ASSESSING THE QUALITY OF WETLANDS.
A FRAMEWORK BASED ON A CRITICALITY APPROACH OF NATURAL CAPITAL

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Résumé :
L'objet de la communication vise à montrer comment le concept de capital naturel critique peut contribuer à la réflexion sur l'analyse économico-écologique des zones humides.

Abstract:
The paper provide an ecological-economic wetlands framework based on a criticality approach of natural capital.

INTRODUCTION

While the critical natural capital has various meanings in the literature, the concept is practically always closely connected with the sustainability issue of development. Indeed, an important issue for the conservation of natural resources in the context of sustainability relies on the fact that some components of natural capital are important for the maintenance of life and of ecosystems survival in a context where economic activities have an increasing impact on nature and bring irreversible damages both directly and on the long run. It follows that a central question for the maintenance of natural capital on the long run is how much natural capital do we need to sustain the development of a society. This point is closely connected with the debate around weak and strong sustainability (Chiesura et De Groot, 2003).

On the first hand, and from a neoclassical viewpoint, a constant economic output can be maintained indefinitely if there is the possibility to substitute manufactured capital to natural capital (weak sustainability), the level of the total capital being constant in time. Within such a perspective, the economy can create a sufficient amount of man-made capital in order to compensate for the losses in natural capital (mainly losses of ecosystem services as well as biological species indirectly threatened by the loss of their habitat). The basic hypothesis of this approach lies in the substitution possibilities between all the kinds of capital, without any concern for the question of scale or of the natural dynamics of the complex systems involved (Limburg et al., 2002).

On the other hand, and from an ecological economics perspective, economic production is perceived as a transformation process using energy to transform materials into goods and services (e.g. dissipative process). This process takes place within a biophysical environment so that economic activities cannot escape from biological, physical and ecological constraints given by nature (laws and properties). Accordingly, the complementary relationship between man-made and natural capital is generally emphasized (strong sustainability hypothesis) while some components of natural capital need to be protected when some irreplaceable functions are at stake: there is no substitution possible for life support functions provided by elements of environmental systems such as biological diversity, climate regulation, pollination, freshwater resources (MEA, 2005). In such a setting, natural capital is defined as a stock of non renewable and renewable resources including the production of ecosystems services and life-support functions (De Groot, 1992 ; MacDonald et al, 1999).

In this approach, the maintenance of the economic throughput on the long run depends mainly on the absolute necessity to hold (at least) constant the level of natural capital and, at the same time, on its protection when its components have no substitute. This protection is at the core of the critical natural capital (CNC) concept: some elements of natural capital have to be preserved, that is to say they cannot be declining or deteriorated as they are unique and irreplaceable. "it ought to be maintained in any circumstances in favour of present and future generations" (Brand, 2009, p.606).

In line with these concerns, this paper analyses various dimensions of the concept of critical natural capital so as to frame its empirical implementation. We the go on by considering a specific environmental system for such an exercise, namely wetlands. Wetlands are a good candidate for a CNC approach because of their multidimensional nature which leads to a complexity of spatial relationships among groundwater, surface water and wetland vegetation. A preliminary framework based on the identification of a resilience potential in a French wetland exposed to economic activities is provided and discussed.

1. Critical natural capital (CNC), a multidimensional concept

1.1. From a functional to an efficiency approach of criticality

Various categorizations of CNC are found in the literature (Chiesura et de Groot, 2003). First, and according to Ekins et al. (2003), CNC may be defined as "natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital" (p.169). This approach is close to the one of Faucheux and O'Connor (1998) as well as Noël and O'Connor (1998) for whom CNC is "a set of environmental resources which at the prescribed geographical scale performs important environmental functions and for which no substitute in terms of manufactured, human or other natural capital exists", or, in a more extended way, "a subset of natural capital including ecological life support systems and irreplaceable cultural artifacts" (Costanza et Daly, 1992)). In the EU-funded project on strong sustainability - CRITINC-, CNC is the " set of environmental resources which performs important functions and for which on substitutes in terms of human, manufactured, or other natural capital currently exist" (Ekins et al, 2003).

This first set of definitions emphasizes the essential role of the environmental functions that ecosystems components (plants, animals...) and processes (biogeochemical cycles) provide. In this respect, and following Pearce and Turner (1990), the features of CNC are organized in terms of source, sink, life-support and well-being functions. The source function is related to the productive area (harvesting) and depends on various uses. The second refers to the assimilative capacity of ecosystems to deal with waste and pollutions. The life-support function is based on the regulation capacity of natural processes (local and global levels). The latter function (well-being function) addresses the quality of life (to which natural capital contributes) and its determinants -use and non use values of the resources- which may refer to socio-economic issues.

Another example of the functional approach of CNC is provided by by De Groot et al. (2002) They suggest a classification of ecosystems and of the services and goods they provide through four environmental functions: regulation, habitat, production and information functions. According to De Groot (1992), those functions capture "the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly". Regulation functions relate to the capacity of ecosystems to regulate ecological processes and life support systems (climate regulation, waste treatment, water regulation...). Habitat functions refer to conservation of biological and genetic diversity. Production functions concern the provision of natural resources for populations (food, raw materials, energy resources, genetic materials...). The last function exemplifies the contribution of ecosystems to support cognitive development of human (recreation and cultural experiments...). The first two functions are essential for human survival and, as such, dominate the last two ones.

A complementary approach of CNC focuses on another aspect of natural capital which is not directly connected with human needs, but concerns the performance of the (underlying) natural ecosystems (Deutsch et al. 2003). More precisely, this approach refers to the dynamic capacity of ecosystem to provide life-support and, by so doing, its ability to sustain the flow of source and sink functions (e.g. the flow of ecosystem services). Such a performance may be tackled through the concept of ecological resilience. Numerous definitions of resilience are present in various disciplines (Brand et al. 2007; Brand, 2009) since the seminal paper of Holling in 1973. The original ecological concept defined by Holling considers that resilience is "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables." (quoted by the authors). According to Deutsch et al. (2003), resilience is "the magnitude of disturbance that can be tolerated before an ecosystem moves into a different state with a different set of controls, i.e. the major processes and functions of the system are changed to the degree that a different set of ecosystem services, or even disservices, are generated" (p.211). In such a perspective, ecosystems are viewed as complex dynamic systems and their adaptive capacity is directly connected with their resilience.

1.2. How to assess the criticality of natural capital? How to make it operational?

The previous subsection presented the various conceptions of critical natural capital prevailing in the literature, each of which shedding specific light on the way economic activities affect the quality of environmental systems. As a consequence there is not a unique measure for criticality of natural capital. Moreover, CNC appears to be, to a significant part of its components, a non monetary valuable asset, which then has to be apprehended in physical terms (MacDonald et al., 1999). As long as the criticality of NC is anchored on the complementary hypothesis between man-made and natural capital (strong sustainability), there is no place for a valuation process (Azqueta et al. 2007). In addition, one could say that the valuation of the criticality of natural capital has much to do with the fact that the value of any services provided by some ecosystems is depending on the value of the services of which other environmental systems are provided (number of species, links between various species living within the system...).

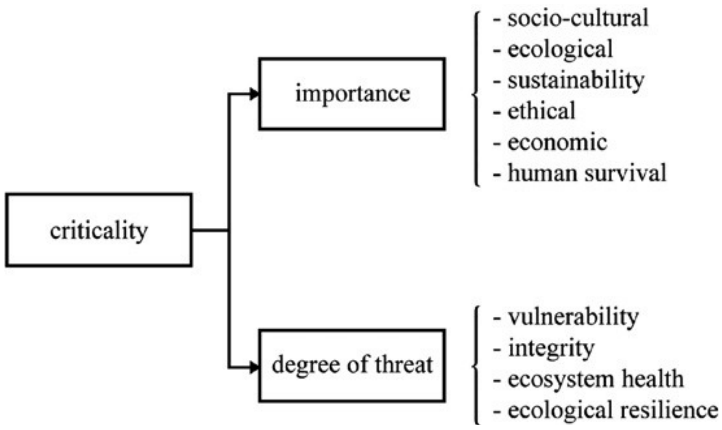
A first way to assess the criticality may go through the analysis of the various functions provided by natural capital. According to De Groot et al. (2003), two main criteria have to be considered in this respect. First, the criticality of natural capital may be assessed from the perspective of the ecological, socio-cultural and economic 'importance' taken by natural systems. Second, criticality has also to take the degree of 'threat' which natural capital is exposed to. Thus, capital natural can be critical because of its societal significance without being threatened (the oxygen reservoir in the atmosphere), although it may not be vital for human welfare (certain animal species without human use or key-role in the ecosystem), or it can be both important and threatened (tropical rainforests, climate change).

In this context, the degree of criticality has been measured by combining the "importance" and "threat" dimensions, following the works of Ten Brink (2000). The former brings about a large number of criteria -depending on ecological, socio-cultural and economic aspects, and for which a complete accounting of the socio-cultural functions of CNC (health, recreation, amenity, quality of human life...) is encouraged-. If a monetary valuation of the "importance" dimension is possible under restrictive conditions (which include the fact that the ecosystem functions are directly related to economic activities (De Groot et al. 2003)), it is not the case for "threat" whose measurement is based on both quantitative and qualitative aspects which are embedded in a natural capital index. Basically, the index is defined by combining an ecosystem quantity indicator which is defined as the size of the ecosystem or habitat (as the percentage of a given area of a region/country) and a quality one which is defined as the ratio between the current state and a postulated baseline state (as a percentage). In particular, the quality is related to the pressures exerted on the ecosystem (as an example of which, we may think about human population density, activities of production and consumption, eutrophisation, acidification...).

The structure and the processes of the environmental system can be disturbed for a long time by economic activities (and there are sometimes irreversible damages). These changes may affect in turn the ecological, socio-cultural and economic functions of the original system. Those feedbacks are the key elements for the valuation of the degree of threat as an indicator of the criticality of natural capital: for instance, the reduction of natural areas below the minimal critical ecosystem size can lead to loss of species or, conversely, to exceed thresholds of ecological systems (like the capacity to assimilate waste).

The previous approach however remains mainly static insofar as the dynamics of the natural processes are not involved into the analysis and no feedback from natural to socio-economic dimension are introduced. Indeed, this index does not capture the dynamic capacity that natural ecosystems may exhibit to sustain the basic environmental functions, namely the source and sink functions.

A way to move towards a dynamic analysis of the criticality of natural capital is suggested by Brand (2009) and by Deutsch et al. (2003). In those studies, ecosystems are defined as complex dynamic systems: the dynamics relies on an organizational and temporal complexity, while the links between the ecosystems and the social systems may be addressed with the concept of resilience. In addition, as Brand mentions, "an ecosystem amount of ecological resilience is directly linked to the degree of threat this ecosystem may face", suggesting that the degree of threat may be tackled through the resilience property (see p.609, Scheme).



Source: A conception of CNC, from Brand (2009).

For Brand (2009), ecological resilience "refers to dynamics far from any equilibrium steady state" and is defined as the capacity of an ecosystem to resist disturbance and still maintain a specific state." (p.606). More generally, ecological resilience refers to relevant properties such as the capacity for renewal of the system, the capacity for reorganization with the recombination of evolved structures and processes, the capacity for development with the emergence of new trajectories (Folke, 2006). Resilience brings about the adaptive capacity for the complex system to survive ! However, ecological resilience cannot be measured directly. Brand has shown that it can be nevertheless estimated through the distance between the current value taken by a slow variable (key controlling variable) which characterize the state of the ecosystem to the predicted value of the ecological threshold (critical level)[1].

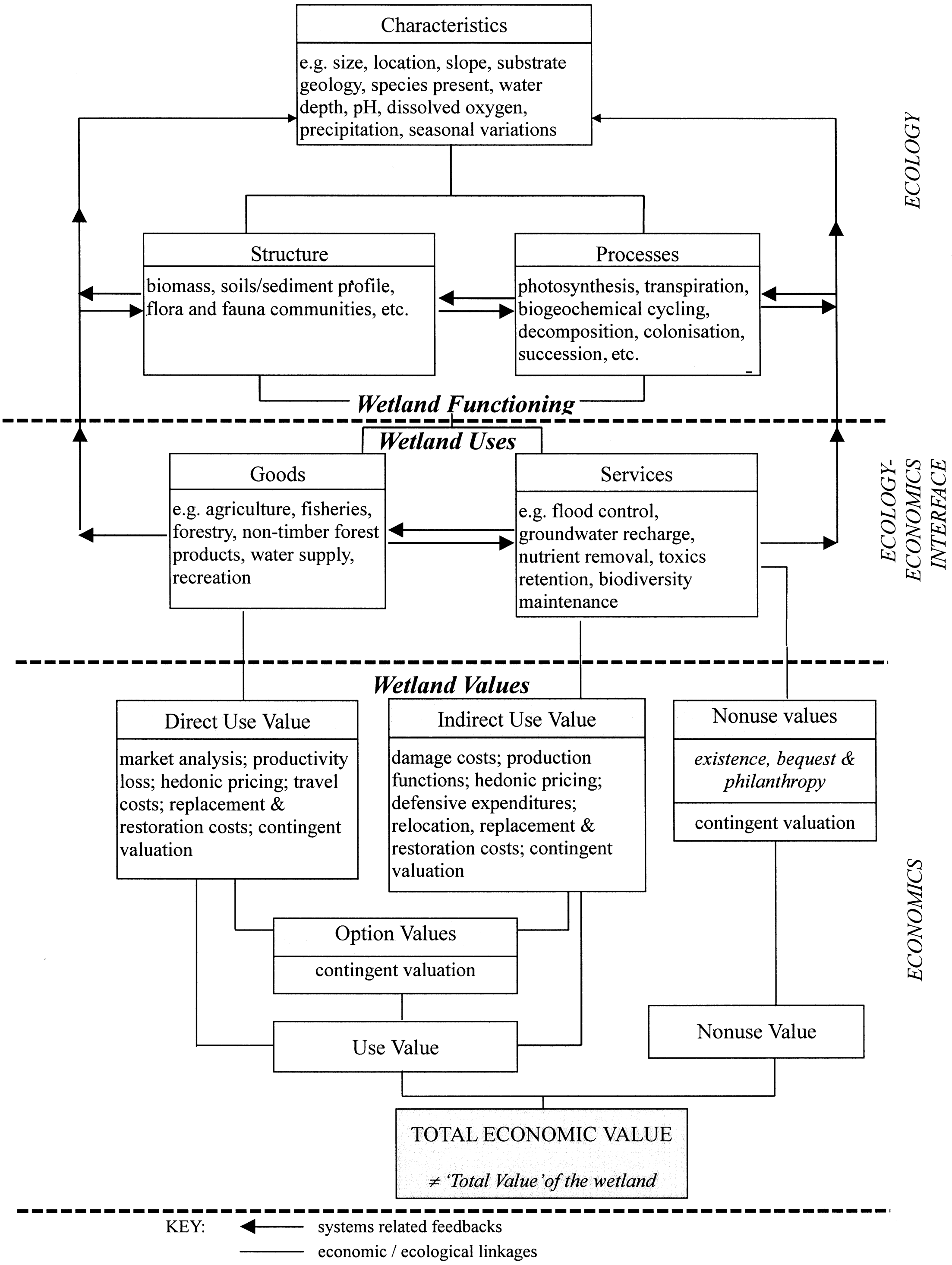
Such a resilience measure is defined regarding the behavior of slowly changing variables (land use and agricultural practices, nutrient stocks, soil properties, water quality...) that determine the thresholds beyond which disturbances (harvesting, polluting activities...) may push the system into another state. It could be applied to the various components of natural capital, and in particular it could refer to different functions (see De Groot classification) provided by ecosystems. However, as Brand (2009) emphasized, the threshold approach can be related to the estimation of ecological resilience only if two hypothesis are checked: 1) ecosystems can shift between different stable states and 2) the ecosystem dynamics can be understood with the identification of a few key variables.

[1] As an example of a slow variable, we may consider the current value of nutrient concentration - such as phosphate - for a shallow lake, or the abundance of woody plants in rangelands.

2. How could wetlands criticality be measured?

2.1. Wetlands characteristics and functions

Wetlands are a good candidate for a CNC approach because they may be considered as complex adaptative ecosystems with a strong multidimensional nature: they have a structure defined by biotic and abiotic webs (vegetation and soil types) and they have processes which are referring to the dynamics of transformation of matter or energy. According to (Turner et al, 2000), "the interactions among wetland hydrology and geomorphology, saturated soil and vegetation more or less determine the general characteristics and the significance of the processes that occur in any given wetland. These processes also enable the development and maintenance of the wetland structure which in turn is key to the continuing provision of goods and services. Ecosystem functions are the results of interactions among characteristics, structure and processes". (p.11)



Source: Connections among wetland functions, uses and values. From Turner et al. (2000)

More particularly, wetlands constitute a diverse group of ecosystems which have been defined by the Ramsar Convention in 1975 as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".

Wetlands are usually sorted in three main parts: marine and coastal wetlands including estuaries, lagoons, inter tidal marshes, coral reefs…, inland wetlands such as lakes and rivers, waterfalls, marshes, peatland or flooded meadows, the third category includes artificial or man-made wetlands, e.g. canals, ponds, water storage or wastewater treatment areas.

French Legal definition of wetlands (art L.211-1 Code de l'environnement) slightly differs from the Ramsar one as it states that wetlands are "farmed or unfarmed lands usually flooded or permanent or temporary filled with fresh, salted or brackish water" ; and where "vegetation when exists, is mainly composed by hygrophilous plants for an undetermined period within a year". Such a definition is less descriptive than the Ramsar one's and mentions also some plant's conditions. A 2007 enforcement order followed by a 2008 ministerial decree (arrêté du 24 juin 2008) presents in a more detailed way wetlands definition's elements. To be defined as a wetland, any area has to check at least at one of two major criteria: 1) its soil should fit some precise soil properties, and/or 2) the vegetation found at a certain level in the area should belong to a list of species of habitats (defined or understood as species communities).

Under the assumption that water is the key variable to characterize a wetland, typology can rely on different elements:

- Dynamic property: running/ stagnant/marine water
- Localization : marine or coastal/ estuarine/ inland
- Level of human intervention : natural/ man-made.

The French national museum of natural history has published in 1996 a biodiversity inventory wherein can be found detailed typology used by French water agencies to identify, describe and list wetlands by dominant type which are referring to their dynamic property. French water agencies used to adopt this typology prior to the 2008 ministerial decree.

Dominant Type	List of wetlands within SDAGE (Guideline water development and management scheme at a water agency level)	List of wetlands within SAGE (water development and management scheme at local level)	European Community classification
Marine Water	*Large, wide estuaries*	*Mud flats, seagrass bed, salt meadows, dunes, lagoons and coastal lakes, salt marshes, ponds from aquaculture*	*Estuaries and deltas*
	Mid size estuaries and bays		*Marine and coastal wetlands*
	Coastal marshes, lagoons		
	Brackish marshes		
Running water	*Riversides or shores*	*bushes, grazeland, reedy marshes peatlands, flooded vegetation, springs*	*Rivers and floodplains*
	Floodplains		*peatlands*
Stagnant water	*Mountainous wetlands*		
	Lakes	*Woods, meadows Paddy fields, birch, ponds and barrages,*	*Lake Marshes, Artificial wetlands*
	Lake shores		
	Plains Wetlands and moors		
	Temporary wetlands		
	Agricultural marshes		
	Artitificial wetlands		

Source: Museum d'Histoire Naturelle, France.

Because of the diversity of ecosystems within the wetland group, there are various classification of wetlands. Pearce and Turner (1990) provided a first one with four basic types with their corresponding functions and services.

Functions/services of the most threatened wetland types.

Wetland types	Functions/services
(1) Floodplains	Flood storage; flood protection; wildlife habitats; nutrient cycling/storage and related pollution control; landscape value; agriculture; recreation (incl. hunting); reduction of water erosion impact; storage of ground water and recharge
(2) Coastal wetlands	All those listed under (1) above, with the exception of aquifer recharge; shoreline protection/storm damage buffer zones; recreation; extended food web control; salinity balance mechanism; commercial goods output
(3) Wet meadows	High bio-diversity; hydrologic cycle control; landscape; water quality and aquifer storage; buffer zones for agricultural run-off; recreation
(4) Peatlands	Same as (3) above; global atmospheric cycle; resource extraction (energy and non-energy); specialised habitats

Source: Pearce et Turner (1990).

Wetlands perform many environmental functions (water and climate regulation, wildlife habitat, nutrient cycles...) and provide also a large set of services and goods to the society such as recreational services, fishing, buffer zone against flood risk) while they are under heavy economic pressures (urban, industrial and agricultural sprawl).

As we have seen, the typology "source/sink/life support functions" is widely used, others typology can be set up focusing on other ecologically oriented variables. In this respects, pedological, hydrologic, geochemical, biodiversity or climatic functions are the main wetlands functionalities and each of them can be related to life support functions or services. For example, peatland can play a role in climatic regulation by carbon storage and oxygen production (life support function) and being a buffer zone smoothering climatic change (service to mankind). Based on De Groot's classification, Van der Perk et al. (2000) suggested the following important functions for coastal wetlands (the dutch wadden sea): regulation functions (climate regulation, water regulation, protection against erosion, waste treatment by purification and filtering, biological control), habitat functions (nursery function, refugium function), production functions (food production and production of raw materials -fish, worms, sellfish, shrimp-), information functions (aesthetic information, recreation/tourism...).

However, whatever the type of wetland we consider, the complexity of spatial relationships among groundwater, surface water and wetland vegetation suggests that the criticality of wetlands could be also defined by a potential resilience of the wetland under study. A first attempt to identify such a potential has been recently done in the case of *constructed* coastal wetlands in the Baltic Sea for combating eutrophication phenomenon (Gren, 2010). While the model gives some useful insights for determining the resilience value of coastal wetlands, the dynamics of water pollution has not been included into the analysis and more investigation is needed to overcome this limit (in particular concerning data). In this respect, a more integrated analysis of wetlands is needed in which biophysical and socio-economic aspects are to be put together.

2.2. Drawing up wetlands criticality indicators from a local management tool: "SAGE" (Water development and management scheme) "Gironde Estuary and Associated environment"

Among European estuarine areas, the Gironde estuary is probably the ecologically most unspoiled one and economically less exploited but this large ecosystem experienced since years some decreases in its global environmental quality. In this respect, policy tools carried by the water agencies aim to prevent further or heavier environmental damage on estuarine wetlands. As an example, guideline water development and management scheme (SDAGE) has been put in place: it represents the reference point for all decisions related to territorial development at a large catchment level. At a local level, e.g. for smaller hydrographic area (around 3000 km^2), water management may be organized around a local planning tool: Water development and management scheme called 'SAGE' which gives guidelines about quality goals, protection rules, usage regulation etc… The SAGE is also meant to improve collective management of water resource imply at different levels all the stakeholders.

The "Gironde estuary and associated environment" SAGE has been built up to improve the global estuarine environmental quality and sustains economic activity in its perimeter (SAGE, 2010). To fulfill this stake, ten major goals have been voted by stakeholders after 4 years of studies and consultations among which seven are directly related to ecological preservation, these concern: global environment, turbidity dynamics, chemical pollution management, benthic habitat preservation, surface water quality and ecological quality of river catchment, halieutic resources preservation, and wetlands preservation. Within this SAGE perimeter, the major types of wetlands are estuary (10% of total surface), floodplains and marshes. These three estuarine ecosystem components carry out the following functions: groundwater recharge and runoffs, flood control, shoreline stability and erosion control, toxic deposits storage, local climate regulation, and deliver a large amount of services such as: navigability, recreation, wild species resources and biodiversity richness, halieutic resources, agricultural resources, water supply.

To achieve the major goal of “wetland preservation” within the SAGE, ten actions are planned and a multicriteria assessment of their direct/ indirect, short/mid/long term effects on five subjects has been made (SAGE, 2010). Those items can be linked to functions and services typology: for instance, biodiversity may be matched with life support function, resources with source function, pollutions with sink function, landscape with cultural service and risk with human health and well being services. From a general viewpoint, the set of actions aims to improve life support functions and should have a positive impact on the source function. Short term and indirect effects actions are essentially characterized by knowledge improvement ranging from wetlands location to their insertion in local land planning schemes in order to build up some optimal management rules and reduce anthropic impact on wetlands. In addition, indirect and midterm effects actions consist in a yearly policy assessment, a comprehensive wetlands inventory elaboration and the definition of the strategic wetland areas regarding optimal water management goals. Direct effects should be raised from two actions that aim to identify protection or restoration areas for specific wetlands. Finally, to monitor and assess the various effects on wetlands, a list of indicators has been set up (for instance, the number of urban documents including the wetlands areas or their protection) and are close to state indicators although the reference state is missing due to the lack of initial information on the wetlands types, numbers and locations.

At this stage, only a functional approach of wetlands criticality is involved in the "Gironde Estuary" SAGE. No critical criteria related to their ecological resilience have been still identified within this local tool. For this purpose, more knowledge is needed about the ecological functions which allow the maintenance of wetland (quantity/quality) in time and about their interactions with human needs and activities. A first step for defining the criticality of wetlands should be to understand the dynamic for each wetland located in the Gironde estuary. For each criterion, a minimum requirement should be identified both in relation to the maintenance of the wetland (regulation, habitat functions) and the availability of its different functions (functions underlying ecological principles like regulation or habitat functions, and also functions connected with human needs like production and information functions). Van der Perk et al. (2000) have identified a set of criteria for a coast wetland that allow to assess the degree to which current wetland use can stay below or go beyond the carrying capacity of the ecosystem without threatening the availability of the related environmental functions.

Table: Examples of criteria and measurement units to identify critical natural capital

Criteria	Short description	Measurement unit
Naturalness/Integrity	Degree of human presence in terms of physical, chemical or biological disturbance	Air, water, soil quality ; % key species ; Minimum critical ecosystem size
Uniqueness/rarity	Local or global rarity of ecosystems and species	Endemism ; % surface area remaining
Fragility/vulnerability	Sensitivity of ecosystems for human disturbance	Resilience ; carrying capacity
Life support value	Importance to maintenance of essential ecological processess and life support systems	Critical functions that maintain ozone layer, climate regulation, genetic diversity
Threat	External pressures on remaining natural capital	Critical thresholds (qualitative/quantitative) ; minimum critical ecosystem size

Source: From Van der Perk et al. (2000).

As soon as we shift attention to the quality of wetlands in a long-term context (sustainability view), we necessarily address the ecosystem health or its integrity. Doing this, we have to determine some basic properties for analysing wetlands criticality in this respect such as stability or ecological resilience. In our study, a special emphasis has been put on the resilience because such a property may be relevant for defining the threat to which the wetland is exposed to as we have noted previously. In this context, the adaptive capacity for wetlands to adapt to anthropic stress and pressures depends on the way its functions are connected and how these connections (links, feedbacks) are complements or not on the long run. In addition, wetland being a complex multifunctional system (according to Turner et al (2000)), key dimensions of complexity can be analysed by ecological resilience (Plummer and al. 2007).

It must however be acknowledged that it is a real challenge to define indicators for managing resilience insofar as it requires to understand the components of the systems and their dynamic interactions over temporal and spatial scales (Deutsch et al., 2003). In particular, managing the resilience of wetlands involves to identify the slow controlling variables that make up ecosystem configuration (types of habitats, biophysical features - soil structure, geomorphology..., relationships between components, diversity -biological and functional-), and the faster variables which are operating at small spatial and temporal scales (Plummer et al. 2007). For instance, and in the particular case of wetlands (See the Everglades case study), the slower variable could be saw grass while the fastest could be periphyton (Gunderson et al, 2002).

Moreover, if the diversity of organisms, the heterogeneity of ecological functions (source, sink for instance) are good signals of ecosystems resilience, it may be necessary to test the system by perturbing it and then observe the response (Arrow et al., 1995). In addition, it is not the number of species per se that can sustain the ecosystem in a particular state but rather the existence of species groupings or functional groups (predators, pollinators, herbivores, nutrient transporters, water flow modifiers... with overlapping characteristics anchored in physical processes (Folke, 2006). This point underlines the fact that species that may be redundant for ecosystem functioning during particular stages of ecosystem development may become of a great importance for regenerating the system after disturbance.

Finally, without resilience, wetlands may lose their capacity to sustain source and sink functions and, consequently, they reduce their capacity to support human life. Resilience is thus more than a state indicator of the ecosystem dynamics: it underlies the capacity of ecosystems to maintain their own functions and provide goods and services for generations, present and future.

CONCLUSION

The paper provides some preliminary insights for defining and measuring the criticality of wetlands within a CNC approach. A further step will be to apply our analysis to the case of wetlands in Gironde estuary. First, we want to provide a typology of wetlands in this area which includes characteristics, structures and processes associated to them. Second, we will identify the critical aspects of these wetlands by combining ecological (physical, biological principles) and socio-economic data (in relation with some relevant economic activities such as agriculture, fisheries) and, by this way, indicate what should be sustained in the future for the maintenance of wetlands (quantity and quality aspects such as the shape of wetlands, energy/matter flows, critical thresholds...).

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