzzy cognitive mapping of wetland perceptions in Uganda. *Land Policy* 60, 181–196. doi: 10.1016/j.landusepol.2016.10.010

Bouillon, S. (2011). Storage beneath mangroves. *Nat. Geosci.* 4, 282–283. doi: 10.1002/ecy.2916

Braat, L. C., and de Groot, R. (2012). The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosyst. Serv.* 1, 4–15. doi: 10.1016/j.ecoser.2012.07.011

Campagne, C. S., and Roche, P. (2018). May the matrix be with you! Guidelines for the application of expert-based matrix approach for ecosystem services assessment and mapping. *One Ecosyst.* 3:e24134. doi: 10.3897/oneeco.3.e24134

Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., et al. (2009). Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci. U.S.A.* 106, 1305–1312. doi: 10.1073/pnas.0808772106

Carrasquilla-Henao, M., and Juanes, F. (2017). Mangroves enhance local fisheries catches: a global meta-analysis. *Fish Fish.* 18, 79–93.

CEREMA (2016). *Diagnostic et État des lieux du Document Stratégique de Bassin Maritime (DSBM)*. Available online at: http://www.dm.guyane.developpement-durable.gouv.fr/diagnostic-et-etat-des-lieux-du-dsbm-a117.html. (accessed 12 3, 2021).

Costanza, R., De Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., et al. (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosyst. Serv.* 28, 1–16. doi: 10.1016/j.ecoser.2017.09.008

CTG (2013). *Schéma Régional de Développement du Tourisme et des Loisirs de Guyane. Schéma D'aménagement Touristique (annexe 3)*. Buffalo, NY: CTG, 47.

CTG (2016). *Chiffres Clés du Tourisme en Guyane 2016*. Buffalo, NY: CTG, 4.

Dahdouh-Guebas, F., Ajonina, G. N., Amir, A. A., Andradi-Brown, D. A., Aziz, I., Balke, T., et al. (2020). Public perceptions of mangrove forests matter for their conservation. *Front. Mar. Sci.* 7:901.

Daily, G. C. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press.

de Souza Queiroz, L., Rossi, S., Calvet-Mir, L., Ruiz-Mallén, I., García-Betorz, S., Salvà-Prat, J., et al. (2017). Neglected ecosystem services: highlighting the socio-cultural perception of mangroves in decision-making processes. *Ecosyst. Serv.* 26, 137–145. doi: 10.1016/j.ecoser.2017.06.013

DEAAF (2020). *Agreste Guyane - Memento 2020, Novembre 2020*. New York, NY: DEAAF, 40.

DEAL (2015). *Dossier Départemental des Risques Majeurs, Région Guyane, Préfecture de Guyane*, 124. Available online at: http://www.guyane.developpement-durable.gouv.fr/le-dossier-departemental-des-risques-naturels-r1061.html (accessed 27 December, 2021), 124.

DEAL (2017). Plan d'action pour les services d'eau potable et d'assainissement de la Guyane. *Conf. Régionale Acteurs Document Stratégique Juillet* 2017:29.

Diop, B., Blanchard, F., and Sanz, N. (2018). Mangrove increases resiliency of the French Guiana shrimp fishery facing global warming. *Ecol. Model.* 387, 27–37. doi: 10.1016/j.ecolmodel.2018.08.014

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim. Chang.* 3, 961–968. doi: 10.1038/nclimate1970

Farley, J. (2012). Ecosystem services: the economics debate. *Ecosyst. Serv.* 1, 40–49. doi: 10.1016/j.ecoser.2012.07.002

Fiard, M., Cuny, P., Sylvi, L., Hubas, C., Jézéquel, R., Lamy, D., et al. (2022). Mangrove microbiota along the urban-to-rural gradient of the Cayenne estuary (French Guiana, South America): drivers and potential bioindicators. *Sci. Total Environ.* 807:150667. doi: 10.1016/j.scitotenv.2021.150667

Fiot, J., and Gratiot, N. (2006). Structural effects of tidal exposures on mudflats along the French Guiana coast. *Mar. Geol.* 228, 25–37. doi: 10.1016/j.margeo.2005.12.009

Friess, D. A., Thompson, B. S., Brown, B., Amir, A. A., Cameron, C., Koldewey, H. J., et al. (2016). Policy challenges and approaches for the conservation of mangrove forests in Southeast Asia. *Conserv. Biol.* 30, 933–949. doi: 10.1111/cobi.12784

Friess, D. A. (2016). Ecosystem services and disservices of mangrove forests: insights from historical colonial observations. *Forests* 7:183. doi: 10.3390/f7090183

Fromard, F., Puig, H., Mougin, E., Marty, G., Betoulle, J. L., and Cadamuro, L. (1998). Structure, above-ground biomass and dynamics of mangrove ecosystems: new data from French Guiana. *Oecologia* 115, 39–53. doi: 10.1007/s004420050489

Fromard, F., Vega, C., and Proisy, C. (2004). Half a century of dynamic coastal change affecting mangrove shorelines of French Guiana. A case study based on remote sensing data analyses and field surveys. *Mar. Geol.* 208, 265–280. doi: 10.1016/j.margeo.2004.04.018

Furukawa, K., Wolanski, E., and Mueller, H. (1997). Currents and sediment transport in mangrove forests. *Estuar. Coast. Shelf Sci.* 44, 301–310. doi: 10.1006/ecss.1996.0120

Gardel, A., and Gratiot, N. (2005). A satellite image-based method for estimating rates of mud bank migration, French Guiana, South America. *J. Coast. Res.* 21, 720–728. doi: 10.2112/03-0100.1

Gilman, E. L., Ellison, J., Duke, N. C., and Field, C. (2008). Threats to mangroves from climate change and adaptation options: a review. *Aquat. Bot.* 89, 237–250. doi: 10.1111/gcb.14063

Giry, F., Binet, T., and Keurmeur, N. (2017). Les bénéfices de la protection des mangroves de l'outre-mer français par le Conservatoire du littoral: une évaluation économique à l'horizon 2040. *Etudes Caribéennes* 36:2017.

Goldberg, L., Lagomasino, D., Thomas, N., and Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Glob. Change Biol.* 26, 5844–5855. doi: 10.1111/gcb.15275

Gomes, H., Kersulec, C., Doyen, L., Blanchard, F., Cisse, A. A., and Sanz, N. (2021). The major roles of climate warming and ecological competition in the small-scale coastal fishery in French Guiana. *Environ. Model. Assess.* 26, 655–675. doi: 10.1007/s10666-021-09772-8

Gourguet, S., Marzloff, M. P., Bacher, C., Boudry, P., Cugier, P., Dambacher, J. M., et al. (2021). Participatory qualitative modelling to assess the sustainability of a coastal socio-ecological system. *Front. Ecol. Evol.* 9:493. doi: 10.1016/j.scitotenv.2021.150512

Gray, S. A., Gray, S., Cox, L. J., and Henly-Shepard, S. (2013). "Mental modeler: a fuzzy-logic cognitive mapping modeling tool for adaptive environmental management," in *Proceedings of the 46th Hawaii International Conference on System Sciences* (Wailea, HI: IEEE), 965–973.

Gray, S. A., Gray, S., De Kok, J. L., Helfgott, A. E., O'Dwyer, B., Jordan, R., et al. (2015). Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. *Ecol. Soc.* 20:11.

Gray, S. A., Zanre, E., and Gray, S. R. (2014). "Fuzzy cognitive maps as representations of mental models and group beliefs," in *Fuzzy Cognitive Maps for Applied Sciences and Engineering*, ed. E. I. Papageorgiou (Berlin: Springer), 29–48. doi: 10.1007/978-3-642-39739-4_2

Hamilton, S. E., and Friess, D. A. (2018). Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. *Nat. Clim. Chang.* 8, 240–244. doi: 10.1038/s41558-018-0090-4

Himes-Cornell, A., Grose, S. O., and Pendleton, L. (2018). Mangrove ecosystem service values and methodological approaches to valuation: where do we stand? *Front. Mar. Sci.* 5:376.

Hobbs, B. F., Ludsin, S. A., Knight, R. L., Ryan, P. A., Biberhofer, J., and Ciborowski, J. J. (2002). Fuzzy cognitive mapping as a tool to define management objectives for complex ecosystems. *Ecol. App.* 12, 1548–1565. doi: 10.1890/1051-0761(2002)012[1548:FCMAAT]2.0.CO;2

Hochard, J. P., Hamilton, S., and Barbier, E. B. (2019). Mangroves shelter coastal economic activity from cyclones. *Proc. Natl. Acad. Sci. U.S.A.* 116, 12232–12237. doi: 10.1073/pnas.1820067116

IFREMER (2020). *Activité des Navires de Pêche, Quartier Maritime de Cayenne 2019, Système D'information Halieutique*. Brest: IFREMER, 12.

INSEE (2019). La population guyanaise à l'horizon 2050 : vers un doublement de la population? *Insee Analyses* 36:4.

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., and Schneiders, A. (2015). 'The Matrix Reloaded': a review of expert knowledge use for mapping ecosystem services. *Ecol. Model.* 295, 21–30. doi: 10.1016/j.ecolmodel.2014.08.024

Jourdain, F., Girod, R., Vassal, J. M., Chandre, F., Lagneau, C., Fouque, F., et al. (2012). The moth *Hylesia metabus* and French Guiana lepidopterism: centenary of a public health concern. *Soc. fr. Parasitol.* 19:117. doi: 10.1051/parasite/2012192117

Knight, J. M., Dale, P., Dwyer, P., and Marx, S. K. (2017). A conceptual approach to integrate management of ecosystem service and disservice in coastal wetlands. *Fac. Sci.* 4, 431–442. doi: 10.3934/environsci.2017.3.431

Kulkarni, R., Deobagkar, D., and Zinjarde, S. (2018). Metals in mangrove ecosystems and associated biota: a global perspective. *Ecotoxicol. Environ. Saf.* 153, 215–228. doi: 10.1016/j.ecoenv.2018.02.021

Lee, C. K., Duncan, C., Nicholson, E., Fatoyinbo, T. E., Lagomasino, D., Thomas, N., et al. (2021). Mapping the extent of mangrove ecosystem degradation by integrating an ecological conceptual model with satellite data. *Remote Sens.* 13:2047. doi: 10.3390/rs13112047

Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., McKee, K., Bosire, J. O., Cannicci, S., et al. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Glob. Ecol. Biogeogr.* 23, 726–743. doi: 10.1111/geb.12155

Levrel, A. (2012). *Estimation de la Pêche Illégale Étrangére en Guyane Française. RBE/BIODIVHAL 2012-05*. Available online at: https://archimer.ifremer.fr/doc/00114/22522/

Lewis, M., Pryor, R., and Wilking, L. (2011). Fate and effects of anthropogenic chemicals in mangrove ecosystems: a review. *Environ. Pollut.* 159, 2328–2346. doi: 10.1016/j.envpol.2011.04.027

Lovelock, C. E., Ball, M. C., Martin, K. C., and Feller, I. C. (2009). Nutrient enrichment increases mortality of mangroves. *PLoS one* 4:e5600. doi: 10.1371/journal.pone.0005600

Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., et al. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature* 526, 559–563. doi: 10.1038/nature15538

MacFarlane, G. R., Koller, C. E., and Blomberg, S. P. (2007). Accumulation and partitioning of heavy metals in mangroves: a synthesis of field-based studies. *Chemosphere* 69, 1454–1464. doi: 10.1016/j.chemosphere.2007.04.059

Maiti, S. K., and Chowdhury, A. (2013). Effects of anthropogenic pollution on mangrove biodiversity: a review. *J. Environ. Prot.* 4, 1428–1434. doi: 10.4236/jep.2013.412163

Manna, S., Chaudhuri, K., Bhattacharyya, S., and Bhattacharyya, M. (2010). Dynamics of Sundarban estuarine ecosystem: eutrophication induced threat to mangroves. *Saline syst.* 6, 1–16. doi: 10.1186/1746-1448-6-8

Manson, F. J., Loneragan, N. R., Skilleter, G. A., and Phinn, S. R. (2005). An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions. *Oceanogr. Mar. Biol.* 43, 493–524. doi: 10.1201/9781420037449-12

Marchand, C. (2017). Soil carbon stocks and burial rates along a mangrove forest chronosequence (French Guiana). *For. Ecol. Manag.* 384, 92–99. doi: 10.1016/j.foreco.2016.10.030

Marre, J. B., and Billé, R. (2019). A demand-driven approach to ecosystem services economic valuation: lessons from Pacific island countries and territories. *Ecosyst. Serv.* 39:100975. doi: 10.1016/j.ecoser.2019.100975

Martinez, J. M., Guyot, J. L., Filizola, N., and Sondag, F. (2009). Increase in suspended sediment discharge of the Amazon River assessed by monitoring network and satellite data. *Catena* 79, 257–264. doi: 10.1016/j.catena.2009.05.011

Massel, S. R., Furukawa, K., and Brinkman, R. M. (1999). Surface wave propagation in mangrove forests. *Fluid Dyn. Res.* 24:219. doi: 10.1016/s0169-5983(98)00024-0

MEA (2005). *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press, 160.

Mongruel, R., Kermagoret, C., Carlier, A., Scemama, P., Le Mao, P., Levain, A., et al. (2018). *Milieux Marins et Littoraux : Évaluation des Écosystèmes et des Services Rendus. Rapport de l'étude Réalisée pour le Compte du Programme EFESE, IFREMER – UBO – AFB, 354 pages + Annexes*. Brest: IFREMER.

Jolivet, M. (2019). *Morphologie et Dynamique des Littoraux Sableux de Guyane soumis à l'influence de Bancs de Vase Amazoniens : Analyse Expérimentale et Multi-Échelle, du Court Terme au Multi-Décennal. Ph D. thesis*. Cayenne: Université de Guyane.

Muradian, R., and Gómez-Baggethun, E. (2021). Beyond ecosystem services and nature's contributions: is it time to leave utilitarian environmentalism behind? *Ecol. Econ.* 185:107038. doi: 10.1016/j.ecolecon.2021.107038

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C., Clay, J., et al. (2000). Effect of aquaculture on world fish supplies. *Nature* 405, 1017–1024. doi: 10.1038/35016500

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science* 325, 419–422. doi: 10.1126/science.1172133

Ouyang, X., Lee, S. Y., Connolly, R. M., and Kainz, M. J. (2018). Spatially-explicit valuation of coastal wetlands for cyclone mitigation in Australia and China. *Sci. Rep.* 8:3035. doi: 10.1038/s41598-018-21217-z

Owuor, M. A., Mulwa, R., Otieno, P., Icely, J., and Newton, A. (2019). Valuing mangrove biodiversity and ecosystem services: a deliberative choice experiment in Mida Creek, Kenya. *Ecosys. Serv.* 40:101040. doi: 10.1016/j.ecoser.2019.101040

Özesmi, U., and Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecol. Model.* 176, 43–64.

Polidoro, B. A., Carpenter, K. E., Collins, L., Duke, N. C., Ellison, A. M., Ellison, J. C., et al. (2010). The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS One* 5:e10095. doi: 10.1371/journal.pone.0010095

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., et al. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *J. Environ. Manag.* 90, 1933-1949. doi: 10.1016/j.jenvman.2009.01.001

Reis-Filho, J. A., Harvey, E. S., and Giarrizzo, T. (2019). Impacts of small-scale fisheries on mangrove fish assemblages. *ICES J. Mar. Sci.* 76, 153–164.

Richards, D. R., and Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proc. Natl. Acad. Sci. U.S.A.* 113, 344–349. doi: 10.1073/pnas.1510272113

Richards, D. R., Thompson, B. S., and Wijedasa, L. (2020). Quantifying net loss of global mangrove carbon stocks from 20 years of land cover change. *Nat. Commun.* 11, 1–7. doi: 10.1038/s41467-020-18118-z

Rojas-Beltran, R. (1986). "Role de la mangrove comme nourricerie de crustacés et de poissons en Guyane," in *Fragilité de l'Environnement*, ed. S. Sepanrit (Cayenne: Le Littoral Guyanais), 97–110.

Rönnbäck, P. (1999). The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecol. Econ.* 29, 235–252.

Rousseau, Y., Blanchard, F., and Gardel, A. (2018). Spatiotemporal dynamics of larval fish in a tropical estuarine mangrove: example of the Mahury River Estuary (French Guiana). *Can. J. Fish. Aquat. Sci.* 75, 235–246. doi: 10.1139/cjfas-2016-0267

Rowe, G., and Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *Int. J. Forecast.* 15, 353–375. doi: 10.1016/s0169-2070(99)00018-7

Sandilyan, S., and Kathiresan, K. (2012). Mangrove conservation: a global perspective. *Biodivers. Conserv.* 21, 3523–3542. doi: 10.1007/s10531-012-0388-x

Scemama, P., and Levrel, H. (2019). Influence of the organization of actors in the ecological outcomes of investment in restoration of biodiversity. *Ecol. Econ.* 157, 71–79. doi: 10.1016/j.ecolecon.2018.11.003

Schröter, M., Van der Zanden, E. H., van Oudenhoven, A. P., Remme, R. P., Serna-Chavez, H. M., De Groot, R. S., et al. (2014). Ecosystem services as a contested concept: a synthesis of critique and counter-arguments. *Conserv. Lett.* 7, 514–523. doi: 10.1111/conl.12091

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M. L., Wolff, C., Lincke, D., et al. (2018). Future response of global coastal wetlands to sea-level rise. *Nature* 561, 231–234.

Singh, G. G., Sinner, J., Ellis, J., Kandlikar, M., Halpern, B. S., Satterfield, T., et al. (2017). Group elicitations yield more consistent, yet more uncertain experts in understanding risks to ecosystem services in New Zealand bays. *PloS one* 12:e0182233. doi: 10.1371/journal.pone.0182233

Spalding, M., and Parrett, C. L. (2019). Global patterns in mangrove recreation and tourism. *Mar. Pol.* 110:103540. doi: 10.1016/j.marpol.2019.103540

Spalding, M., Kainuma, M., and Collins, L. (2010). *World Atlas of Mangroves. A Collaborative Project of ITTO, ISME, FAO, UNEP-WCMC, UNESCO-MAB and UNU-INWEH*. London: Earthscan.

Steger, C., Hirsch, S., Evers, C., Branoff, B., Petrova, M., Nielsen-Pincus, M., et al. (2018). Ecosystem services as boundary objects for transdisciplinary collaboration. *Ecol. Econ.* 143, 153–160. doi: 10.1016/j.ecolecon.2017.07.016

TEEB (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. London: United Nations Environment Programme, 410.

Teixeira, H. M., Vermue, A. J., Cardoso, I. M., Claros, M. P., and Bianchi, F. J. (2018). Farmers show complex and contrasting perceptions on ecosystem services and their management. *Ecosys. Serv.* 33, 44–58. doi: 10.1016/j.ecoser.2018.08.006

Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A., and Simard, M. (2017). Distribution and drivers of global mangrove forest change, 1996–2010. *PloS one* 12:e0179302. doi: 10.1371/journal.pone.0179302

Trégarot, E., Caillaud, A., Cornet, C. C., Taureau, F., Catry, T., Cragg, S. M., et al. (2021). Mangrove ecological services at the forefront of coastal change in the French overseas territories. *Sci. Total Environ.* 763:143004. doi: 10.1016/j.scitotenv.2020.143004

Tribot, A. S., Deter, J., and Mouquet, N. (2018). Integrating the aesthetic value of landscapes and biological diversity. *Proc. Royal Soc. B* 285:20180971. doi: 10.1098/rspb.2018.0971

Treviño, M., and Murillo-Sandoval, P. J. (2021). Uneven consequences: gendered impacts of shrimp aquaculture development on mangrove dependent communities. *Ocean Coast. Manag.* 210:105688. doi: 10.1016/j.ocecoaman.2021.105688

Truong, T. D., and Do, L. H. (2018). Mangrove forests and aquaculture in the Mekong river delta. *Land Policy* 73, 20–28. doi: 10.1016/j.landusepol.2018.01.029

Van Oudenhoven, A. P., Siahainenia, A. J., Sualia, I., Tonneijck, F. H., van der Ploeg, S., de Groot, R. S., et al. (2015). Effects of different management regimes on mangrove ecosystem services in Java, Indonesia. *Ocean Coast. Manag.* 116, 353–367. doi: 10.1016/j.ocecoaman.2015.08.003

van Vliet, M., Kok, K., and Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies: the use of Fuzzy Cognitive Maps as a communication and learning tool. *Futures* 42, 1–14. doi: 10.1016/j.futures.2009.08.005

Walcker, R., Anthony, E. J., Cassou, C., Aller, R. C., Gardel, A., Proisy, C., et al. (2015). Fluctuations in the extent of mangroves driven by multi-decadal changes in North Atlantic waves. *J. Biogeogr.* 42, 2209–2219. doi: 10.1111/jbi.12580

Walcker, R., Gandois, L., Proisy, C., Corenblit, D., Mougin, E., Laplanche, C., et al. (2018). Control of "blue carbon" storage by mangrove ageing: evidence from a 66-year chronosequence in French Guiana. *Glob. Change Biol.* 24, 2325–2338. doi: 10.1111/gcb.14100

Walters, B. B. (2005). Patterns of local wood use and cutting of Philippine mangrove forests. *Econ. Bot.* 59, 66–76. doi: 10.1663/0013-0001(2005)059[0066:polwua]2.0.co;2

Woudenberg, F. (1991). An evaluation of Delphi. *Technol. Forecast. Soc. Change* 40, 131–150.

WWF (2017). *Vers un Développement Soutenable de la Guyane*. Gland: WWF, 11.

Xiao, K., Wu, J., Li, H., Hong, Y., Wilson, A. M., Jiao, J. J., et al. (2018). Nitrogen fate in a subtropical mangrove swamp: potential association with seawater-groundwater exchange. *Sci. Total Environ.* 635, 586–597. doi: 10.1016/j.scitotenv.2018.04.143

Zouari, I. (2015). La Guyane, une mosaïque de populations. *Popul. Avenir* 725, 15–17.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.