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TECHNICAL REPORT

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Economic assessment of ecosystem services provided by Mediterranean wetlands in terms of climate regulation

United Nations Environment Programme

Mediterranean Action Plan Barcelona Convention

Plan Bleu

Tour du Valat

nomadéis

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Glossary

Aggregate consumption: in macroeconomics, refers to all household consumption across a given area.

Anthropisation: transformation of ecosystems by human action.

Business as usual: refers to a scenario where the current demographic, economic and political trends are extrapolated with no structural changes.

Discount/update: in economics, process aimed at determining the current value of a good or benefit that will be received in the future. The discount rate is used to reduce future costs and benefits at their current equivalent.

Ecosystem service: benefits that humans receive from the function of ecosystems. The expression was forged in the 1970s in the field of biological sciences as a way of demonstrating humanity's dependency on natural environments.

"Episode cévenol": Episode of heavy rains that mainly affects the "Cevennes" region, in the south of France, frequently causing severe flooding.

Grau: permanent or temporary channel that connecting a water body (as coastal lagoon) to the sea.

Hydrogramme: graph of the temporal variation of the waterflow, measured at ground level.

INDC: Intended National Determined Contributions. National commitment of States on the reduction of their greenhouse gases by 2025 to 2030, to limit the global warming.

Least squares regression: a statistical approximation method that adjusts a series of data using a function to minimise the sum of the squares of the distances between the points and the estimated curve.

Marginal: refers to small-scale change in a variable, i.e. an infinitely small variation (single-unit variation is often considered a proxy for marginal variation).

Marginal abatement cost of carbon: monetary indicator denoting the cost of implementation of a policy to reduce emissions of greenhouse gases compared to a usual scenario called "business as usual" (BAU). The "marginal" dimension means that we evaluate the abatement cost of an additional equivalent ton of carbon dioxide (CO_2).

Marginal willingness to pay: the revealed or stated amount stakeholders are willing to pay for an additional "unit" of a good or service.

Method of replacement costs: method of estimating the amount that would have to be paid to replace ecosystem goods or services affected.

Method of avoided costs: Method of evaluating the costs that could be incurred in the absence of the studied environmental asset.

Ramsar Convention: adopted in Ramsar (Iran) in 1971, this convention currently gathers 169 Contracting Parties, who labelled 2,245 sites on a total area of 215,029,368 ha. Its mission is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world" (source: Ramsar Convention website).

Régnier's Abacus: a decision-making graph to facilitate collective negotiation (source: Godet, 1997).

Social cost of carbon: monetary indicator to measure the present value of damage caused globally by the emission of one ton of extra greenhouse gases in the atmosphere.

Utility: in economics, a measurement of well-being or satisfaction obtained by the consumption, or at least procurement, of a good or service. **Disutility** refers to the loss of utility associated with decreased consumption.

List of acronyms

ADEME: French Environment and Energy Management Agency

BRGM: Bureau of Geological and Mining Research.

CBD: Convention on Biological diversity

CDM: Clean Development Mechanism

CEPRI: European center for flood risk prevention

CEREMA: Center for the study and expertise of risks, environment, mobility and development

CICES: Common International Classification of Ecosystem Services

DIC: Dissolved Inorganic Carbon

DOC: Dissolved Organic Carbon

DEM: Digital Elevation Modeling

DKM: Doga Koruma Merkezi / Nature Conservation Center

EbA: Ecosystem based Adaptation

EDF: Expected Damage Function

EEA: European Environment Agency

EFESE: French Evaluation of Ecosystems and Ecosystem Services

EID: Entente Interdépartementale de Démoustication (interdepartmental mosquito control alliance)

GDP: Global Damages Potential

GTP: Global Temperature Change Potential

GHG: Greenhouse Gases

GIZ: German international cooperation agency for development (“Deutsche Gesellschaft für Internationale Zusammenarbeit”)

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC: Intergouvernemental Panel on Climate Change

IAM: Integrated Assessment Models

ICPDR: International Commission for the Protection of the Danube River

INDC: Intended Nationally Determined Contribution

ISRBC: International Sava River Basin Commission

IUCN: International Union for Conservation of Nature

JI: Joint Implementation

MAP: Mediterranean Action Plan

MEA: Millenium Ecosystem Assessment

NEE: Net Ecosystem Exchange

ODN: Ordnance Datum Newlyn

SCC: Social Cost of Carbon

SIEL: « Syndicat mixte des Étangs Littoraux » (Management structure for coastal ponds)

SOC: Soil Organic Carbon

SYBLE: « Syndicat mixte du Bassin du Lez » (Management structure for Lez Basin)

TEEB: The Economics of Ecosystems and Biodiversity

UNEP: United Nations Programme for the Environment

UNFCC: United Nations Framework Convention on Climate Change

VCM: Voluntary Carbon Market

1. Introduction

Wetlands are home to some of the richest yet most threatened ecosystems on the planet (Pearce, *et al.*, 1994). Half of Mediterranean wetlands disappeared during the 20th century and they now only represent 18 million hectares, 1 to 2% of the world's total wetlands (Mediterranean Wetlands Observatory, 2012). This was caused by the conversion of wetlands for agriculture or urban development, unwise use of their resources, and in general, poor understanding of their many functions (Gren, *et al.*, 1994).

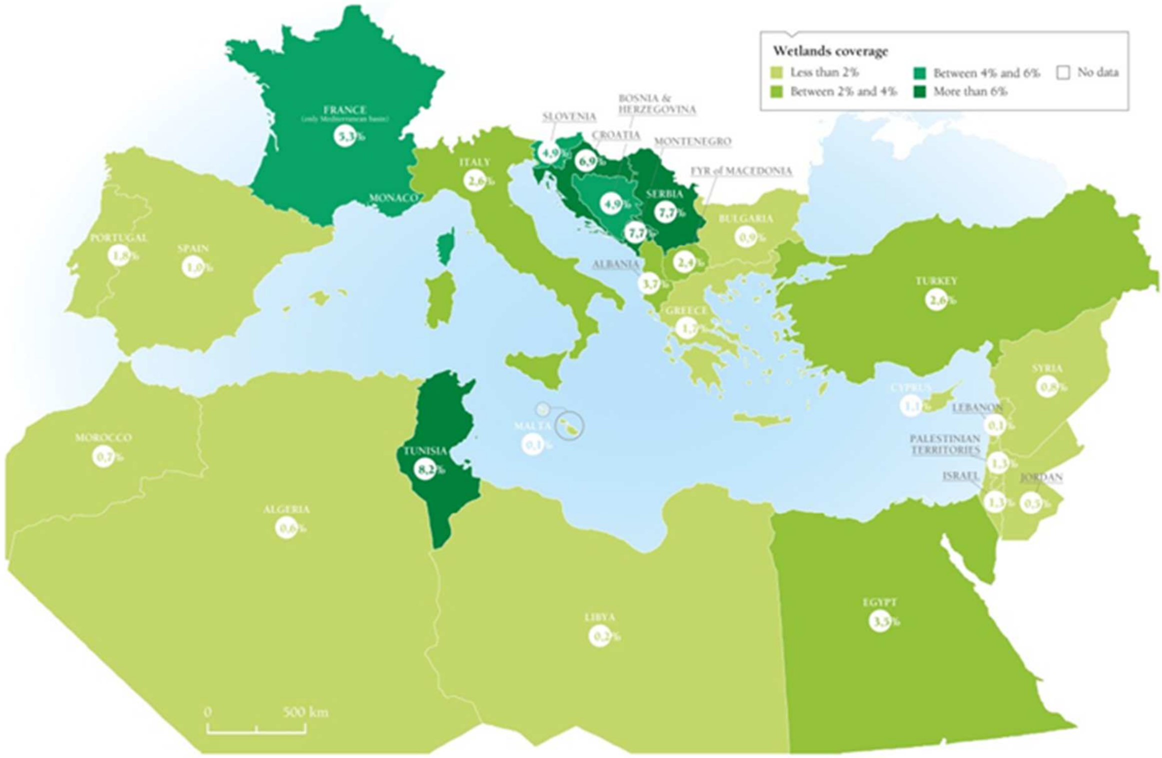


Figure 1: Distribution of wetlands in the Mediterranean Basin (Mediterranean Wetlands Observatory, 2012)

The term wetlands encompasses a vast diversity of areas (in terms of location, surface area, configuration, function and functionalities). The one point in common is that water is the main influencing factor for the habitat (biotope) and ecological community (biocoenosis) in all these areas. At international level, the definition provided by the RAMSAR Convention[1] is less restrictive than that recognised by some signatory states. Whether these areas are of natural or anthropogenic origin, they represent an estimated 6% of global land mass and are among the most diverse and productive ecosystems on the planet.

Wetlands provide many ecosystem services that promote human well-being, such as regulating services (e.g. water purification, erosion control, flood regulation), provisioning services (e.g. fishing, irrigation, raw materials) or cultural services (e.g. recreational or educational services) (Figure 2).

[1] "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" RAMSAR Convention, 1971.

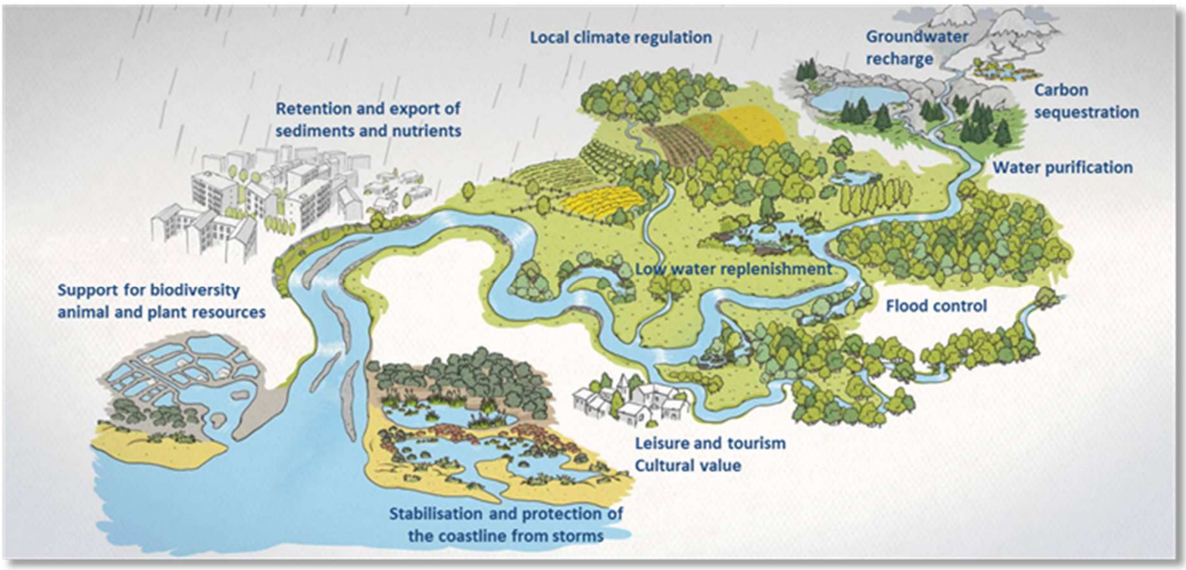


Figure 2: Main ecosystem services provided by wetlands (source: Plan Bleu, adapted from an illustration by the Rhone-Mediterranean and Corsica Water Agency)

Biodiversity in continental and aquatic environments is continuing to fall, primarily due to the pressures caused by human activities, including the modification or degradation of natural habitats by urban sprawl, intensive farming or forest management, the overexploitation of natural resources, various pollutions, the settlement of exotic invasive species and the increasing impact of global warming. Wetlands are especially affected, as demonstrated in the 2015 European Environment Agency (EEA) Report[2].

The renewable surface and groundwater water stocks, including transboundary aquifers, continue to be overexploited or exploited without control, for agricultural, domestic and industrial reasons, altering the functionality of some wetlands, particularly in arid and semi-arid regions. North Africa countries, with 92% of their renewable fresh water extracted, already exceeded their water resources sustainability threshold.

Mediterranean wetlands are particularly impacted as, according to IPCC reports, the Mediterranean is one of the most vulnerable regions to climate change, with significant repercussions on water resources, particularly in arid and semi-arid environments (Ramsar)[3]. These are **transition areas (ecotones) subject to daily, seasonal or annual fluctuations** (land flooding, salinity of fresh, brackish or salt water and its nutrient composition) according to climate conditions, the location of the zone within the water basin and the geomorphological context. By definition, wetlands are complex environments, which explains the difficulty assessing the benefits provided by these areas and their inclusion in public policies.

An increase in extreme events (floods, heat waves, droughts, etc.) is expected, and has already been witnessed in some Mediterranean regions, along with the associated risks in terms of economic losses and the loss of human lives.

Many studies demonstrate the impact of climate change on ecosystems, including wetlands. Conversely, it seems that **the role of ecosystems as an adaptation or mitigation tool is still little understood and underestimated in countries outside the European Union**.

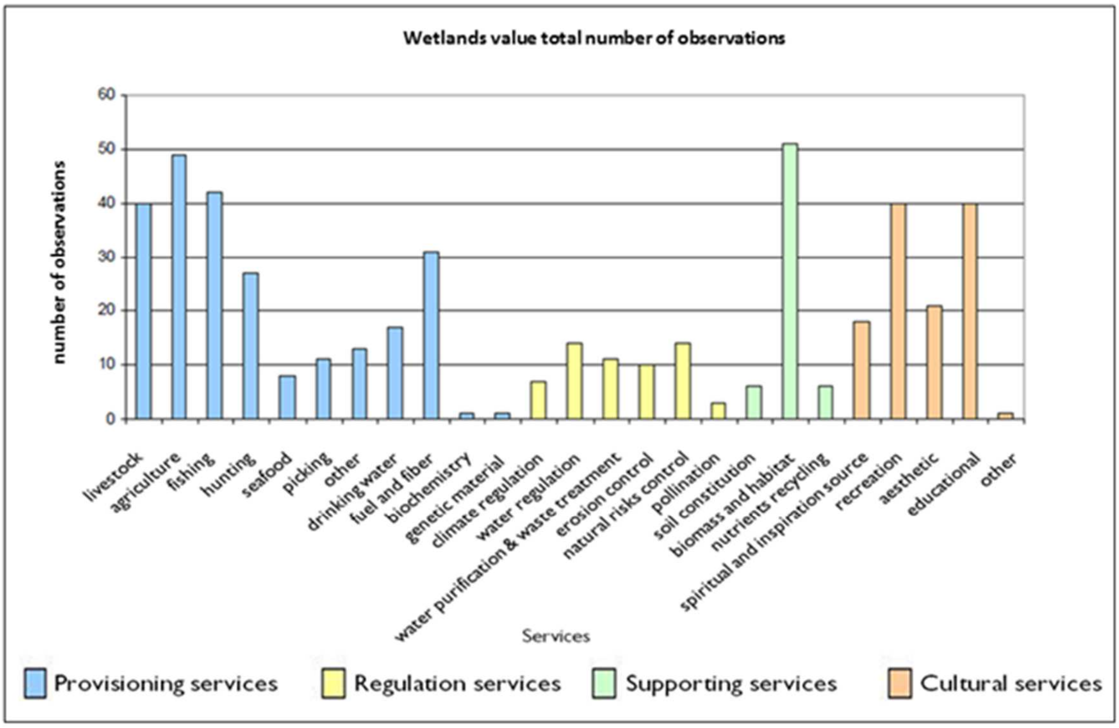
When wetlands are not degraded, they can mitigate the effects of climate change, helping to regulate the climate by reducing the level of greenhouse gas emissions (sequestration by peatlands, salt marshes, etc.), or provide adaptation by protecting us from flooding, drought and coastal storms (lagoons, mangrove swamps, floodplains). Intact floodplains help to limit the risk of flooding by storing up water and then releasing it gradually into streams and rivers.

Similarly, coastal lagoons that have been little anthropised are buffer areas with respect to storms or sea level rises. Where there are no artificial protection structures, they are also vital transit areas for sandbank movement confronted by these loads.

[2] EEA, 2015. L'environnement en Europe : état et perspectives 2015 – Synthèse. Agence européenne pour l'environnement, Copenhague.
[3] http://www.ramsar.org

Ecosystem-based Adaptation (EbA) is an effective alternative to traditional adaptation measures such as the construction of artificial infrastructure (embankments, dams) which can prove to be more costly and can exacerbate some negative impacts (i.e. deterioration of sediment dynamics, erosion). By drawing on the sustainable management of provisioning and regulating services, this "no regret" or "low regret" adaptation strategy produces benefits regardless of the climate change scenario considered, while also providing significant associated benefits such as continued biodiversity and reduced poverty.

This approach is based on the concept of ecosystem services, developed in 2005 by the Millennium Ecosystem Assessment (MEA). Ecosystem services reflect the benefits that humans draw from their natural environment, particularly in terms of social and cultural well-being. This notion is especially well suited to wetlands, which, historically, were important environments for the production of enormous coal deposits during the Carboniferous Period, play a major role in the water cycle, and have been the preferred home of communities associated with the key stages of human development (Matby *et al.*, 2011).



Source : Quentin Liautaud, 2010.

Figure 3: Distribution of studies for the economic valuation of the services provided by wetlands in the Mediterranean basin by the services assessed

Despite the recognised ecological, social, cultural and economic utility of wetlands, economic valuation of the services associated with these aspects is uneven across the Mediterranean (Figure 3). Regulating services are the least assessed category of the various existing categories (provisioning, regulating, cultural services) and require additional research.

In order to improve knowledge and report on the climate mitigation role of Mediterranean wetlands in adaptation and natural disaster prevention policies, Plan Bleu launched the Med-ESCWET project in partnership with Tour du Valat in 2013. This project on the "*economic valuation of the ecosystem services provided by wetlands in terms of climate change adaptation in the Mediterranean*" was co-funded by the MAVA Foundation and the Prince Albert II of Monaco Foundation. It **seeks to develop an ecosystem-based approach and promote the use and restoration of natural infrastructure as climate change adaptation measures, rather than the artificial infrastructure which was widely preferred until now.**

As part of Med-ESCWET, economic valuation was completed for three regulating ecosystem services associated with climate change adaptation:

- the coastal storm protection service,
- the flood control service,
- and the carbon sequestration service.

Four Mediterranean pilot sites were identified to value these services in Croatia, France, Egypt and Turkey. It should be noted that this is not about giving monetary value to services without a market price, but about creating a common language so that policymakers can consider the environment as a natural capital on which most business sectors depend.

Economic valuation is an exercise combining ecology, economics, hydrology and sociology, and requires prior biophysical assessment which is vital for the soundness of the study (Barbier, 2011a; CGDD, 2010). Hydroperiods (water budget and storage capacity) and flood pulsing (rhythm) in the areas studied need to be taken into account in the assessment. They determine the constitution of hydromorphic soils and some of the wetland's functionalities that influence the ecosystem services. In line with the data, available resources and the limitations of the chosen economic techniques, the following study illustrates the interest of an ecosystem-based climate change adaptation approach via wetlands. By doing so, it strengthens a view that is already recognised and encouraged across the world, particularly by the Convention on Biological Diversity (CBD, UNFCCC), and at the Mediterranean level (IUCN, UNEP/MAP).

2. General methodology

2.1. PILOT SITE SELECTION PROCESS

Following a scoping study completed in 2013 (Plan Bleu, 2013), a documentary research allowed to identify 12 Mediterranean wetlands with interesting characteristics for valuation of 4 ecosystem services (i.e. Carbon sequestration, flood control, low water replenishment and coastal protection). This research was based on a literature review and questionnaires (see template in Appendix A), completed by local experts and/or Mediterranean wetland managers.

No.	Site name	Country	Type of environment	Surface area (ha)	Services provided*		
1	Lake Mellah	Algeria	Freshwater lake	870	Flood control	Low water replenishment	No service
2	Lonjsko polje	Croatia	Freshwater river	2,255	Flood control (studied)	No service	No service
3	Burullus Lake	Egypt	Brackish lagoon	41,000	Carbon sequestration (studied)	Coastal protection	Flood control
4	Ebro Delta	Spain	Delta	7,800	Coastal protection (studied)	Flood control	No service
5	Vic coastal lagoon	France	Brackish lagoon	1,900	Coastal protection (studied)	Flood control	Low water replenishment
6	Etangs de la Dombes	France	Freshwater river	35,000 including 4,500 ponds	Flood control	Low water replenishment (studied)	No service
7	Lake Ichkeul	Tunisia	Freshwater to brackish lake	12,600	Flood control (studied)	Low water replenishment	Coastal protection
8	Ghar El Melh	Tunisia	Brackish lagoon	10,168	Coastal protection (studied)	Flood control	Low water replenishment
9	Lake Yeniçağa	Turkey	Freshwater lake	617	Carbon sequestration (studied)	Flood control	No service
10	Lake Akgöl	Turkey	Freshwater lake	2,300	Carbon sequestration (studied)	Flood control	No service
11	Lake Gölhisar Gölü	Turkey	Freshwater lake	800	Carbon sequestration (studied)	Flood control	No service
12	Evros Delta	Turkey	Delta	9,267 – 13,121	Coastal protection	Flood control	No service

* According to existing literature

No service; Carbon sequestration; Flood control; Low water replenishment; Coastal protection; Ecosystem service studied

Table 1: Regulating ecosystem services by order of intensity of the service provided (from left to right)

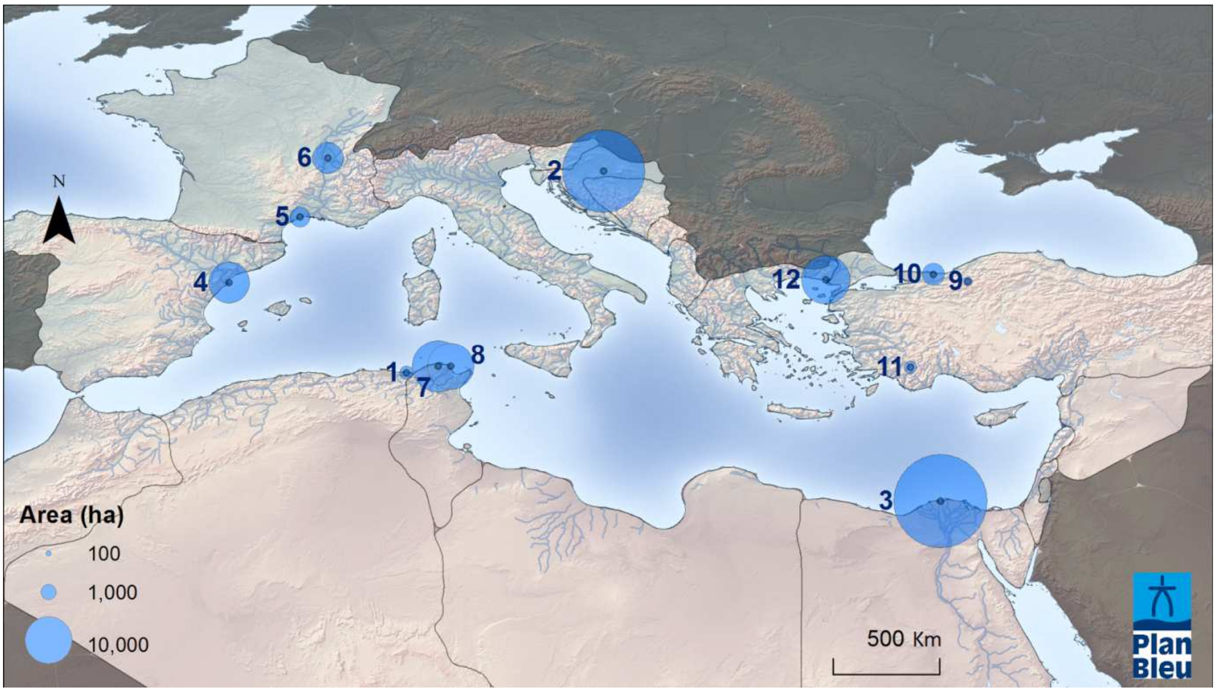


Figure 4: Geographical distribution of the wetlands studied across the Mediterranean Basin

A feasibility study[4] was carried out across twelve ecosystem service / wetland pairs. Eight pairs were pre-selected and submitted to the Med-ESCWET Steering Committee members for a vote (Table 2). The other pairs were eliminated due to a lack of available data (e.g. Lake Mellah in Algeria) or their location at the bottom of a catchment area, of little relevance for the ecosystem service studied (e.g. flood control in Lake Ichkeul in Tunisia).

Pairs proposed for the study and submitted to a Steering Committee vote

Site name	Countries	Services provided
Lonjsko polje	Croatia	Flood control
Lonjsko polje	Croatia	Low water replenishment
Burullus Lake	Egypt	Carbon sequestration
Burullus Lake	Egypt	Coastal protection
Etang de Vic	France	Coastal protection
Ghar El Melh	Tunisia	Coastal protection
Yeniçağa lake	Turkey	Carbon sequestration
Akgöl lake	Turkey	Carbon sequestration

Table 2: List of pairs adopted in the step-by-step selection of wetlands and pairs studied prior to the Steering Committee vote (May 2015)

The vote issued a score of 1 to 8 (1 corresponding to the most highly recommended site and 8 to the least recommended site). Four pilot sites were then selected for the economic valuation of one regulating service as part of the Med-ESCWET project:

- **Vic coastal lagoon (France) for storm protection,**
- **Lonjsko Polje floodplains (Croatia) for flood control,**
- **Burullus Lake coastal lagoon (Egypt) for carbon sequestration,**
- **Yeniçağa Lake peatlands (Turkey) for carbon sequestration.**

The areas selected had already been the subject of well-documented, readily-available studies and the ecosystem services chosen are recognised in these wetlands. Some biological assessments have already been carried out in the past 5 years. The four pairs are very interesting to study with regard to the knowledge of the service in the area in light of the Med-ESCWET project selection criteria and completion timeline. As suggested in the feasibility report, the “low water replenishment” service was set aside as it has been studied far too little, and no relevant study site could be identified.

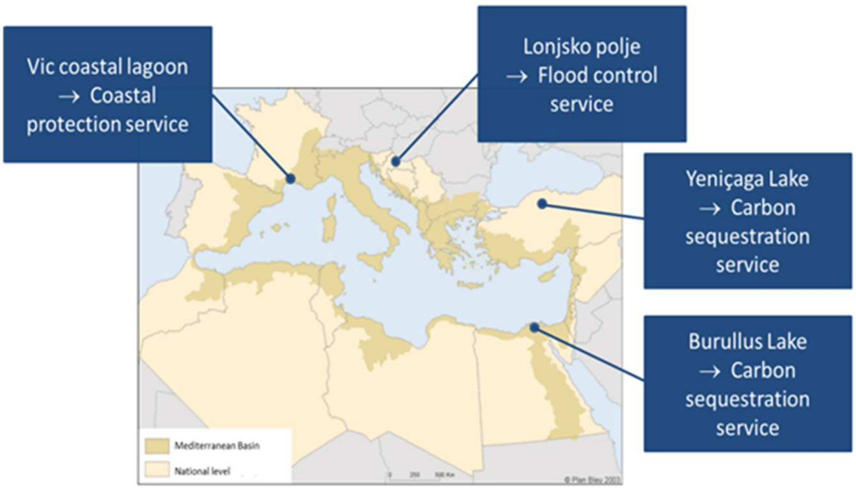


Figure 5: Location of the pilot sites

[4] Available from Plan Bleu upon request

2.2. ORDERED INVENTORY OF THE PANEL OF ECOSYSTEM SERVICES PROVIDED

On each of the pilot sites, an inventory of all categories of ecosystem services was completed using a literature review and online questionnaires sent to local stakeholders.

This inventory lists 13 services, defined according to the **Millennium Ecosystem Assessment classification (2005) in Appendix B**, which determines 3 major service categories:

- Provisioning services, i.e. production by ecosystems of goods consumed by humans;
- Regulating services which are processes that control some natural phenomena, with a positive impact on human well-being;
- Cultural services which offer intangible benefits that humans can enjoy thanks to these ecosystems.

In accordance with the recent proposal for a Common International Classification of Ecosystem Services - CICES (European Environment Agency, 2011), followed by IPBES and other ongoing projects (EFESE, MAES etc.) to assess ecosystem services, the “support services” category previously defined by the French Ministry of the Environment and Sanitation (MEA), no longer appears in guidelines. This category was removed as it leads to some services being counted twice.

In order to more easily present the services as packages, the six provisioning services established by the MEA have been combined into four main services, the regulating services have been reduced to seven (in which all four climate change adaptation services in this study are explicitly mentioned), while the cultural services, which are little developed in most reference documents, have been summarised in two main categories (Table 3).

Provisioning services	Water resources	High-quality freshwater reservoirs are found in the natural environment, which may be suitable for drinking water (groundwater, rivers or wetlands, etc.), for domestic consumption or for farming, energy or industrial production purposes.
	Fishery and aquaculture products	Wetlands such as coastal lagoons and lakes are especially used by communities for fishing or aquaculture.
	Crop and livestock agricultural production	Wetlands are sources of food of plant or animal origin, taken from species used in crop or livestock farming.
	Extraction of materials and other agroresources	Natural environments are sources of materials or substances such as timber and other wood products, fibres and resins, cotton, hemp, rubber, animal hide (leather), etc. They are filled with materials and products that can be used for medicinal purposes. Most molecules in medicines come from plants, animals or micro-organisms.
Regulating services	Global climate regulation	Some natural environments, such as forests and oceans, play an important role in global climate regulation by capturing and storing some atmospheric gases (in particular carbon dioxide).
	Local climate regulation	Natural environments influence the local and regional temperature, precipitation and other climate factors such as cloud cover or humidity.
	Water purification	Some natural environments such as wetlands have filtration and self-purification functions that provide excellent quality water.
	Maintenance of air quality	Some natural environments regulate the chemical composition of the atmosphere thanks to their foliage that traps airborne particles.
	Flood control	Wetlands play an important role in flood control thanks to their capacity for water retention; plant components in ecosystems hold the soils in place.
	Coastal protection	Wetlands play an important role in coastal protection by creating a buffer zone or natural physical barrier against damage caused by storms and flooding.
	Low water replenishment	Some wetlands act as “sponges”, storing water during wet periods and gradually releasing it during dry periods, thereby mitigating the effect of drought and the risk of fire.
Cultural services	Cultural-based services (environmental amenities)	Nature is the source of various cultural activities, based on social relationships, spiritual and religious values, knowledge systems, educational values and cultural heritage, inspiration and aesthetic values, and creating a feeling of belonging.
	Leisure-based activities	Natural environments offer various opportunities for tourism and leisure activities, such as outdoor sports, recreational hunting and fishing, etc.

Table 3: List of 13 ecosystem services selected for the inventory on each of the Med-ESCWET project pilot sites

The panel of ecosystem services provided by all four sites were drawn up by sending an online questionnaire to kick-off workshop participants (Appendix C), with the support of a literature review. For each pilot site, a descriptive report was produced, summarising the ecosystem services identified, the contributing factors, the beneficiaries and the associated pressures: Appendix D for the Vic coastal lagoon, Appendix E for the Lonjsko polje floodplains, Appendix F for Burullus Lake and Appendix G for Yeniçağa Lake.

However, this initial inventory approach is intentionally a summary and is not based on the systematic, quantitative analysis of each service, but instead, primarily on the perception of experts.

The ecosystem services provided by a single site are represented as shown below (Figure 6) to make them easier to visualise.

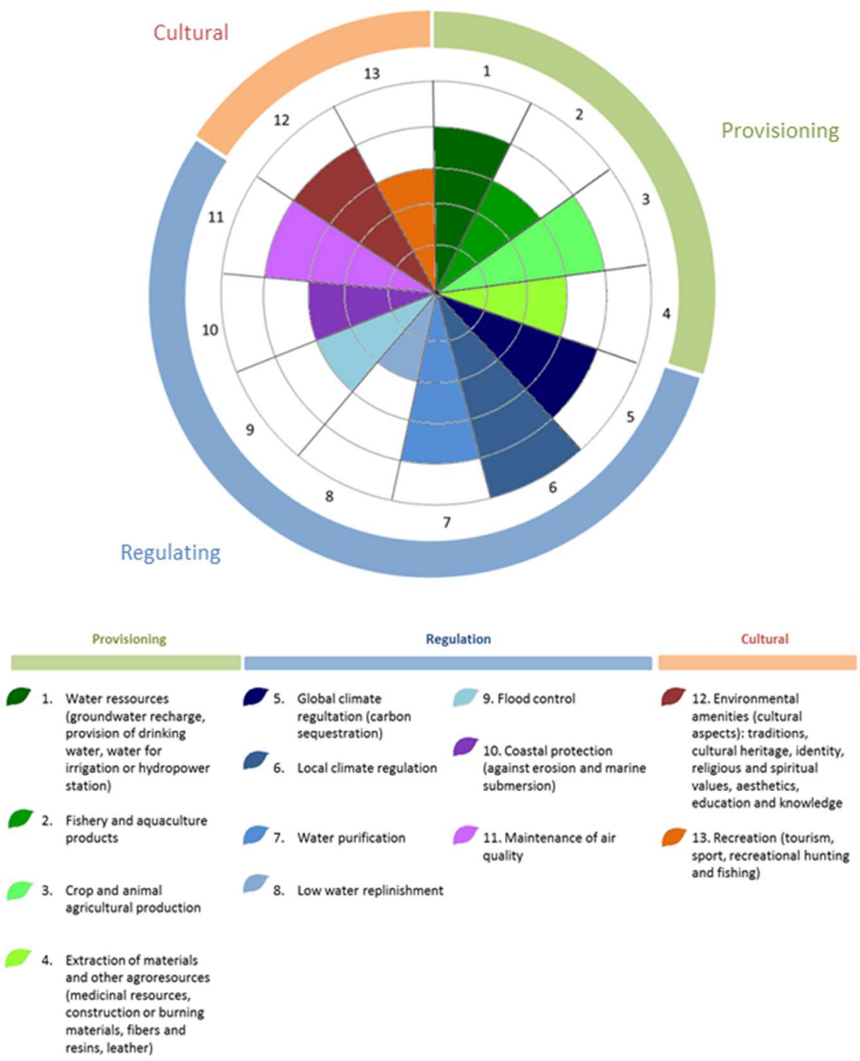


Figure 6: Example of the representation of the panel of ecosystem services and list of the 13 reference services used in this project

The panel of ecosystem services provided was then broken down geographically, and organised according to the different areas on each pilot site studied. In this study, the Ramsar geographical boundaries were used for three of the four sites studied. The last site (Lake Yeniçağa) is not a classified Ramsar site and is described in terms of the bordering peatlands and farmlands. This type of representation is generally organised using existing boundaries (ecoregions, hydroecoregions), isolating regions that share the same dominant physical processes. This is based on criteria combining geology, relief and climate, which are universally considered to be the main determining factors for large catchment areas to function[5]. The scale of the sites considered in the Med-ESCWET project does not systematically lend itself to this type of geographical structuring, which was therefore adapted to the requirements of the study. The areas defined share a common capacity for providing certain ecosystem services.

2.3. BIOPHYSICAL AND ECONOMIC APPROACHES USED FOR THE STUDY

Biophysical assessment

Generally speaking, the biophysical assessment methods used for this study are based on existing, local work and more general methodological data on the type of service or wetland in question.

The project scoping phase carried out in 2013 identified an ecosystem service valuation tool (Invest: Integrated Valuation of Ecosystem Services and Tradeoffs), but it was not possible to get all the data required. An index developed by the Trinidad Institute was also identified for the coastal protection service, but it proved poorly suited to our study as it is especially useful for mangrove and coral reef wetlands which are little present or inexistent in the Mediterranean. In addition, the semi-quantitative nature of this index makes it difficult to assign monetary value to the service, disqualifying it from use in this study. As these methods were not used, other methodological options were pursued for the valuation of the three services in this study:

- For the **coastal protection service**, qualitative analysis of the service was inspired by the index used in the Liteau III "Multidune" project (University of Nantes - LETG - UMR 6554/Géolittomer, 2007) to describe the protective capacity of Atlantic coastal dunes. Quantitative analysis was primarily based on the results of local hydrological modelling conducted by SYBLE (*Syndicat Mixte du Bassin du Lez*) in 2012 (SYBLE, 2012), which compared the surfaces flooded and corresponding volumes during frequent floods (in winter) or extreme floods, with and without the service;
- For the **flood control service**, a hydrology assessment was conducted to determine the dynamics and volume of water which can be stored in the wetland. This volume was estimated using analysis of the hydrographs (flowrates over time) from all available stations in the study area during a recent one-hundred-year flood event (September 2010);
- **The service of climate regulation via carbon sequestration** was considered using pre-existing estimations of the carbon stock in the soils on the two sites studied. For the Turkish site, this value was fine-tuned by combining it with other on-site data or with data calculated for similar environments, whereas for the Egyptian site, the value was adjusted using sequestration rates calculated on site, available in local literature. In Egypt, earth observation techniques developed by Tour du Valat also allowed to calculate the carbon stock in line with recent changes to the ground cover.

Economic valuation

As the feasibility and soundness of the economic valuation are closely linked to the prior biophysical assessment, these two methodological steps were considered together from the start of the study in order to jointly develop the general methodological approach.

Direct indicators or proxies were therefore used for the **biophysical characterisation** of the services studied, **keeping in mind the requirements of the economic valuation step**. The methods planned for assigning monetary value are the approaches most commonly used in the available literature for the type of services studied (Appendix H), and are based on the revealed preference theory. The indirect replacement cost or damage cost avoided methods were applied to value the flood control and coastal protection services respectively, whereas the carbon sequestration service was assessed using the social cost of carbon and carbon marginal abatement cost methods. More specifically:

- During extreme events, the volumes of water retained by a floodplain or coastal lagoon can be expressed in economic terms by the hypothetical cost of construction and maintenance of one or more artificial retention structures that provide a service equivalent to the natural ecosystem. The replacement cost of other more

[5] Bruno Maresca, Xavier Mordret, Anne Lise Ughetto and Philippe Blancher (2011). Évaluation des services rendus par les écosystèmes en France. Les enseignements d'une application du Millennium Ecosystem Assessment au territoire français.

complex aspects, such as the ability to delay flooding or smooth out peak flood flows, may be taken into account, but are more difficult to assess. The main difficulty inherent in this method is to identify infrastructure that is truly equivalent and to conduct the exercise at an appropriate time scale, expressed via the economic notion of a discount rate[6]. In addition, the material damage generated during such events can be quantified and compared to varying degrees of precision with the damage that would have been generated without the protective service provided by the wetland. This is known as the **damage cost avoided** method, which is used to determine the damage prevented by the presence of a given area.

- The service of climate regulation by carbon sequestration is more theoretical than the previous services. The size of the carbon stock recorded represents a "carbon capital conservation" service and the annual benefits of an equivalent capital are generally estimated by its value on the carbon market. However, where this market exists, there are significant disparities between countries (Appendix I) and choosing a consistent discounted value at a relevant time frame is one of the difficulties of the exercise. In order to improve understanding, this stock can be linked to a more comprehensive review of the wetland in terms of greenhouse gas emissions

[6] During economic valuation of ecosystem services, it is common practice to discount annual values. The application of a discount rate seeks to take into account time preferences. Individuals generally prefer to receive the benefits as soon as possible while delaying the costs. A discount rate "gives weighting to the benefits and costs occurring in different time periods" (Barbier, *et al.*, 1997). The discount rate is chosen in accordance with the circumstances of the study.

3. Description of the four pilot sites selected

3.1. VIC COASTAL LAGOON, FRANCE

- **Local climate change context**

In 2011, ADEME (French Environment and Energy Management Agency) collaborated with Meteo France to publish an inventory of indexes for climate change observed in Languedoc-Roussillon for over 100 years. An overall increase in the maximum, mean and minimum temperatures was observed for most seasons right across the region. However, the conclusions for precipitation are less clear with relatively stable seasonal and annual rainfall (ADEME, 2014).

No increase in the number or intensity of sea storms was observed across the study area. Work carried out by the Joint Research Unit Geosciences (Montpellier University) and the results of the multi-disciplinary MISEEVA project (BRGM, 2011) demonstrate that the increased risks for the population appear to be more closely linked to the sector's growing vulnerability (population growth) rather than the nature of the risks it is facing.

Despite local uncertainty with regard to increasing changes to storm activity due to climate change, many swells and storms were recorded in Languedoc-Roussillon between 2003 and 2014[7]. In addition, the Vic coastal lagoon is located in a sector exposed to intense rainfall phenomena, which often occur in late autumn and are almost always accompanied by sea wind, which can cause severe flooding. Some of the most violent torrential rain events observed in the Hérault department include the ones in November 2007 (see photos below) and September 2014, which caused significant damage along the coast. The 2014 episode, in particular, led to a state of natural disaster being declared in some towns close to the study site (Villeneuve-lès-Maguelone and La Grande-Motte) due to the damage caused following the flooding and physical shocks associated with storm waves[8].

Figure 7: Situational comparison of a small swell in October 2006 (left) and during the storm of November 2007 (right) along the Palavas-les-Flots coastline (Hérault, France) (Source: EID & DRE, 2007)

- **Added value of the study**

The hydraulic function of the Palavasian lagoons during flooding and/or sea storms is still little understood and had never been specifically studied in this sector prior to the study conducted by the *Syndicat du Bassin du Lez* in 2012 (SYBLE, 2012).

[7] See the storm reports available on the DREAL Languedoc-Roussillon-Midi-Pyrénées website

[8] EID and DRE Languedoc-Roussillon, 2007 - *Analyse de la tempête marine sur le littoral Languedoc-Roussillon du 19 au 22 novembre 2007*

- **Site description**

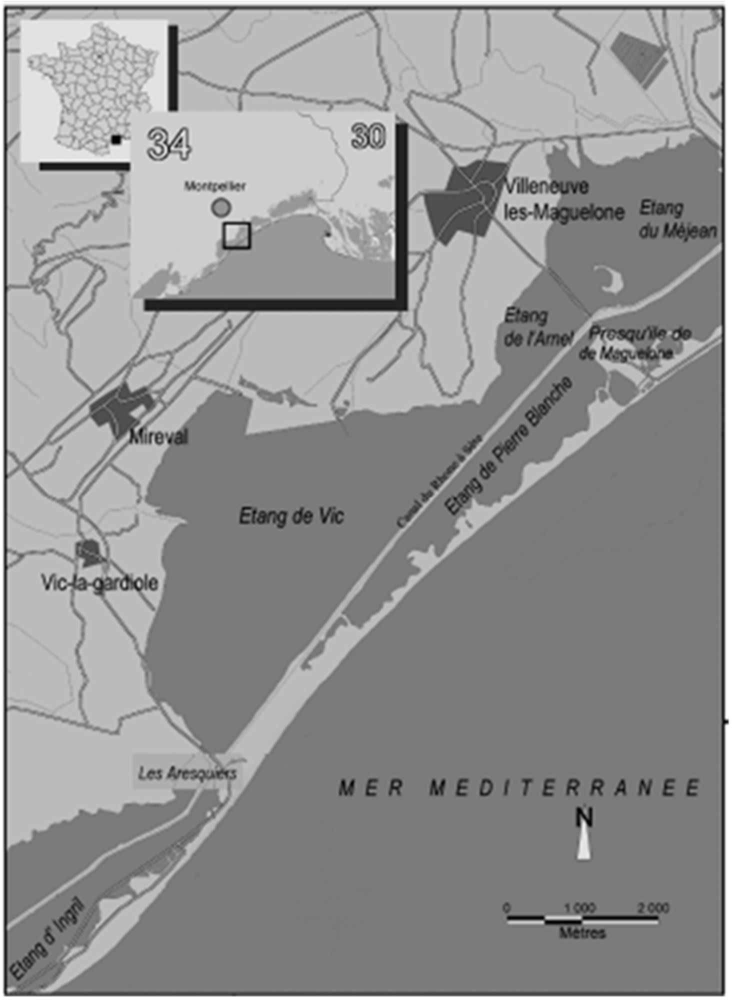


Figure 8: Location of the Vic coastal lagoon (« Étang de Vic »), France (source: Durand et Heurtefeux, 2006)

The Vic coastal lagoon is an approximately 1,900 ha lagoon along the French Mediterranean coastline. It is part of the Ramsar and Natura 2000 "*étangs palavasiens*" (Palavasian lagoons) site and stretches across four towns along the Hérault coast: Vic-la-Gardiole, Villeneuve-lès-Maguelone, Mireval and Frontignan. After the *Canal du Rhône à Sète* was built in the early 17th century, the lagoon complex was divided into different ponds connected via a system of connecting channels. Etang de Vic has no direct, permanent link to the sea and is primarily supplied with brackish water from this canal. The various parts of the site are managed by the *Syndicat des Étangs Littoraux* (SIEL), Thau inter-council partnership, the *Conservatoire du Littoral* and the Languedoc-Roussillon-Midi-Pyrénées *Conservatoire des Espaces Naturels* (Salines de Villeneuves). This site was once home to salt production activities and is now associated with uses such as hunting, traditional fishing, recreation and tourism. Its natural environment has been preserved thanks to limited urbanisation, supported by the presence of the *Conservatoire du Littoral* across most of the site. The sandbank separating the lagoon from the sea is the only sandbar in the Hérault department that has not been subject to development or urbanisation. The site is home to diverse natural habitats suited to many species, particularly migratory birds. The main threats associated with the site are water quality and the regression and fragmentation of the sandbar and its dune ridge.

- **Overall panel of ecosystem services provided**

The Vic coastal lagoon provides regulating services, particularly coastal protection, provisioning services and cultural services, including environmental amenities (traditional fishing, landscapes, birdlife) and leisure activities. The stakeholders questioned had a relatively similar perception of the various services provided.

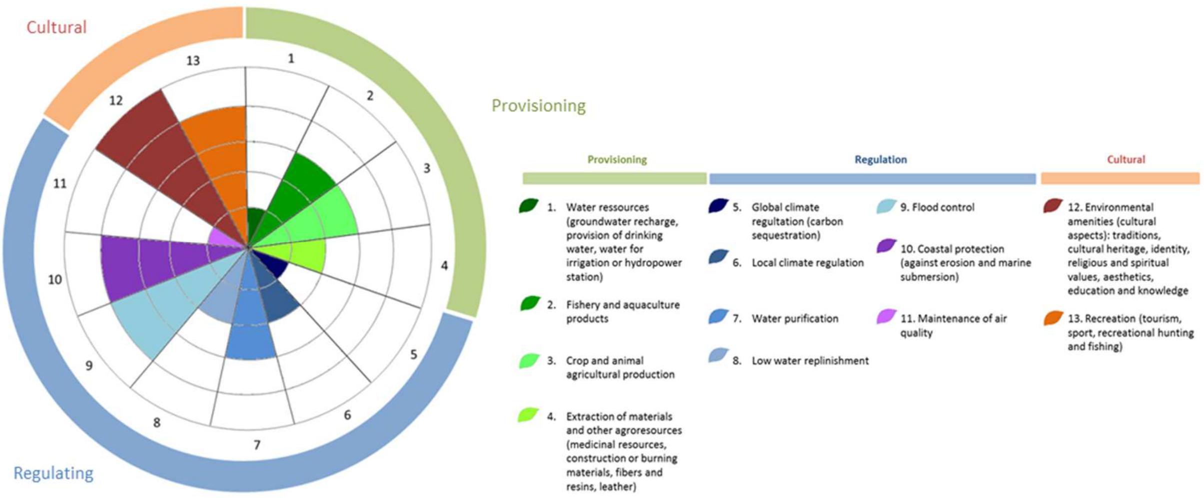


Figure 9: Overall panel of ecosystem services provided by the Vic coastal lagoon

- **Sector-specific panel of ecosystem services provided**

On the basis of the three main lagoon sectors defined in the Etang de Vic management plan (Conservatoire du Littoral, 2014), extended to the entire Ramsar site, three areas were defined to describe the services provided by the site: a permanent water area (lagoon, former saltmarshes, connecting wetlands), a peripheral area next to the wetlands (primarily viticulture and orchards) and the sandbar area. The three resulting panel of ecosystem services are shown below.

The three areas described play an important role in terms of environmental amenities: the banks are a place for walking and hiking, the sandbar is a seaside resort and the lagoon is home to traditional fishing activities, supporting rich biodiversity that contributes to the site's quality landscapes. The natural dynamics of the sandbar and limited development of the northern banks strengthen the coastal protection provided by the site. The peripheral areas are especially used for agricultural purposes (viticulture, orchards) whereas the lagoon sector offers a greater diversity of services (water purification, flood control, local climate regulation).

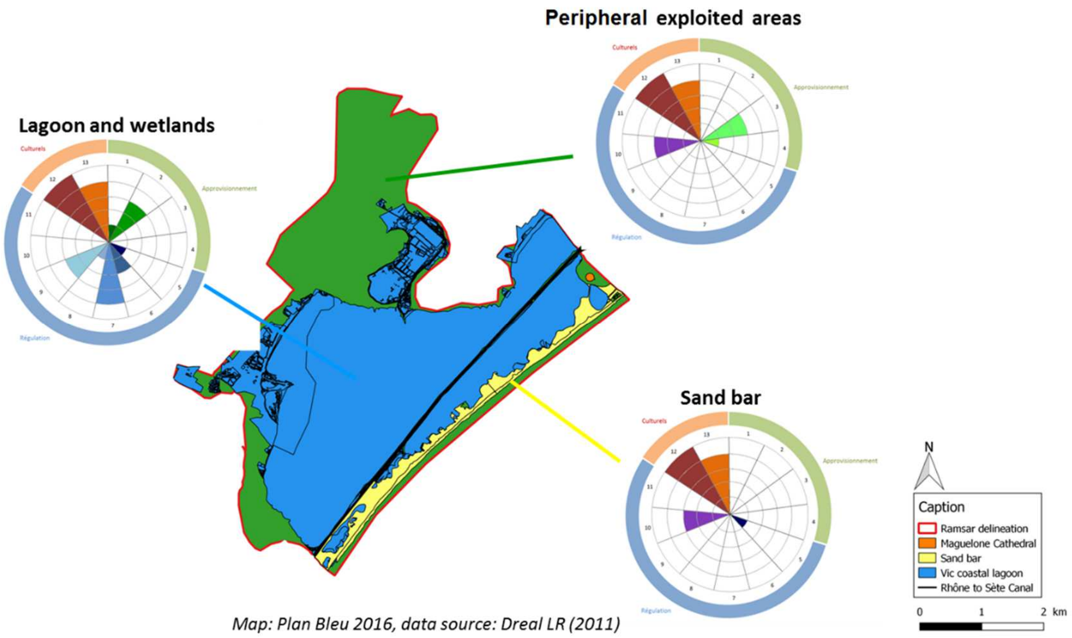


Figure 10: Geographical distribution of the various ecosystem panels of ecosystem services provided across Etang de Vic lagoon (source: Plan Bleu, 2016; GIS data: Dreal LR, 2011)

3.2. LONJSKO POLJE FLOODPLAINS, CROATIA

- **Climate context**

In recent years, a significant increase in the frequency and intensity of flooding phenomena has been observed in Croatia, particularly in the Sava River Basin (Babic, 2015). All reports into the impact of climate change in this basin predict an increase in these events in the future (Brilly, *et al*., 2015). A climate change adaptation plan has consequently been drawn up for the Sava Basin (World Bank, 2015).

- **Site description**

Lonjsko Polje Nature Park (LPNP) is located in the Central Sava Basin. The site is one of the last in Europe to have retained a relatively natural alluvial plain with great biodiversity. The Central Posavina flood defence system is one of the main examples across the world of flood protection based on the use of a natural floodplain, known internationally as the “room for the river” strategy.

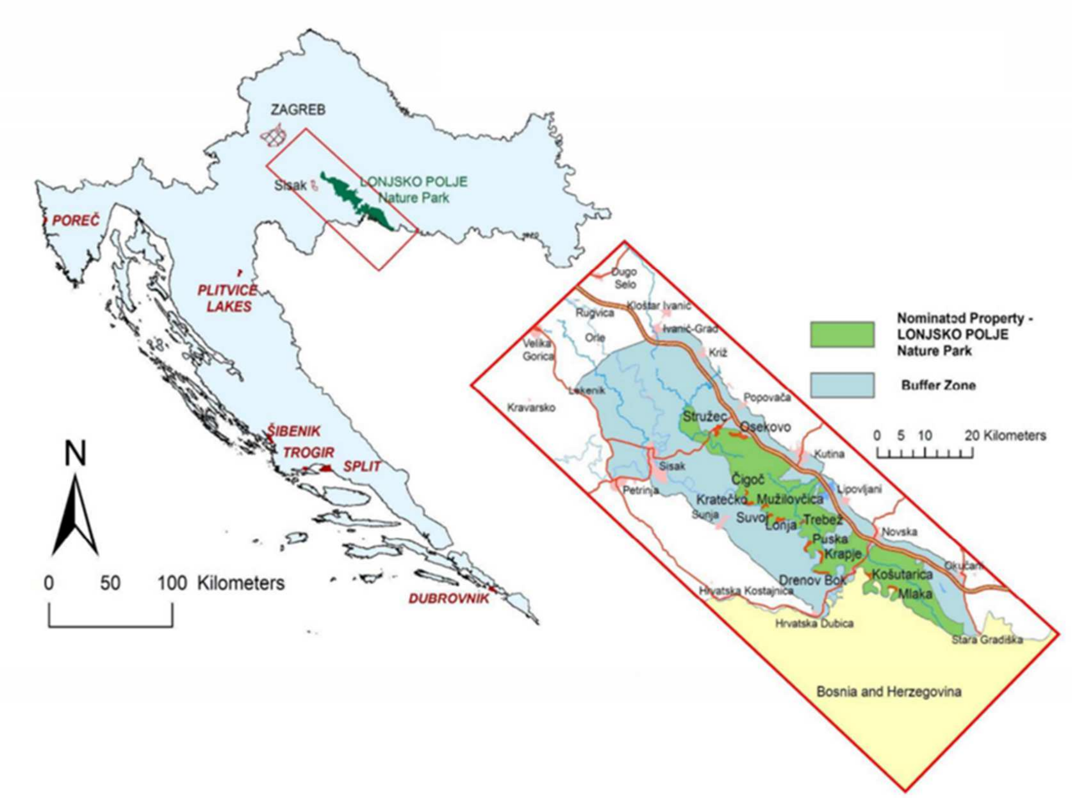


Figure 11: Location of Lonjsko polje Nature Park in Croatia and the flood protection buffer zone (source: Lonjsko polje Nature Park)

- **Overall panel of ecosystem services provided**

According to the experts questioned, the site as a whole offers a wide range of ecosystem services (Figure 12). Its role in protecting against extreme climate events is especially important for flood control as flooding in the Sava plain is very frequent and intense. It also provides local populations with various resources (drinking water, wood, fish, etc.). Furthermore, its state of preservation and heritage value make it an especially interesting site from a cultural perspective: educational services (contract with school, training courses, awareness campaigns) and recreational services (tourism promotion) are developed by the site manager. The experts state flood control to be the main service. Other services, such as agriculture, fishing, water resources, global climate regulation and water purification were also frequently mentioned in the questionnaires. Perceptions are more varied for some regulating services, such as maintenance of air quality and local climate regulation, probably as they are more difficult to assess (poor understanding of underlying functions) and their estimation requires special expertise.

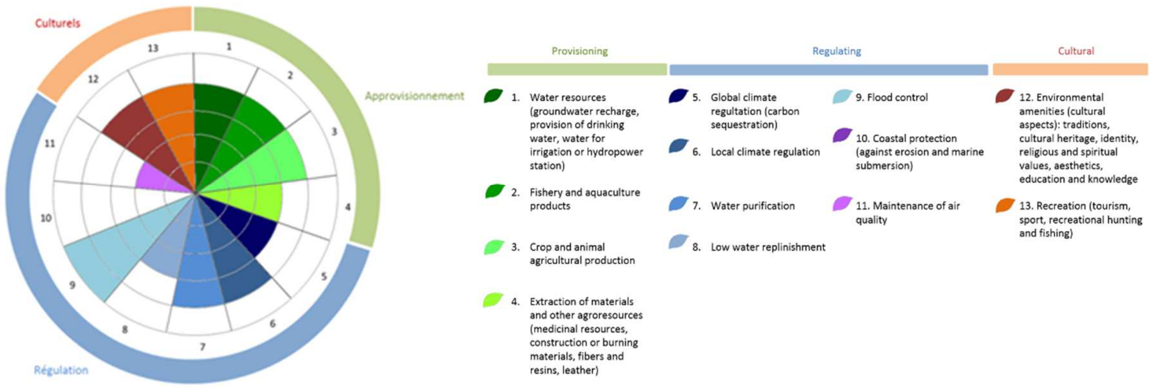


Figure 12: Global ecosystem services provided by Lonjsko polje floodplain

- **Sector-specific panel of ecosystem services provided**

Lonjsko polje Nature Park offers various types of cultural services in each of the defined areas:

- on the one hand, the site's heritage value is found in rural areas with traditional livestock farming (local domesticated species) and traditional wooden dwellings (Krapje village and also Čigoč village which belongs to the European Stork Villages Network).
- on the other hand, the natural landscape boasts the largest complex of preserved alluvial forests in Europe, thereby contributing to the site's unique identity and its invaluable landscapes and biological diversity. Recreational fishing and hunting activities are regulated on the site, which is visited for cultural or outdoor tourism, with a major educational focus.

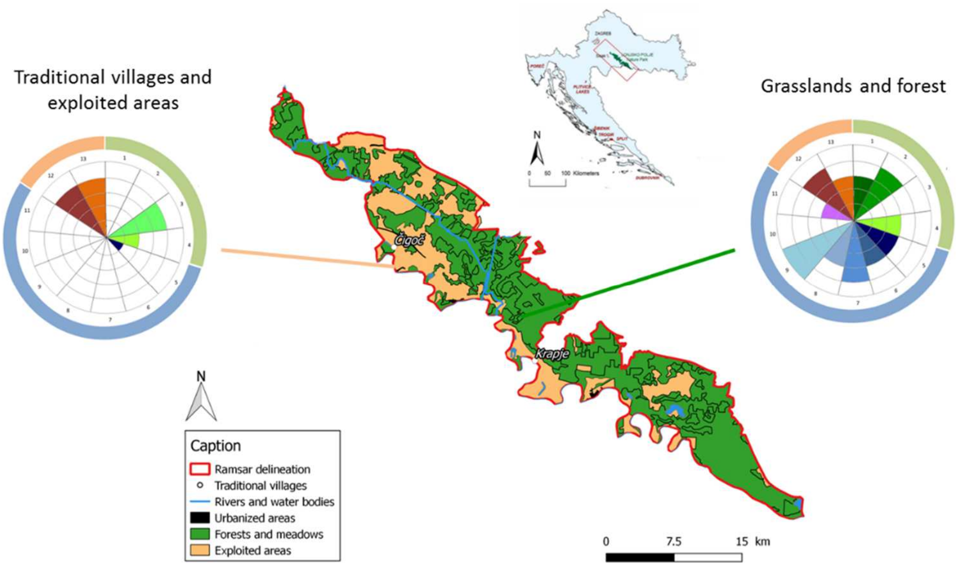


Figure 13: Geographical distribution of the various ecosystem services provided across the Lonjsko polje floodplains (source: Plan Bleu 2016, GIS data: Sava Life project 2009)

The natural areas are more associated with the regulating services and the floodplain, in particular, has been developed to optimise flood control, based on the natural retention capacity of a number of successive basins. These retention areas not only support flood control, but also contribute to water purification and groundwater replenishment. Forest covers around 70% of the site and also contributes to groundwater purification and carbon sequestration. Finally, the two types of areas defined supply complementary resources in terms of drinking water, granular materials (gravel), wood (primarily oak, which has great economic value) and fish.

3.3. BURULLUS LAKE, EGYPT

- **Local climate change context**

According to the Intergovernmental Panel on Climate Change (IPCC), the Nile Delta region is one of the areas in the world most affected by the impacts of climate change (El Adawy, *et al*., 2013). In the future, Egyptian coastal areas will be especially affected by an increase in the number and intensity of extreme events (sand storms, heatwaves, sea storms) (Osberghaus & Baccianti*,* 2013).

- **General description**

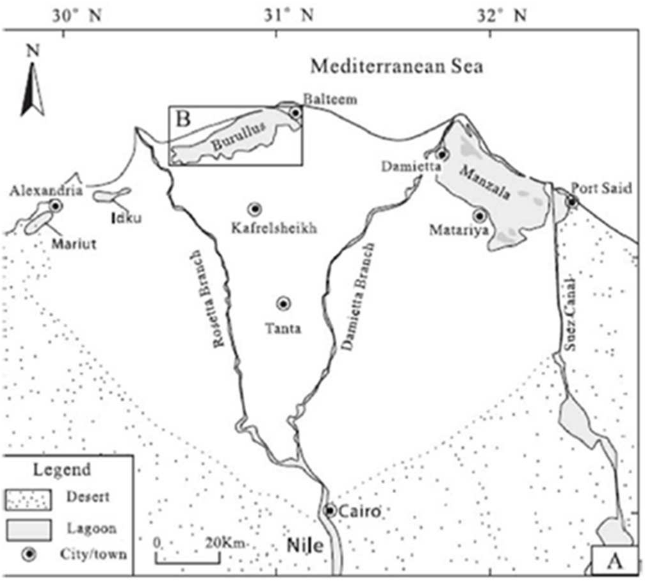


Figure 14: Location of Burullus Lake, Egypt (source: Zingstra, 2013)

Burullus Lake is located to the north of the Nile Delta and stretches for 65 km along the Egyptian coast, west of the Baltim region. An estimated 185,000 people interact with the lagoon daily, which is an important fishing and aquaculture site for local populations and a migration stopover for many bird species. Burullus Lake has a surface area of 41,000 hectares within a protectorate recognised by the Ramsar Convention and stretches across 5 districts. The site is primarily used as an outfall for surrounding agricultural water, which constitutes 90% of its water inflow. This leads to problems with pollution, plant proliferation and desalinisation, which impact populations and aquatic biodiversity.

- **Overall panel of ecosystem services provided**

Burullus Lake primarily offers provisioning services by providing significant fish resources, and indirectly, aquaculture resources (water and fry for external pools). Fishing is a vital activity for the local population, but aquaculture generates twice as many fish, with a significant impact on the environment. The protectorate only includes a small area of farmland, although agriculture is very well established around the site. Nevertheless, the area described can be considered to provide a very important service for this use, not through a direct contribution to agricultural yield, but via its use as an overflow for agricultural water.

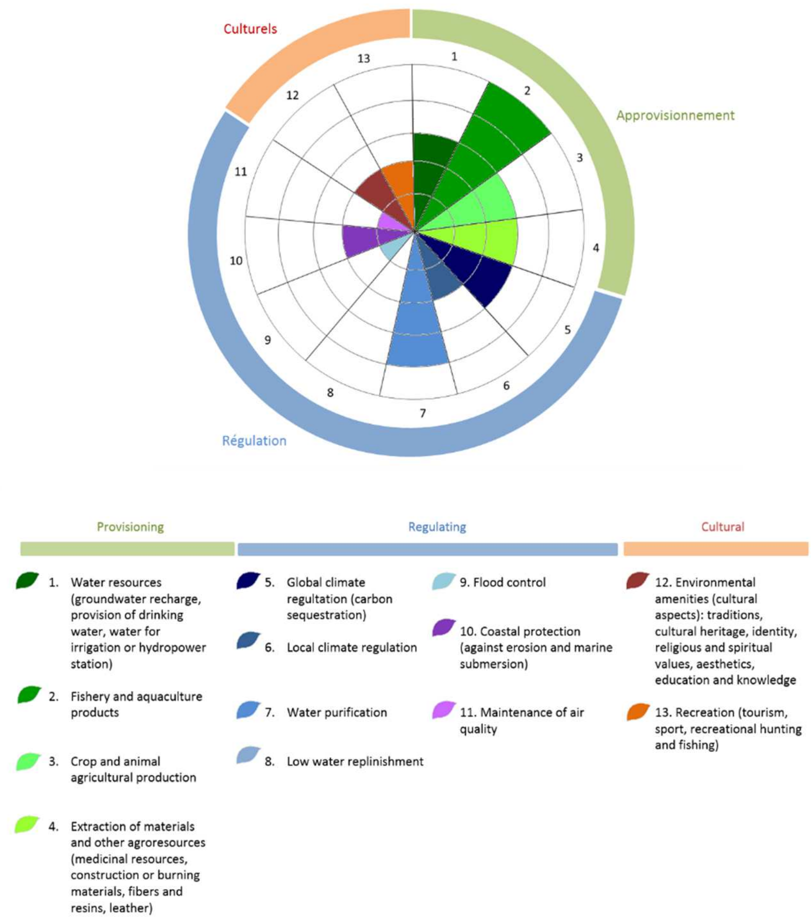


Figure 15: Overall panel of ecosystem services provided by Burullus Lake

The coastal protection service is one of the local priorities in terms of climate change adaptation, although the Aswan Dam upstream on the Nile has considerably weakened this service by contributing to the subsidence of the delta. The flood control service is now very weak due to over-filling generated by the inflow of agricultural water. The site also has significant cultural aspects and a tourism potential that remains largely underdeveloped.

However, stakeholder opinions are split concerning the water supply, agriculture and water purification services. These differences in perception can be explained by the interpretation of water supply as meaning drinking water, the belief that agricultural activity is primarily located around and not inside the protectorate, and the contrast between the theoretical role played by the reed marsh in water purification and the poor water quality observed.

It is important to note that the ecosystem services recorded in this specific case are provided by a considerably degraded site. Overexploitation of the ecosystem has a negative influence on most functions provided by the wetlands, although some processes such as carbon sequestration are supported by the site's overproduction.

- **Sector-specific panel of ecosystem services provided**

Burullus Lake was sub-divided into three areas, as shown in Figure 16: the sandbar (yellow), the lagoon and wetlands (blue) and farmlands (green).

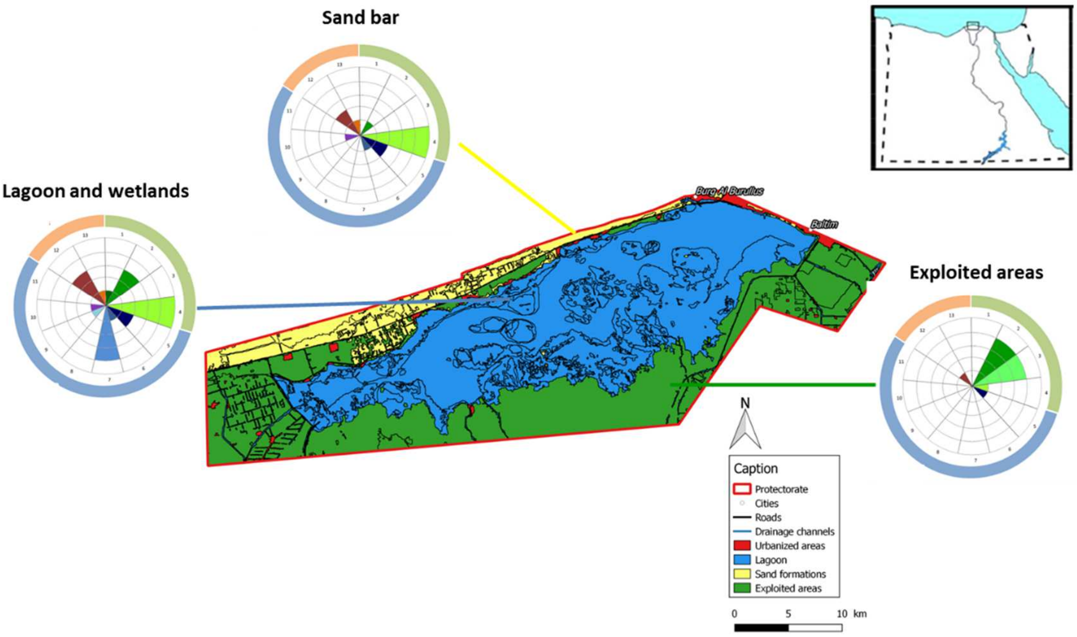


Figure 16: Geographical distribution of the panel of ecosystem services provided across Burullus Lake (source: Plan Bleu, 2016; GIS data: Tour du Valat-OZHM, 2015)

Sandbar

This area has an untapped potential in terms of environmental amenities (6 listed historical sites, including some buried under the dunes) and leisure activities, which are impeded by the sandbar becoming increasingly artificial (recent road construction, over-farming of land for aquaculture and agriculture, plans for a power plant, urbanisation and the associated pollution). The El Boughaz channel to the east of the sector is the sole connection with the sea, although exchanges are very limited by the inflow of agricultural water on the site, which impedes the flow of sea water into the lagoon, thereby impacting the site's biodiversity. The coastal protection service theoretically provided by the sandbar is weakened by the reduced sediment deposits since the construction of Aswan Dam in the 1960s. In this area, coastal marshlands are gradually converted into salt pans, aquaculture pools and agricultural plots, but the rare remaining natural areas in the Baltim dunes region are home to important on-land animal and plant biodiversity.

Farmlands (excluding the sandbar)

The south of this sector mainly contains areas used for aquaculture, whereas agriculture dominates the west of the protectorate. Farmlands contribute to carbon sequestration, but not as much as the lagoon's sediment compartment.

Lagoon

In terms of water supply, the water quality in the lagoon is not suitable for consumption, but it is the exclusive source for the constantly expanding aquaculture pools around the lagoon. Nevertheless, the site has a significant salinity gradient and the freshest water located to the west of the lagoon is used for irrigating the sector's few agricultural plots.

The lagoon's islands offer rich biodiversity, as they are exempt from human presence. The lagoon's landscape only makes a small contribution to environmental amenities due to the pressure generated by its increasing anthropisation. The site is home to one of the largest reed beds in the Mediterranean, which helps provide regulating services such as water purification and carbon sequestration. However, overexploitation on the site reduces these capacities, along with flood control, which used to be significant. Before the construction of the Aswan High Dam, the lake received the Nile floods in late summer and autumn[9].

[9] Medwet Culture website http://www.medwetculture.org/wetland_items/burullus/

3.4. YENIÇAGA PEATLANDS, TURKEY

- **Context of climate change**

In the future, temperatures are set to rise right across Turkey in all seasons. In winter, this increase will be greater in eastern Turkey, whereas in summer, the west and especially south-west will witness the biggest temperature rises. The Aegean Region will face mean temperatures 6 degrees higher than current temperatures. Forecasts show that between 2071 and 2100, the mean annual temperatures across the area will rise by approximately 2-3°C compared to the 1961-1990 period (taken from Osberghaus & Baccianti, 2013).

- **Description**

The Yeniçağa peatlands are located around Lake Yeniçağa in the rural Bolu province. These minerotrophic peatlands[10] were the largest peat production site in Turkey until 2009, when a protection project[11] stopped production on the west of the site and greatly reduced it in the north. The site supports a wealth of biodiversity and has a strong fishing potential, used by local fishermen. The outflow that empties into Çağa Creek to the north-east of the lake (Figure 17) provides regulation by guaranteeing a certain water level in summer when two of the lake's tributaries dry up. The peatlands to the west and north-west of the lake are flooded intermittently depending on the water level.

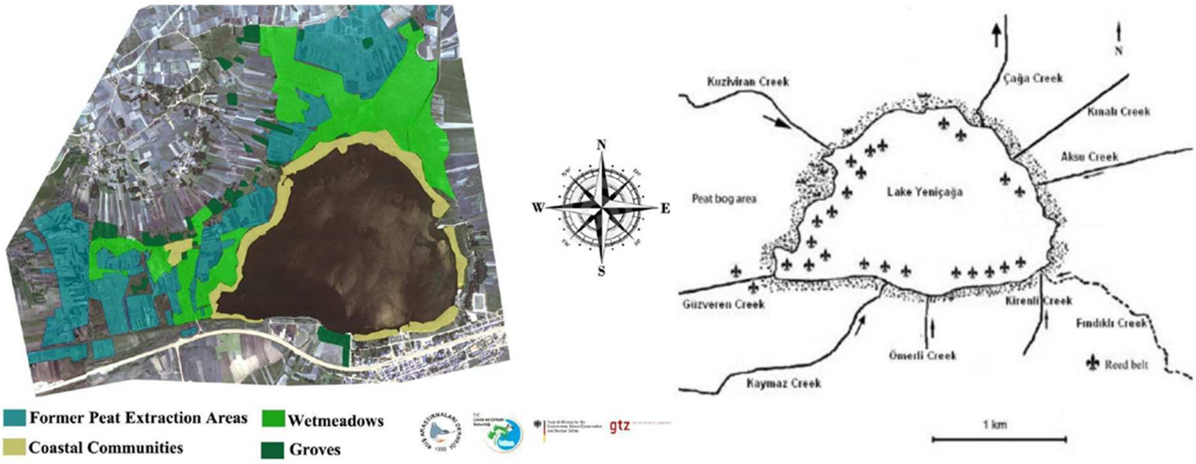


Figure 17: Main tributaries and outflows in Lake Yeniçağa (*Doga Koruma Merkezi Nature Conservation Center, 2012*)

- **Overall panel of ecosystem service provided**

The efforts made to restore the site have helped its transition from uses centred on peat extraction to optimising its tourism potential, while helping mitigate climate change by reducing the greenhouse gas emissions associated with peat extraction.

The perception of the experts questioned testifies to this context as the main service is perceived to be global climate regulation. According to the responses, the site provides a number of important and equivalent services (e.g. cultural services, water resources, climate regulation, water purification), but it has a weaker contribution to maintaining air quality, livestock farming and the production or extraction of agroresources.

[10] "Low-moor" peatlands are supplied by groundwater, catchment area run-off or freshwater sources (as opposed to ombrotrophic or "high-moor" peatlands, which are supplied by precipitation.)

[11] *Wetlands and climate change project*, Turkish Ministry of Environment and Forestry, 2009 to 2011.

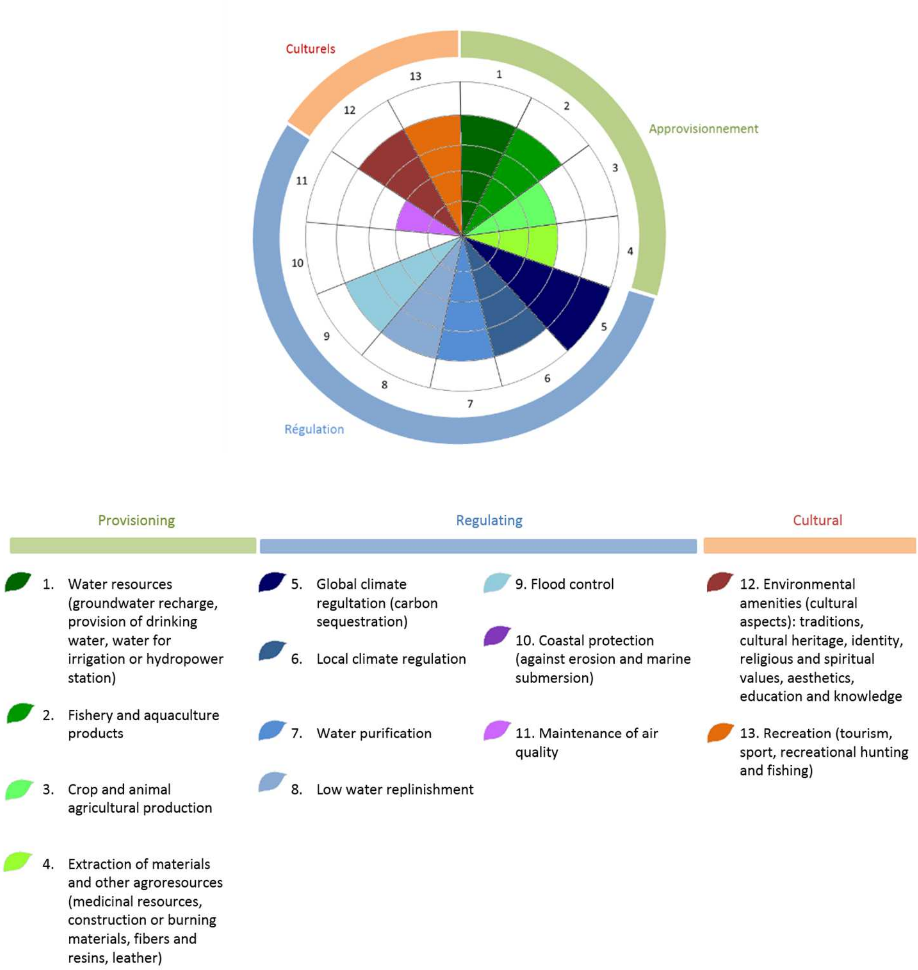


Figure 18: Overall panel of ecosystem services provided by Yeniçağa peatlands

- **Sector-specific panel of ecosystem services provided**

The peatlands along with the lake's overflow system, which works autonomously depending on the water level, help mitigate drought (local climate regulation) and regulate flooding.

The global climate regulation service of carbon sequestration is primarily provided by peat grasslands that have never been exploited, although a smaller percentage is contained in the lake's sediments and vegetation.

The lake helps provide water and fish resources, and contributes to water and landscape quality (reeds provide purification and birdlife support), making the site more attractive for the local population. The lake is also home to recreational activities (swimming, recreational fishing) and the peat grasslands offer a special habitat for some bird species such as the common crane.

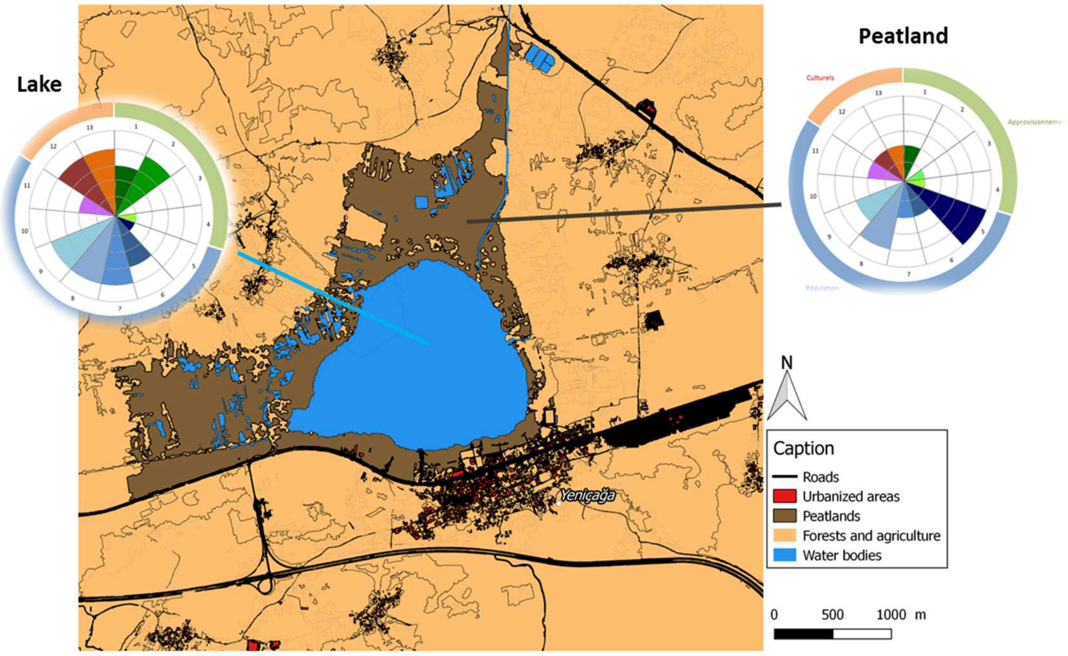


Figure 19: Geographical distribution of the panel of ecosystem services provided across Yeniçağa peatlands (source: Plan Bleu 2016; GIS data: Tubitak Project no. 109Y186)

In conclusion, this organised inventory of the ecosystem services provided by the project's four pilot sites demonstrates the various situations with regard to the sites' level of anthropisation and management methods:

- Degraded and weakened cultural and regulating services in overexploited areas, in favour of provisioning services, for example in Burullus Lake in Egypt;
- Successful integration of human activities in the landscape, which promotes many services, such as cultural services and flood control on the Lonjsko Polje site in Croatia, or the application of a non-interventionist coastline management strategy that favours coastline mobility in the Etang de Vic coastal lagoon;
- Transition of an area which was long used for peat extraction towards a protected area where recreation and regulating services are promoted, for example on the Yeniçağa site in Turkey.

4. Valuation of the storm protection service, Vic coastal lagoon (Hérault), France

The aim is to assess the coastal protection service provided by the wetland in its current state compared to a theoretical situation where the service is not available. This service has three components: protection from erosion, from rising water and from land flooding. The overall contribution of these elements to the coastal storm protection service is quantitatively estimated with two storm scenarios. The economic value of the coastal protection ecosystem service provided by the area was then considered using the Damage Cost Avoided Method.

4.1. CHOICE OF STORMS SCENARIOS

The choice of scenarios was based on various constraints associated the site characteristics. **Storms regularly occur at the same time as very high water on inland water courses** (extreme rainfall events known as *épisodes cévenols*), which make it difficult to differentiate between the protection provided from flooding associated with sea storms and from flooding associated with high waters.

After reviewing the available literature, it would seem that two scenarios from the "*Etude du fonctionnement hydraulique du complexe 'étangs palavasiens – étang d'Ingril – étang de l'Or' en situation de crue et de tempête marine*" study carried out by the *Syndicat Mixte du Bassin du Lez* (SYBLE)[12] can meet these constraints[13]. There are two advantages of selecting these scenarios. Firstly, they are both based on low catchment area flood levels (two-year return period). The impact of these floods is therefore weaker than that of the sea storms considered in this study. The impacts specifically associated with the storm can therefore be identified by comparison. These two scenarios (Table 4) show a low-intensity flood at a fixed frequency (two-year return period) with sea storms of variable intensity (two-year and one-hundred-year return period).

Scenario A is a frequent (biennial), low-intensity storm combined with a frequent flood with a two-year return period.

Scenario B is an exceptional (one-hundred-year) high-intensity storm combined with a biennial flood, which remains slight (frequency identical to Scenario A).

Scenario	Flood return period	Coastal storm return period	Initial lagoon level	Maximum lagoon level	Flooding of peripheral areas
A	2 years	2 years (0.8 m ODN) frequent storm	0.1 m ODN	0.56 m ODN	No flooding of critical areas
B	2 years	100 years (1.5 m ODN) exceptional storm	0.1 m ODN	0.88 m ODN	Flooding for approx. 3 hours

Table 4: Scenarios adopted for estimating the coastal storm protection service (ODN: French benchmark metres above sea-level)

4.2. BIOPHYSICAL ASSESSMENT OF THE COASTAL STORM PROTECTION SERVICE

In order to assess the coastal storm protection service provided by the ecosystem, each of the two scenarios adopted was broken down into two assumptions.

In the one case, the real behaviour of the environment is considered, where the elements contributing to the coastal protection service effectively play their role. In this instance, the water levels modelled for the study area as part of the SYBLE study (EGIS Eau, 2012) are used.

[12] EGIS Eau, 2012 - Phase 2 report, scenarios no. 1 and no. 13
[13] These case studies focus more on flood patterns rather than coastal storms, which is the opposite to what we are seeking to expand upon in this report.

In the other case, the event in which the ecosystem does not play its storm protection role is considered. This second assumption supposes that the sandbar is fully open to sea inflow across its entire width and that the lagoon peripheral areas (wetlands, canal banks, farmland) are inactive with regard to the service in question (in other words, offer no resistance to rising water or flooding). Sea water would therefore easily penetrate inland without physical slowdown or ground infiltration. In concrete terms, we consider the water level flooding the study area to be equal to the maximum sea level reached during the event.

Table 5 summarises the scenarios studied according to these assumptions.

Scenario	Assumption	Maximum sea level	Maximum flooding level
A	Effective ecosystem protection	0.80 m ODN	0.56 m ODN*
A'	No ecosystem protection	0.80 m ODN	0.80 m ODN
B	Effective ecosystem protection	1.50 m ODN	0.88 m ODN*
B'	No ecosystem protection	1.50 m ODN	1.50 m ODN

* Results taken from modelling in Phase 2 of the SYBLE study (EGIS Eau, 2012)

Table 5: Scenarios and assumptions for valuation of the storm protection service

For each scenario, the water level reached (elevation in ODN metres) is subtracted from the altitude provided by a digital elevation model (DEM) for the study area. This approach can determine both the flooded surfaces and the water levels flooding each area before calculating the volumes of water penetrating inland.

The difference in surface areas and volumes between Scenarios A' and A provides the estimated flooded surface areas and volumes of water avoided thanks to the protection provided by the ecosystem for a frequent storm (two-year return period).

Similarly, the difference between Scenarios B' and B provides the estimated flooded surface areas and volumes of water avoided thanks to the protection provided by the ecosystem for an exceptional storm (one-hundred-year return period).

4.2.1. Sequential description of a storm and natural protective elements

a) Storm description

In calm weather, before a coastal storm arrives, the Etang de Vic (1,355 ha) and Etang de Pierre-Blanche (231 ha) lagoon system is separated from the sea by the closed sandbar. Water circulates indirectly between the sea and the lagoons via the *Canal du Rhône à Sète* whose various side channels provide communication between the lagoons. The lagoons located at both ends of the lagoon complex (Etang du Prévost in the east and Etang d'Ingril in the west) are in direct contact with the sea via permanent artificial channels, with temporary natural channels forming on the Etang de Pierre-Blanche sandbar. The flow depends on the relative water levels between the sea and the lagoon and on the circulation generated by the wind. When the ecosystem experiences a coastal storm, the dynamics follow the sequence described below, which is summarised in Figure 20.

<u>Start of the storm</u>

The traditional weather pattern generating a storm in this area is the arrival of a depression with strong southerly or south-easterly winds (blowing from the sea inland), along with relatively heavy rains, leading to a risk of high water on inland water courses (an *épisode cévenol* heavy rainfall event) at the same time as the sea storm.

The wind and depression raise the sea level. The swell from the high seas and the waves generated locally by the wind create an additional storm surge, impacting the beach and the rest of the sandbar (dune and backdune) if there is sufficient energy.

While the sandbar remains closed, water indirectly circulates between the sea and the lagoons via the canal and side channels towards the Etang d'Ingril, Etang d'Arnel and Etang de Prévost. The high sea level limits water outflow via the canal. The sea water entering the lagoons increases the water level. In the event of simultaneous high water on inland water courses, outflow towards the sea is limited by the high sea level and corresponding sea winds that push back water from the two artificial channels (Etang de Prévost and Etang d'Ingril) at their mouth. The freshwater inflow contributes to increasing water levels in the lagoon. The lowest-lying peripheral areas begin to flood and if the water level reached is high enough, the freshwater or brackish waters from the northern lagoon can submerge the canal towards the southern lagoon.

Sandbar breach and overwash

If the energy of the storm waves is sufficient, a breach and then a channel can form in the coastline. Openings occur in the most fragile areas characterised by a limited sandbar width, an altitude often lower than 1 m ODN and no or chaotic dunes with no or reduced vegetation.

Once a channel has been opened, the lagoon directly communicates with the sea. Sea water and the sediments it transports enter the lagoon (phenomenon of overwash or washover), contributing to the rising water level. The current travelling through the channel subsides at the lagoon entrance and deposits sediments taken from the sea and sandbar. The storm intensity and relative water levels between the sea and lagoon influence the size of the overwash deposit (i.e. distance from the coast and lateral dispersion).

Sea water mixes with the Etang de Pierre-Blanche lagoon water before crossing the canal via side channels to enter into Etang de Vic. If the water level is high enough and the sea wind intense, the canal embankments are flooded and greater quantities of sea water enter into the northern lagoon. The increased water level in the lagoons due to salt water and freshwater inflow increases the flooding of peripheral areas. If the sandbar has been breached, greater sea water inflow increases the salinity of the water in the submerged areas[14].

End of storm and sandbar closure

After a storm event, the winds die down and turn from a south-easterly to northerly wind. There is an increase in atmospheric pressure and the skies clear. The sea returns to its average level. The water level remains higher in the lagoons and water drains into the sea via the canal and temporary channel (if the sandbar was breached). A fraction of suspended sediments carried by the sea and streams during the storm are then deposited once the wave and current intensity dies down. If a temporary channel was opened, these sediments help close it and consequently the sandbar.

b) Identification of natural elements for storm protection

Various elements in the ecosystem come into play during a coastal storm like the one we just described and contribute to the protection ecosystem service. This protection service can be broken down into three sub-services. Firstly, protection from erosion, then, protection from rising sea water (marine flooding) and finally, protection from land flooding. Each of these services is characterised by forcing parameters consisting of the physical phenomena against which the ecosystem elements resist, and by biophysical indicators for estimating the capacity to resist these forces (Table 6).

Beach and sandbar erosion is caused by waves, which in turn, are generated by the wind and characterised by their height, force and direction. The sandbar's resistance to erosion can be calculated using the topography (altitude and width of the sandbar) and vegetation cover. Vegetation reduces the speed of the wind and water and reduces sediment transport by trapping the sediments. It controls erosion, and fixes and promotes aggradation[15].

The rise in water levels occurs indirectly via the *Canal du Rhône à Sète* and then directly via sea water inflow when temporary channels are open. The water retention capacity of the lagoons and peripheral wetlands (non-permanent bodies of water, former salt pans) help limit the expansion of water over land. Rising water in the land environment depends on the topography.

Ecosystem sub-service for protection from…		Forcing parameters	Service indicators	Geographical sectors
ES 1	erosion	Force and direction of the wind and waves	- Topography - Vegetation cover	Sandbar
ES 2	rising water	Water level	- Topography - Water retention capacity	- Sandbar - Lagoons - Peripheral areas
ES 3	land flooding	- Flooded surface areas - Soil infiltration capacity	- Soil permeability - Resilience to salinity - Vegetation cover	Peripheral areas

Table 6: Coastal protection sub-services, forcing parameters and associated indicators

[14] The Mediterranean Sea has an average salinity of 38 g/l, whereas it varies between 24 and 32 g/l in the Palavasian lagoons.

[15] In geology, aggradation corresponds to the deposition of sediment in the waterway bed and its direct vicinity. Aggradation occurs when the sediment input is higher than the carrying capacity of the streams.

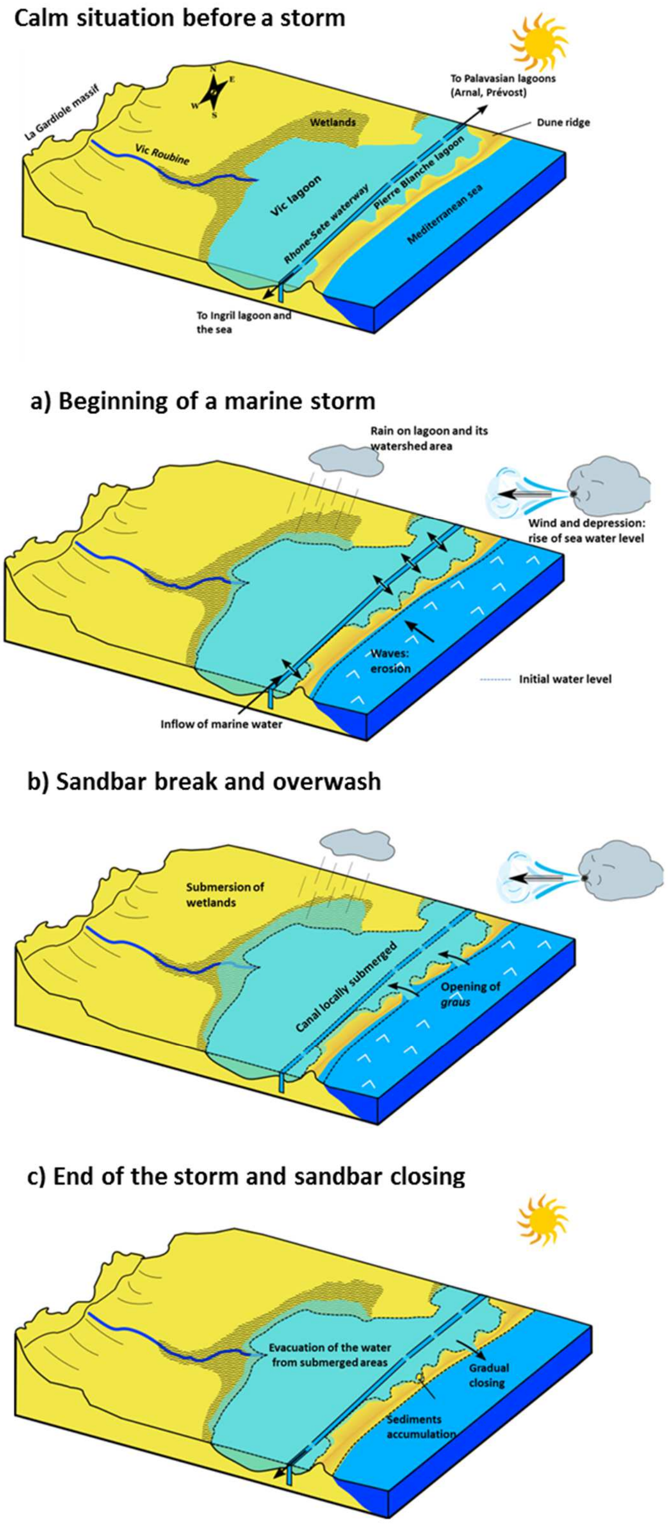


Figure 20: Sequential diagram of a storm over the Etang de Vic lagoon

Land flooding is caused by the expansion of water from the storm over land surfaces. The soil's capacity to absorb this water (and therefore the storm frequency), will determine the extent of the service provided. Resistance to land flooding therefore depends on the soil permeability, which influences the infiltration capacity of a mass of water during flooding. The vulnerability of the uses associated with these flooded lands also depends on their resistance to salinity (former salt pans, *sansouires*[16] and salt meadows will be more resistant than crops such as vineyards). Finally, dense vegetation cover limits water expansion by reducing flow via resistance. The roots system also helps water to better infiltrate the soil. Each protection indicator identified above was then characterised by biophysical sub-indicators (Table 7).

Indicators	Sub-indicators
Vegetation cover	Density estimated visually using aerial photographs
Topography	- Altitude (m ODN) - Sandbar width (m)
Water retention capacity	- Surface area (km^2) - Type of water expansion zone (permanent bodies of water, wetlands, land)
Resilience to salinity	Type of land cover (salt meadows, *sansouires*, crops, etc.)
Soil permeability	- Geological composition of the soil (limestone, clay, silty, sandy) - Artificially sealed areas (car parks, urban areas, roads)

Table 7: Protection indicators and the biophysical sub-indicators that characterise them

4.2.2. Qualitative assessment of the sub-services contributing to the coastal protection ecosystem service

a) Methodology

For each of the ecosystem sub-services identified above, the methodology was to categorise the intensity of the protection from coastal storms on the basis of data that provides quantitative or qualitative assessment of the forcing parameters and biophysical protection indicators. Assessment via an index that incorporates the indicators of each ecosystem sub-service enabled mapping of the ecosystem's coastal protection.

Protection from erosion sub-service

Resistance of the sandbar to erosion during a storm is an essential first barrier in the coastal protection capacity provided by a lagoon ecosystem. It is the breaking of waves on the sandbar ("run-up"[17]), the associated rip currents and the phenomenon of sea flooding that will lead to erosion. Their intensity is therefore a key forcing parameter and their direction plays a part. Waves that directly attack the coastline perpendicularly are more likely to impact the sandbar across a significant distance towards the lagoon.

The region's beaches are subject to wind conditions that alternate between frequent and strong land winds (80% of observations) and more rare sea winds that may still be strong. Land winds primarily consist of *tramontane* (westerly to north-westerly wind) and secondly, *mistral* (north-easterly wind); whereas sea winds mainly come from the south-east. Land winds generate frequent local swells (primarily south-westerly), but these are not especially aggressive due to their limited fetch[18], whereas sea winds create swells that are less frequent but much more effective from a morphogenic perspective (primarily south-easterly and south/south-easterly). Although 80% of swells have a significant wave height (SWH) lower than 1 m, the situation is very different during a storm, with maximum SWHs of over 6 m in extreme cases, such as in November 1982 or December 1997 in Sète, and very large surges reaching 1.35 m ODN (where the Highest Astronomical Tide does not exceed 0.35 m ODN)[19]. South-easterly swells break almost perpendicularly to the sandbar and its width is therefore estimated in this direction for the index. The sandbar erodes more easily and breaches in areas with reduced width. Sectors where the

[16] *Sansouire* is a Mediterranean term (lagoons, Camargue) for Mediterranean salt pastures and meadows composed of marsh samphire, *Salicornia sp*. from the Chenopodiaceae family (Source: aquaportail.com)
[17] By definition, run-up is the maximum height reached by a wave on a slope, calculated from the resting water level.
[18] Fetch (meaning "open", "extent of a bay") is the distance a wind blows without interruption (ashore) over the sea or other body of water, from where it begins on the water, or from the shoreline from which it comes. All other things being equal the greater the fetch, the higher the waves. Conversely, the wave height will be minimal when sheltered by the coastline (land wind), even if the wind is very strong, because the fetch is smaller.
[19] EID data, 25% of residual winds turn to Mistral (north-easterly) at the end of the storm.

width (between the sea and lagoon) is greater than 100 metres received an index point, whereas those with a smaller width did not.

Nevertheless, the sandbar's resilience is also linked to its topography and vegetation cover. The topography is especially characterised by the altitude (in metres ODN) of the sandbar, particularly the dune ridge. A higher dune ridge is less likely to be directly eroded by the waves and will resist for longer. The sandbar's lower points (altitude below 1 metre) offer little resistance to the breaking swell during a storm and received one point. Areas with an altitude of between 1 and 2 metres resist more significant storms and were awarded two points. Finally, areas with an altitude greater than 2 metres received three points.

Vegetation cover on the sandbar also plays a role in erosion resistance. When sand is fixed by dense vegetation across a large surface, it is more difficult to move and better resists the force of the waves. The presence of dense vegetation cover increasing resistance was awarded an extra point for the index[20].

The sum of these three sub-indicators (altitude, sandbar width, vegetation cover) summarised in Table 8 created an erosion resistance index from 1 (sandbar with an altitude lower than 1 metre, limited width and no vegetation cover) to 5 (sandbar with an altitude greater than 2 metres, large width and vegetation cover).

Erosion protection sub-indicators	Resistance criteria	Points
Sandbar width	Width of less than 100 m	0
	Width greater than 100 m	1
Sandbar altitude (m ODN)	Low resistance, sandbar lower than 1 m	1
	Intermediary resistance, 1 to 2 m sandbar	2
	High resistance, sandbar higher than 2 m	3
Vegetation cover	No vegetation cover	0
	Vegetation cover	1

Table 8: Criteria for estimating the erosion protection index

Protection from rising water sub-service

During a storm, the rising sea water level creates the risk of flooding low-lying land along the coast. The sandbar may therefore be flooded locally without erosion from the waves if its altitude is lower than the maximum level reached during the storm. This is true for other ecosystem elements (lagoon banks, peripheral wetlands). Some low points in the ecosystem, such as depressions and areas which are not permanently flooded, are capable of retaining rising waters.

The key forcing parameter is the maximum water level reached during a storm. The index's estimation range was limited by the maximum water elevation level reached during significant flooding. A scenario presented in the SYBLE hydraulic study (EGIS Eau, 2012) simulates combination of a coastal storm with a one-hundred-year sea level and a catchment area high-water event which also has a one-hundred-year return period. The maximum water level across the Etang de Vic and Etang de Pierre-Blanche lagoons area is 1.53 m ODN elevation. The area below this height was broken down using a digital elevation model (DEM) in order to estimate the rising water protection index. Any part of this area that could contribute during rising waters was awarded an index point. Lagoons that are always filled with water (Etang de Vic, Etang de Pierre-Blanche and Etang de Gâchon), with a significant water storage capacity right across their surface in the event of rising waters, were given the maximum index with two extra points. Wetlands and non-permanent bodies of water that can retain water when it rises received one extra point for their retention capacity. Rising water may also affect flooded areas outside of wetlands without any particular water retention capacity. All criteria for estimating protection from rising waters are summarised in Table 9.

Rising water protection sub-indicators	Resistance criteria	Points
Topography	Greater than 1.53 m ODN (no submersion)	0
	Lower than 1.53 m ODN	1
Water retention capacity	Land excluding wetlands	0
	Wetlands and non-permanent bodies of water	1
	Permanent lagoons	2

Table 9: Criteria for estimating the rising water protection index

[20] The sand particle size is not taken into account, as it is generally identical across the entire exposed part of the beach with a d_{50} of 0.35 mm.

Protection from land flooding sub-service

The final storm protection element is the flood resistance of land. The size of the flooded surfaces and the duration of submersion are key parameters. The topography was used to define the size of the flooded areas, which were then categorised according to the protection they offer in the event of sea flooding. Three categories were created using the following indicators: soil permeability, density of vegetation cover and resistance of the land cover to salinity.

Soil permeability was estimated based on its geological composition (limestone, clay, silty, sandy), according to whether or not it allows water to infiltrate and could therefore absorb some of the water carried by the storm. Sandy, silty and limestone soils allow infiltration and obtained one point. Naturally impermeable clay soils and artificially sealed ground (roads, car parks, buildings) received an overall index of 0.

Surfaces which also have dense vegetation cover (uniform vegetation with no isolated plants visible from an aerial view) block the advancing waters and promote infiltration via its root system. They received an extra point.

Finally, the soil's capacity to withstand salt water received an extra resistance point. Salt meadows, former salt pans and *sansouires* in peripheral wetlands received an extra point for their contribution to the coastal protection service compared to more sensitive agricultural areas such as vineyards and other crops.

The allocation criteria for the land flooding protection index are summarised in Table 10.

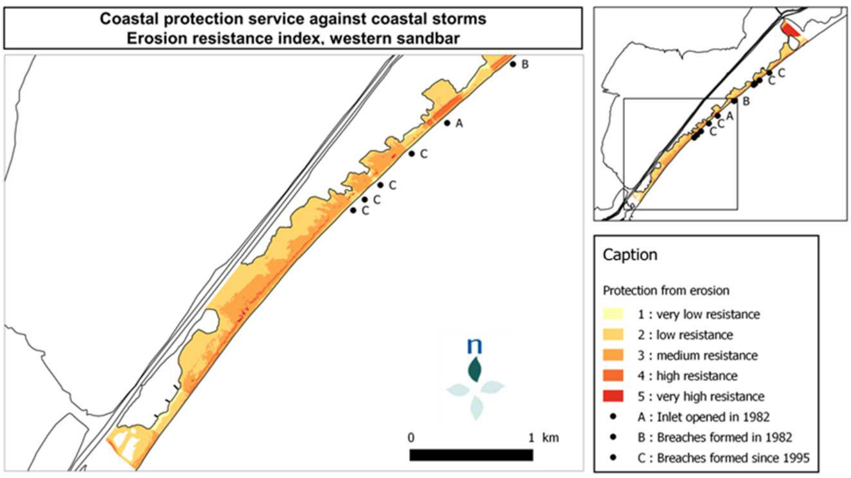
Land flooding protection sub-indicators	Resistance criteria	Points
Soil permeability	Clay soils and impermeable, sealed ground (no infiltration)	0
	Sandy, silty and limestone soils	1
Salinity resistance	Land sensitive to salinity	0
	Salt meadows, salt marshes, *sansouires*	1
Vegetation cover	None or low density	0
	High density	1

Table 10: Criteria for estimating the land flooding protection index

b) Results

Protection from erosion sub-service

The index for valuation of the protection from erosion sub-service that contributes to the coastal storm protection service is based on three indicators characterising the resistance of the sandbar to erosion via run-up, the associated currents and sea flooding during a storm event. The sandbar's altitude, width (between the sea and lagoon) and the presence or absence of vegetation cover were taken into account. The following maps (Figure 21 & Figure 22) show the results of this index, categorised from 1 (very low resistance) to 5 (very high resistance).



MapLab Nomadéis and Jérôme Castaings – 2015
Basic data sources: EID Méditerranée, DREAL LR, IGN

Figure 21: Map of the erosion resistance index for the western Etang de Pierre-Blanche sandbar

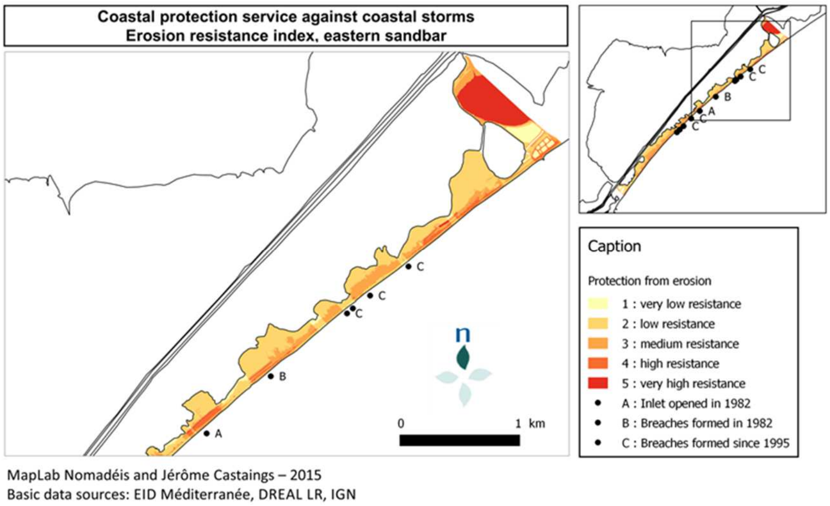


Figure 22: Map of the erosion resistance index for the eastern Etang de Pierre-Blanche sandbar

Areas of varying resistance are found right across the sandbar. The average of 2.5 across the entire sandbar surface demonstrates average to low overall resistance for this index. The dune ridges are clearly shown along the sandbar, with alternate areas where they form a significant barrier (indexes 4 and 5) and areas where the sandbar erosion resistance index is weaker or totally absent. Large breaches were formed in the sandbar at Points A and B during the fifty-year storm of 6 to 8 November 1982. At Point A, a channel remained open for several months after the storm, forming a large sand deposit. A sand-covered embankment was developed and vegetation replanted during work in 1989-1990, creating a storm-resistant area. Similarly, another embankment was created at Point B in 1993. Points C show the location of breaches that have regularly opened during coastal storms since 1995. These breaches are fragile points in the sandbar and can sometimes be reshaped until a temporary channel is formed under the effect of erosion and high sea levels during a storm. The mean protection index of these areas is 2.1, representing low sandbar resistance.

Protection from rising water sub-service

The index for valuation of the protection from rising water sub-service during coastal storms is based on the water retention capacity of the elements constituting the service. The following map (Figure 23) shows the results of this index, categorised from 1 (floodable areas) to 3 (permanent bodies of water).

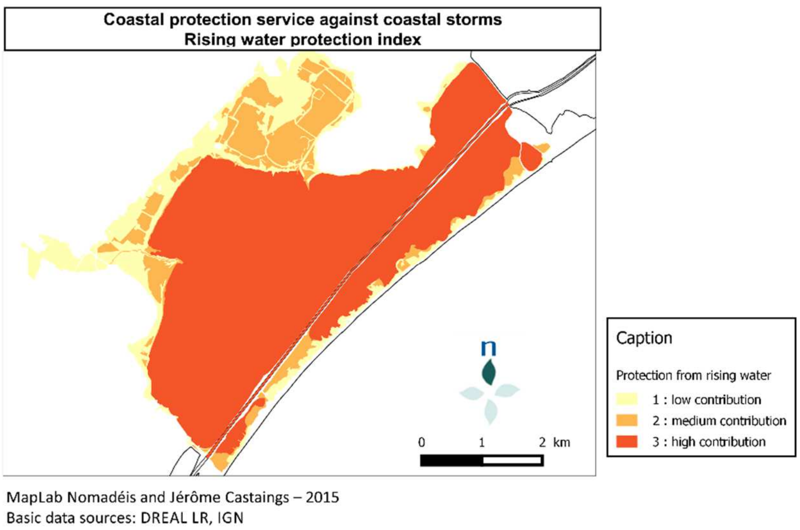


Figure 23: Map of the rising water protection index

Permanent bodies of water are the main contributing elements when faced with rising waters during a coastal storm. Their large surface area allows for significant water retention during the event of approximately 164,000 m^3 per centimetre of water above 0 m ODN. Frequently flooded temporary bodies of water and salt marshes offer an additional water retention capacity of approximately 32,000 m^3 per centimetre. Other flood-prone lands have a weaker contribution to rising waters. In the event of maximum water levels (up to 1.53 m ODN elevation), their storage capacity is 39,000 m^3 per centimetre of water above 0 m ODN.

Protection from land flooding sub-service

The index for valuation of the protection from land flooding sub-service which contributes to the coastal storm protection service is based on three indicators, which characterise the capacity of flooded surfaces to absorb water and resist salinity. Soil permeability, salinity resistance and dense vegetation cover were taken into account. The following map (Figure 24) shows the results of this index, categorised from 1 (low resistance) to 3 (high resistance).

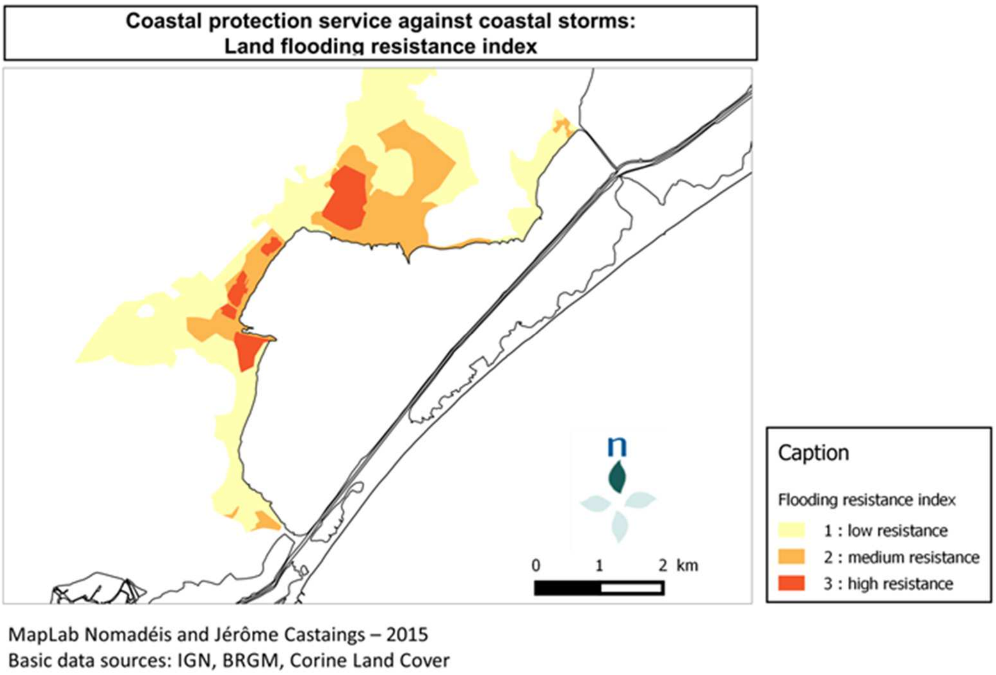


Figure 24: Map of the land flooding resistance index

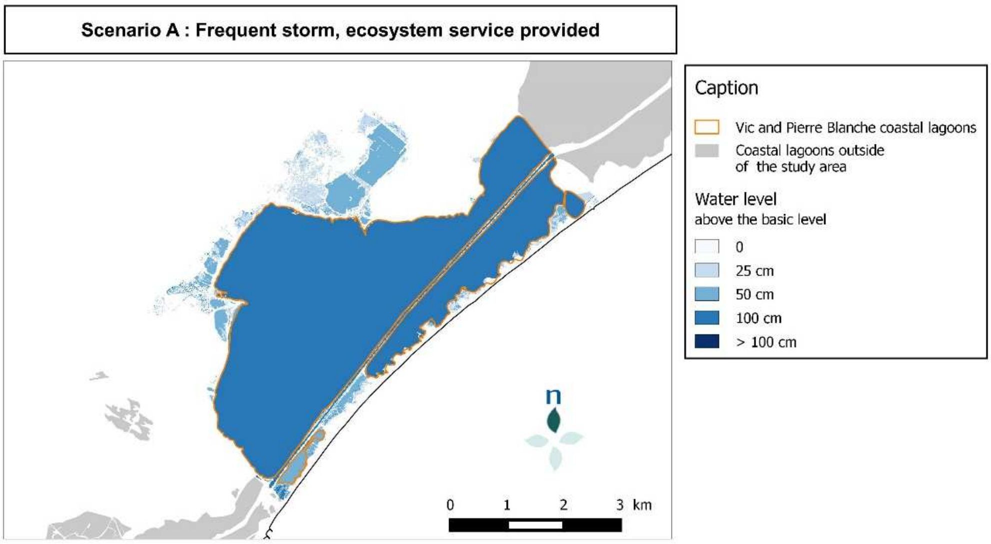
The Etang de Vic area is primarily formed of recent silty sediments and Jurassic limestone sediments that enable water infiltration during flooding. Impermeable areas are limited to a few, small clay zones and artificially sealed zones (car parks, urban areas). The wetlands, former salt pans and pasturelands along the Etang de Vic northern bank offer medium to high resistance in the event of flooding by a coastal storm. The western and north-eastern banks are less resistant, particularly due to farmland and vineyards that are sensitive to salinity and have less dense vegetation. This protection index was estimated at an overall scale on the basis of the Corine Land Cover inventory (1:100,000; 2006 data). There are occasional important locations within all the mapped areas that would be impacted by flooding, such as an isolated dwelling, for example.

The protection indexes helped assess the protection provided by each element constituting the coastal storm protection service. It was then important to quantify the contribution of the entire ecosystem service, incorporating all three sub-services together.

4.2.3. Quantification of overall site protection

a) Case of frequent storm

This scenario describes a relatively frequently occurring coastal storm with a two-year return period, along with a two-year watercourse inflow situation. The scenario was studied for the current ecosystem status (Scenario A) and for a situation where the storm protection service provided by the ecosystem is ineffective (Scenario A'). The flooded surface areas and volumes of water involved in these scenarios were calculated. Please note that the total volume of water was calculated above the baseline lagoon level, i.e. beyond the permanent volume water. The maps (Figure 25 and 26) and Table 11 below summarise the results obtained.



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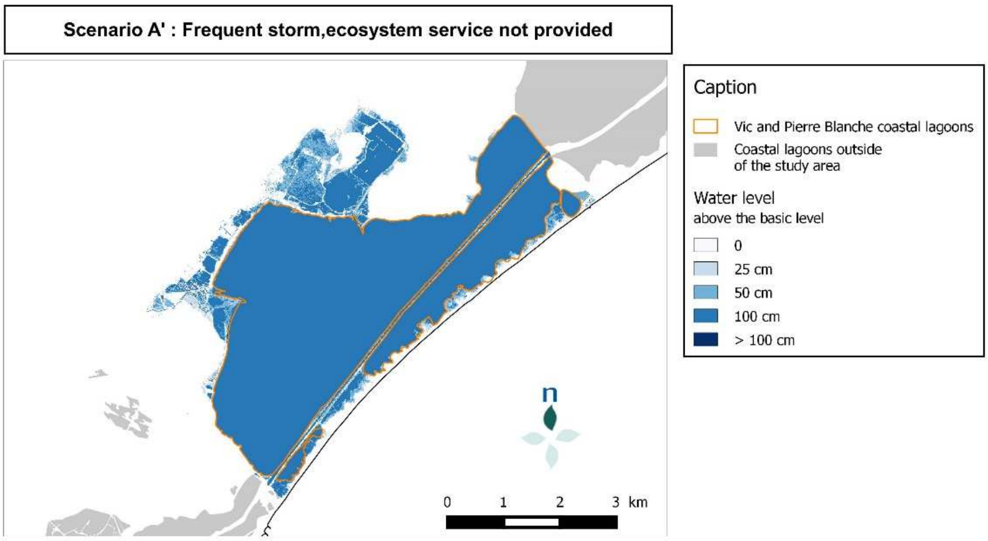
Data Sources : DREAL LR, IGN, SYBLE

Figure 25: Map of flooded areas in scenario A: two-year coastal storm return period and effective ecosystem protection service



MapLab Nomadéis and Jérôme Castaings – 2015
Data sources : DREAL LR, IGN, SYBLE

Figure 26: Map of flooded areas in scenario A': two-year coastal storm return period and ineffective ecosystem protection service

Scenario	Average water elevation (cm)	Volume of water (Mm^3)		Flooded surface (ha)	Duration of submersion
		Total	On-land		
A: ecosystem service provided	52	10.2	1.0	311	1 hour after the storm
A': ecosystem service not provided	74	15.6	2.4	475	1 hour after the storm
Difference	22	5.4	1.4	164	-

Table 11: Estimated protection service in the event of a frequent coastal storm

Most of the volume of water generated by a frequent storm is absorbed by the lagoons, (90% when the ecosystem service is provided and 85% when it is not provided). The flooded surface area is multiplied by 1.5 whereas the volume of water flooding land more than doubles, increasing from 1 to 2.4 Mm3. The average water elevation for flooded land increases by 22 centimetres when the ecosystem's protection service is not provided. However, most of the areas flooded in these two scenarios are not especially strategic (wetlands when compared with Figure 27).

A breakdown of the flooded surfaces by land cover category is summarised in Table 12. When the ecosystem service is ineffective (Scenario A'), there is an overall increase in the surface areas affected and new usage categories are impacted (arable land, vineyards and forests), but nevertheless across moderate surface areas (less than a hectare). This distribution forms the basis of the economic valuation of the coastal storm protection ecosystem service.

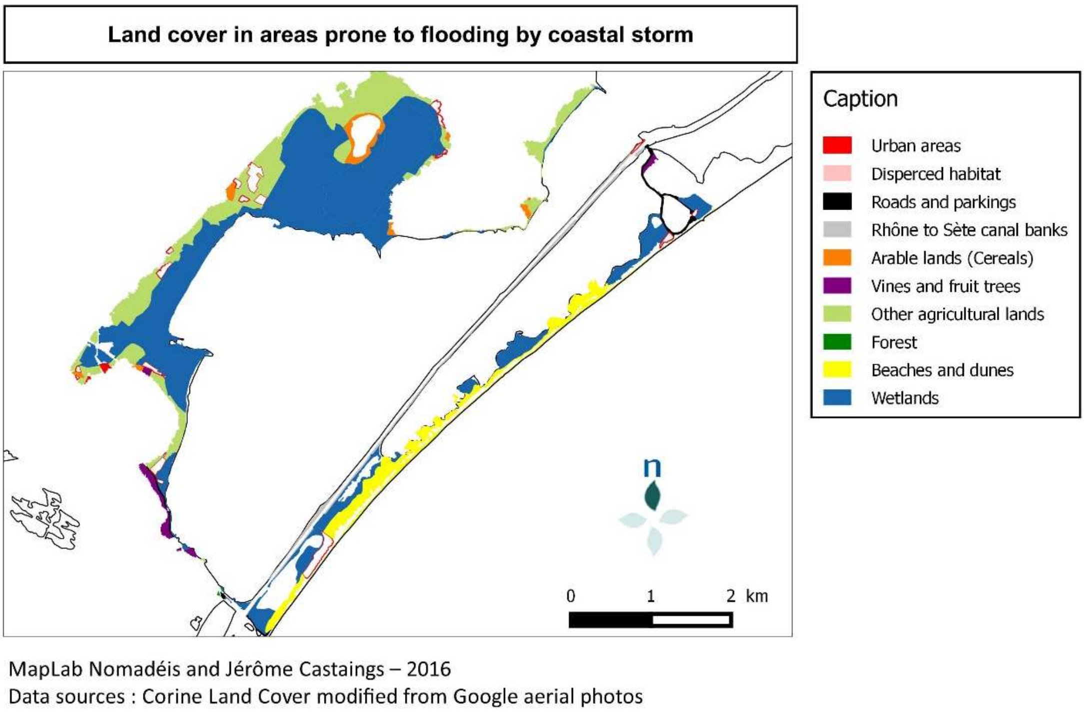


Figure 27: Land cover map in areas prone to flooding by a coastal storm

Land cover	Scenario A		Scenario A'	
	Flooded surface (ha)	Water elevation (cm)	Flooded surface (ha)	Water elevation (cm)
Urban areas	0	-	0	-
Scattered dwellings	0.4	11	8	15
Roads and car parks	0.1	8	3	20
Canal banks	4	25	9	25
Arable land	0	-	0.4	8
Vineyards and fruit trees	0	-	0.5	7
Other farmland	21	8	61	15
Forests	0	-	0.1	3
Beaches and dunes	12	12	25	15
Wetlands	284	16	377	35

Table 12: Distribution of surfaces flooded by a frequent storm, broken down by land cover

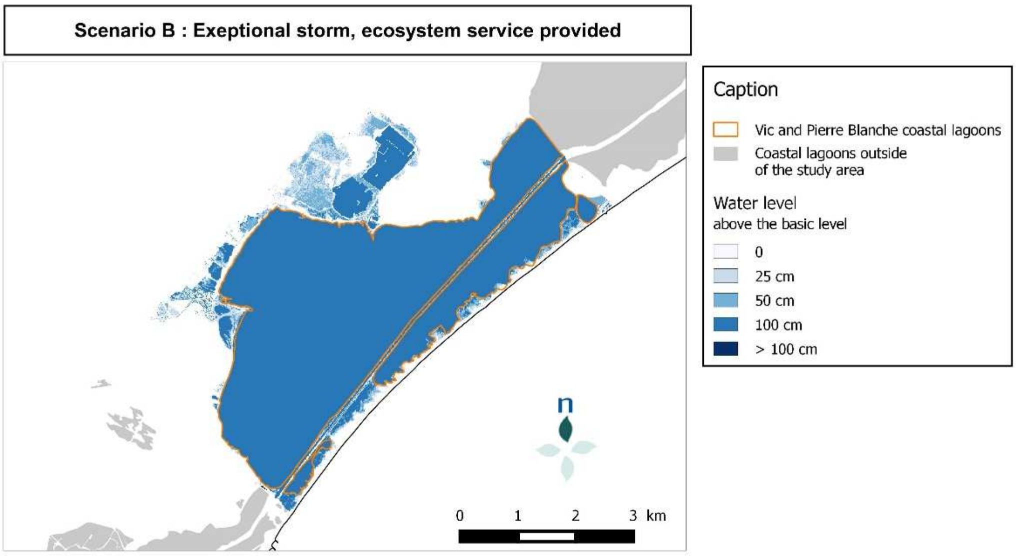
b) Case of a one-hundred-year storm

This scenario describes an exceptional coastal storm with a one-hundred-year return period, along with a limited two-year watercourse inflow situation. The scenario was considered for real ecosystem conditions with an ecosystem service (Scenario B) and for an ineffective ecosystem service (Scenario B'). The flooded surface areas and volumes of water involved in these scenarios were calculated. As for the previous scenario, the total volume of water was calculated above the lagoon baseline level. The Maps (Figure 28 & Figure 29) and Table 13 below summarise the results obtained.

Scenario	Average water elevation (cm)	Volume of water (Mm^3)		Flooded surface (ha)	Duration of flooding
		Total	On-land		
B: ecosystem service provided	79	16.4	1.9	430	3 hours after the storm
B': ecosystem service not provided	132	31.5	6.7	732	3 hours after the storm
Difference	53	15.1	4.8	302	-

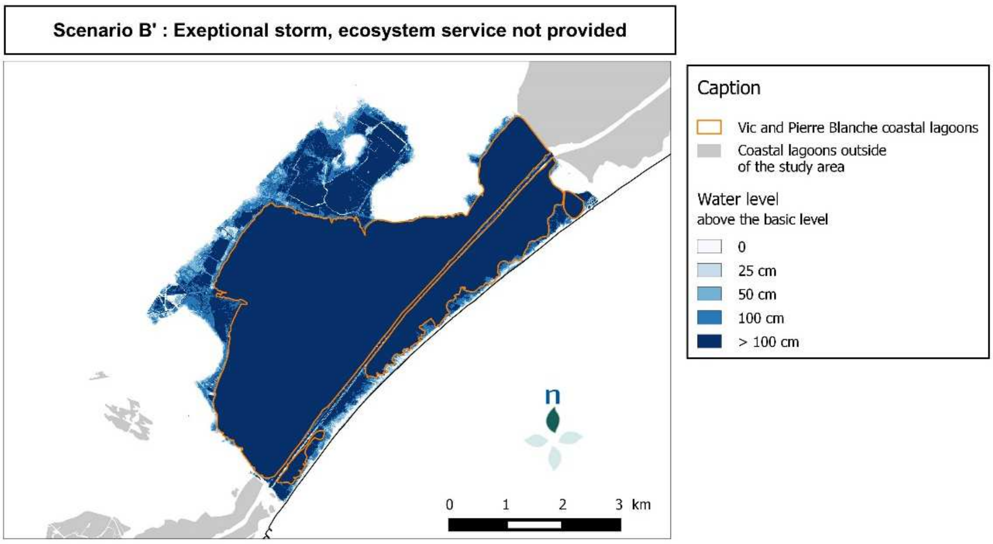
Table 13: Estimated protection service in the event of an exceptional coastal storm

Most (88%) of the volume of water generated by an exceptional storm is absorbed by the lagoons when the coastal protection service is effective, whereas only 79% is absorbed when the service is inactive. When the ecosystem service is not provided, the flooded surface area is multiplied by 1.7, which is similar to that of a frequent storm, and the volume of water flooding land triples from 1.9 to 6.7 Mm^3. Similarly the average water elevation on flooded land increases by 53 centimetres when the ecosystem's protection service is not provided.



MapLab Nomadéis and Jérôme Castaings – 2015
Data sources : DREAL LR, IGN, SYBLE

Figure 28 : Map of flooded areas in scenario B: 100-year storm return period and effective ecosystem protection service



MapLab Nomadéis and Jérôme Castaings – 2015
Data sources : DREAL LR, IGN, SYBLE

Figure 29: Map of flooded areas in scenario B': 100-year storm return period and ineffective ecosystem protection service

Comparison of the maps for Scenarios B and B' clearly shows the extension of the impacted areas in the absence of ecosystem protection from coastal storms. When the ecosystem service of protection is not provided, almost all the sandbar and area around the lagoons is flooded. These impacts underwent more concrete assessment during the economic valuation of the coastal protection service.

The breakdown of the flooded surfaces by land cover category is summarised in Table 14. When the ecosystem service is ineffective (Scenario B'), there is a general increase in surface areas affected. Highly strategic areas (residential areas, arable land, fruit trees) are more widely affected and this scenario even impacts almost one hectare of urban area, which was untouched in the other scenarios. Economic valuation on this basis will more carefully define the interest of the coastal storm protection ecosystem service.

Land cover	Scenario B		Scenario B'	
	Flooded surface (ha)	Water elevation (cm)	Flooded surface (ha)	Water elevation (cm)
Urban areas	0	-	0.9	20
Scattered dwellings	3	21	25	49
Roads and car parks	3	22	5	42
Canal banks	12	29	19	70
Arable land	0.6	11	15	31
Vineyards and fruit trees	0.5	13	10	31
Other farmland	40	17	156	53
Forests	0.2	14	0.3	35
Beaches and dunes	29	15	65	43
Wetlands	360	32	425	92

Table 14: Distribution of surfaces flooded by an exceptional storm, broken down by land cover

4.2.4. Biophysical assessment: Conclusion

The coastal storm protection service is provided by the Etang de Vic ecosystem via protection from erosion, protection from rising water and resistance to land flooding. The sandbar, particularly its dune ridge, is an important barrier in the event of coastal storms, by reducing the direct inflow of sea water up to a certain threshold. The lagoons have a large storage capacity for dealing with rising water and limiting its expansion inland. The peripheral wetlands provide an additional retention capacity in the event of rising water. Their salinity resistance and vegetation cover also limit the impacts of land flooding.

The methodology used to quantify the protection service provided by Etang de Vic during storm scenarios has demonstrated that this service reduces the overall surface area of flooded land by 30 to 40% and generally reduces the water elevation of flooded areas. The volumes of water flowing inland are reduced by a factor of approximately 3.5 during a 100-year storm and 2.4 during a frequent storm with a two-year return period. In addition, analysis of the results raised a notable point. The results of Scenario A' and Scenario B are roughly similar in terms of the surface area flooded (475 and 430 ha) and volumes of water (2.4 and 1.9 Mm^3). **It can therefore be assumed that without the ecosystem protection service, a two-year coastal storm would generate the same impacts as currently generated by a 100-year coastal storm for the Etang de Vic catchment area (watercourse flow rates unchanged).**

Nevertheless, it is important to note that although these results are a reliable estimation of the coastal protection service, their precision is limited due to the methodology used and precision of baseline data.

In particular, the methodology based on GIS (Geographic Information System) processing is easier and quicker to implement than building a hydraulic model, but does not achieve the same quality of results.

Firstly, it does not take into account interactions between the study zone (Etang de Vic and Etang de Pierre-Blanche) and the other lagoons in the Palavasian complex, which communicate via various channels and the *Canal du Rhône à Sète.* These interactions are nevertheless partially considered in Scenarios A and B (but not A' and B') where the water levels are taken from the results of hydraulic modelling, taking into account the entire lagoon complex.

Secondly, the maximum sea level considered in Assumptions A' and B' as the overall flood level is probably overestimated with regard to the results of modelling under the same conditions (coastline fully open and peripheral areas inactive). The estimated figures for the ecosystem service are of the right order of magnitude, but greater precision could be achieved in further studies.

Finally, the absence of temporal dynamics in this estimation method prevents the estimation of flooding durations, and the effect of repeated storms. Some impacts associated with a coastal storm are linked to the duration of flooding (e.g. the time for which a flooded road remains inaccessible) or to the frequency of these events. With a view to the economic valuation of the coastal protection service, the absence of the time factor is a limitation for the estimated quantities presented above. Nevertheless, monetary value can still be assigned to the ecosystem service by basing calculations on the flooding durations observed in the models on which the scenarios are based.[21]

4.3. ECONOMIC VALUATION OF THE COASTAL PROTECTION SERVICE

4.3.1. Damage cost avoided method

Barbier, *et al.* (2011b) emphasise the absence of economic valuation of the coastal protection service provided by a dune ridge in literature. For other types of environment, no precise study has been published that we know of, although the few estimations available would suggest that the economic value of this service can be very high, especially in areas exposed to extreme events[22].

Two types of method are generally considered for economic valuation: stated preference (contingent valuation) or revealed preference (replacement cost and damage cost avoided).

The stated preference approach (contingent valuation, etc.) requires a significant number of interviews to be carried out in order to obtain a sound estimate of the population's willingness to pay in order to conserve or achieve given conditions (conservation or optimisation of one or more services). Time and material constraints in this study made it impossible to carry out this approach under satisfactory conditions and it was therefore not selected.

The main alternatives to the stated preference method are the damage cost avoided and replacement cost methods. For the Vic coastal lagoon and particularly the protection role provided by its sandbar, there are two difficulties inherent in implementing the replacement cost approach:

- One key characteristic of the Vic coastal lagoon sandbar is its changing morphology over time, during occasional events (e.g. storms) and also in the long term (erosion, sedimentation, etc.). No artificial coastal protection infrastructure would have this changing dimension and the replacement cost assessment exercise would therefore be somewhat artificial as these two systems would not be strictly equivalent;
- Construction of replacement infrastructure would not necessarily provide the same ecosystem services as the sandbar (salinity regulation, environmental amenities).

The damage cost avoided method therefore seemed the most appropriate, despite a limited number of references available in the literature. Existing work that assesses the damage costs avoided primarily focuses on the coastal protection services provided by mangroves, seagrass beds or coral reefs. However, the methods used often have limited scope as they are based on the transfer of costs observed on other sites (Chong, 2005).

However, two studies into the economic value of the coastal protection service provided by wetlands do deserve a mention, as they are representative of the damage cost avoided approaches already used:

- **Costanza, *et al.*, 1989**: using historical data on the damage caused by various storm episodes in Louisiana (provided by the US Armed Forces), a multilinear relationship was established between the value of the damage and the distance separating the county from the sea (and therefore from the eye of the storm). The model interprets the marginal effect of the county being one kilometre closer to the sea as the value of the protection service provided by one kilometre of wetlands. Costanza, *et al.*, 2008 used a similar methodology applied to the scale of the United States of America[23].

[21] References for the biophysical assessment of the coastal protection service in the Etang de Vic: EGIS Eau , 2012; Durand *et al.*, 2006; Bouchette *et al.*, 2003; Donnelly *et al.*, 2006; Heurtefeux *et al.*, 2006; Lanzellotti, 2004; Valantin, 2003; Dezileau *et al.*, 2014; Castaings *et al.,* 2011.

[22] For example, Liu *et al.* (2005) report on a case in Sri Lanka where a hotel complex was totally destroyed by a typhoon in 2004, leading to 150 deaths and extensive material damage after a protective dune was removed to improve the area's aesthetic potential (unobstructed sea view).

[23] Values calculated: from \$250 to \$51,000 per ha^{-1} per $year^{-1}$, with an average of \$8,240 per ha^{-1} per $year^{-1}$.

Limitations of the method for the Vic coastal lagoon: this approach uses historical data of damage associated with previous storms, but the Vic coastal lagoon area has limited human activity and these figures are not especially useful. In addition, the estimation technique used (least squares regression) is suited to the conditions of the study site and requires data with sufficient variance to produce sound results. This variance can only be obtained by damage caused by extreme events (cyclones, hurricanes), which are rare in the Mediterranean.

- **Cooper, *et al.*, 2009**: this more recent study analyses the damage costs avoided thanks to the coastal protection provided by mangrove forests and coral reefs in Belize. Models simulate the estimated water levels reaching various zones in the event of a storm[24]. The mangrove forests and reefs are given a coastal protection coefficient (proportion of coastal protection attributable to the presence of mangrove forests and reefs). The mean value of the properties located in the vulnerable area is then multiplied by this coefficient. The result is weighted using the simulated storm's annual exceedance probability in order to obtain the economic valuation of the service provided.

  Limitations of the method for the Vic coastal lagoon: the authors assume the value of properties to be zero in the event of flooding, which is an overly simplified assumption. In addition, only damage to property is taken into account. No loss of earnings associated with disruptions to economic activities is considered. However, the sole property approach can be justified by the scale of the study (entire country, i.e. 696 km² of "vulnerable" area), but would not give satisfactory detail at the scale of the Vic coastal lagoon, especially considering that site management by the *Conservatoire du Littoral* has strictly limited urban development in the area.

4.3.2. Damage cost avoided by the expected damage function

The damage cost avoided method selected is an original approach that consists of estimating the "Expected Damage Function" (EDF), which was adapted to the Vic coastal lagoon context (from work by Barbier, 2007). However, in our case study, it proved difficult to formally estimate the probability that a storm would have an economic impact on the basis of historical data[25], as Barbier manages to. Given the water elevations simulated in the various scenarios and for the various areas (A, A', B, B'), the approach adopted consisted of making prior assumptions concerning the respective damage per item of damage[26], and valuing the corresponding costs.

The theoretical framework of our damage costs avoided estimation has been adapted from Barbier (2007) and is based on classic microeconomics mechanisms.

The following standard assumption is required for microeconomic modelling: individuals are assumed to have preferences that are sufficiently similar to be assimilated together into those of a single representative.

Let Z be the number of storms that may damage the coast and S be a natural area presence index, determining its capacity to provide the coastal protection ecosystem service (e.g. sandbar height). Z is subject to a law of probability which depends on S, such that $\frac{\partial\, p(Z\,|S)}{\partial\, S} < 0$ and $\frac{\partial^2\, p(Z\,|S)}{\partial^2\, S} > 0$.

The convexity of the probability shows that damage declines less and less quickly as the ecosystem service presence index improves.

Consequently, this gives: $E(Z|S) = \int_{Z(\Omega)} Z.p(Z|S)dZ|S$.

Let $D: E(Z|S) \longmapsto D(E(Z|S))$ be an increasing positive damage function, which associates the damage caused with a conditional storm expectation.

This gives: $\frac{\partial\, D(E(Z|S))}{\partial\, S} < 0$. The expected damage declines in line with the intensity of the coastal protection service provided.

Let DMP be the representative's marginal willingness to pay for improvement of the coastal protection service. By definition, this gives: $DMP(S) = -\frac{\partial\, D\left(E(Z|S)\right)}{\partial\, S} > 0$. The marginal willingness to pay for improvement of an ecosystem

[24] Storm with an annual exceedance probability of 1/25.
[25] Log-linear regression model to estimate the parameters of a Poisson distribution for the Thailand mangrove forest studied by Barbier.
[26] A breakdown of types of damage caused by a storm is described in Table 16.

service is therefore positive and we can demonstrate that it is a decreasing function of S (due to the convexity of the conditional probability $p(Z|S)$).

The purpose of this analysis is to estimate the costs generated by moving from a scenario where the coastal protection service is present (A or B) to a scenario without the coastal protection service (A' or B'). This is therefore non-marginal variation of S.

Let $C(S, S')$ be the compensatory surplus associated with moving from S to S'. *C(S, S')* represents the sum that the representative is willing to pay to avoid a disaster. In the event that the wetlands are degraded (e.g. moving from Scenario B to Scenario B' described in the biophysical assessment) and now only provides a partial protection service (we go from S to S', $S' < S$), this gives: $C_B(S, S') = -\int_{S_B}^{S_{B'}} DMP(S)dS$. This quantity corresponds to the red zone in the following graph and it is this quantity that we are seeking to estimate.

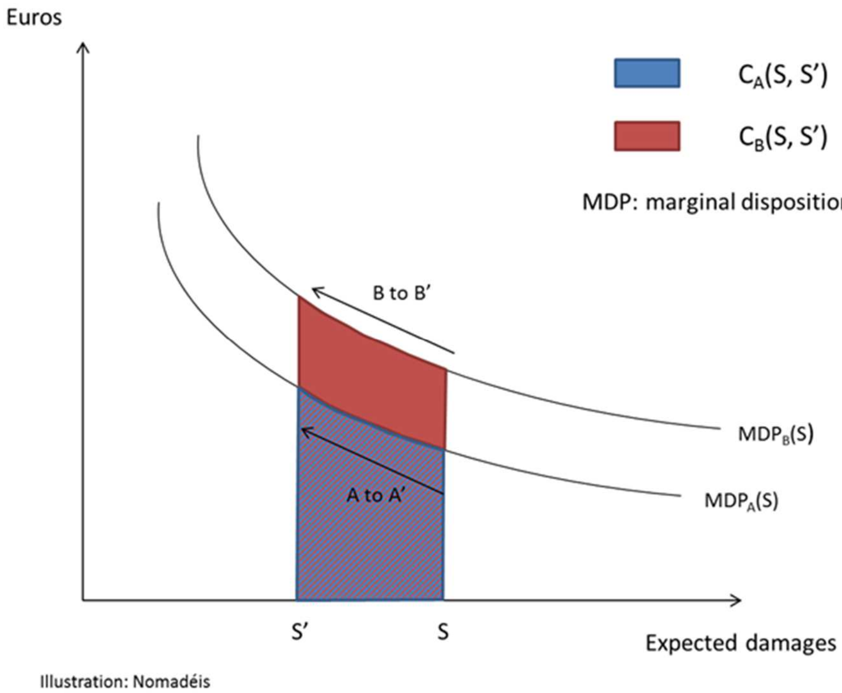


Figure 30: The blue and red areas under the MDP_A and MDP_B curves represent the compensatory surpluses associated with moving from Scenarios A to A' and B to B'. These quantities represent what society would be willing to pay to avoid the loss of the coastal protection ecosystem service for each of the two storm intensities

4.3.3. Assessment of the damage costs avoided

For each item of damage identified (canal, railway, etc.), we sought to estimate the economic value of the damage caused in each of the four storm scenarios (A, A', B, B'). To this end, assumptions were made concerning the type and extent of damage. The damage was calculated for each scenario according to these assumptions.

Table 16 summarises the assumptions and damage costs avoided for each of the items of damage described. The "difference" line shows the difference between the monetary value of damage for the scenarios with and without the coastal protection ecosystem service.

Note: the breakdown and explanations of calculations are presented below.

Estimation of damages and operating losses associated with the activity of the *Canal du Rhône à Sète*

The *Canal du Rhône à Sète* is managed by *Voies Navigables de France* (VNF). Pleasure and freight vessels need to pay to use the canal by purchasing a permit whose price varies according to the size of the boat and the frequency of canal use.

The operating losses caused by interrupted canal traffic can be broken down into several categories, described in the following table.

	Annual loss	1-day loss (Scenarios A' and B)	2-days loss (Scenario B')
Loss of VNF pleasure boat turnover	• 1,200 boats per year[a] • Price of the canal access permit varies according to the size of the vessel and frequency of canal use ⇨ Total annual turnover is estimated at €100,000.	€274	€548
Loss of VNF freight vessel turnover	• 450 boats per year[a] • Price of the canal access permit varies according to the size of the vessel and frequency of canal use ⇨ Total annual turnover is estimated at €1,000,000.	€2,740	€5,480
Loss of pleasure boat rental turnover	• 840 rental boats use the canal each year • The average rental cost is €200 per day ⇨ Total annual turnover is estimated at €168,000.	€460	€920
Loss of freight transport turnover	Difficult to assess	N/A	N/A

[a] Annual VNF data.

Table 15: Damage costs avoided associated with the *Canal du Rhône à Sète*

The total damage caused by a storm in Scenarios A' and B is estimated at €3,474 in both instances, reaching a total of €6,948 in the event of a 100-year storm without coastal protection (Scenario B').

Table 16: Overview of the damage costs avoided for the four storm scenarios (A, A', B and B') and the estimated value of the coastal protection service provided by the Etang de Vic coastal lagoon

<table>
<tr><th colspan="2" rowspan="2">Item of damage</th><th colspan="4">Scenarios</th></tr>
<tr><th>A</th><th>A'</th><th>B</th><th>B'</th></tr>
<tr><td rowspan="3">Canal</td><td rowspan="2">Assumptions</td><td colspan="2">• No canal cleaning required
• No structural damage, but accelerated wear</td><td colspan="2">• No canal cleaning required
• No structural damage, but accelerated wear</td></tr>
<tr><td>No interruption to canal traffic</td><td>No traffic for one day</td><td>No traffic for one day</td><td>No traffic for two days</td></tr>
<tr><td>Cost</td><td>None</td><td>Pleasure + freight operating losses: €3,474</td><td>Pleasure + freight operating losses: €3,474</td><td>Pleasure + freight operating losses: €6,948</td></tr>
<tr><td colspan="2">Difference in cost (A'-A) and (B'-B)</td><td colspan="2">€3,474</td><td colspan="2">€3,474</td></tr>
<tr><td rowspan="3">Railway</td><td rowspan="2">Assumptions</td><td colspan="2" rowspan="2">• Backfilled structure not damaged (just accelerated erosion of the slope toe)
• No interruption to operation</td><td colspan="2">Backfilled structure not damaged (just accelerated erosion of the slope toe)</td></tr>
<tr><td>No interruption to operation</td><td>One-day interruption to operation</td></tr>
<tr><td>Cost</td><td>None</td><td>None</td><td>None</td><td>€15,000</td></tr>
<tr><td colspan="2">Difference in cost (A'-A) and (B'-B)</td><td colspan="2">None</td><td colspan="2">€15,000</td></tr>
</table>

D116 road	**Assumptions**	Backfilled road, no road closure		No road closure	Road flooded at the entrance to Vic-la-Gardiole and in Mas d'Andos One-day road closure
	Cost	None	None	None	- Cost of road closure €1,000 - Cost of road cleaning: €3,100
Difference in cost (A'-A) and (B'-B)		None		**€4,100**	
D114 road (South of Vic)	**Assumptions**	No damage to infrastructure No road closure	Road closure as a precaution (for a few hours)	Road closure as a precaution (for a few hours)	Road closure as a precaution and flooding (for a few hours)
	Cost	None	**€1,000**	**€1,000**	- Cost of road closure: **€1,000** - Cost of road cleaning: **€3,100**
Difference in cost (A'-A) and (B'-B)		**€1,000**		**€3,100**	
D114 road (North of Vic)	**Assumptions**	No risk of flooding		No risk of flooding	
	Cost	None	None	None	None
Difference in cost (A'-A) and (B'-B)		None		None	
Les Aresquiers car park	**Assumptions**	No damage No interruption to access	Access interrupted for a few hours	Access interrupted for a few hours	Flooding (for a few hours), infrastructure damaged
	Cost	None	None	None	Cost of repairs: **€10,000**
Difference in cost (A'-A) and (B'-B)		None		**€10,000**	
Beach infrastructure	**Assumptions**	No damage		No damage	Sand fences damaged
	Cost	None	None	None	Cost of sand fence repair **€3,700**
Difference in cost (A'-A) and (B'-B)		None		**€3,700**	
Scattered dwellings[27] (South of Villeneuve)	**Assumptions**	No damage		No damage	- 50 households (permanent residences) to be rehoused for one day + one night - 2.4 people/household
	Cost	None	None	None	- Cost of a rehousing plan: **€3,900** - Damage caused by 50 cm of water: **€1,167,150**
Difference in cost (A'-A) and (B'-B)		None		**€1,171,050**	
Informal housing[28] in Aresquiers	**Assumptions**	No damage		No damage	- Approx. 20 households (permanent residences) to be rehoused for one day + one night - 2.4 people/household
	Cost	None	None	None	- Cost of a rehousing plan: **€1,625** - Damage caused by 50 cm of water: **€1,046,400**

[27] Dwellings characterised by low-density housing.
[28] Here, informal housing refers to the construction of makeshift permanent or temporary housing, such as shacks or huts, without a building permit

Difference in cost (A'-A) and (B'-B)		None		**€1,048,025**	
Fruit trees (vineyards)	**Assumptions**	No damage		No damage	Harvest lost in the event of 30 cm of water for a few hours
	Cost	None	None	None	**€10,000**
Difference in cost (A'-A) and (B'-B)		None		**€10,000**	
Arable land (cereal crops)	**Assumptions**	No damage		No damage	Harvest lost in the event of 30cm cm of water for a few hours
	Cost	None	None	None	**€4,875**
Difference in cost (A'-A) and (B'-B)		None		**€4,875**	
Restaurant and tourism activity managed by the "*Compagnons de Maguelone*"	**Assumptions**	No damage Access to Maguelone island possible		No damage Access to Maguelone island possible	No access for one day
	Cost	None	None	None	Operating losses: **€356**
Difference in cost (A'-A) and (B'-B)		None		**€356**	
Fishing	**Assumptions**	No net damage No interruption to activity	Activity interrupted for one day	Activity interrupted for one day	- Activity interrupted for one day - Nets damaged
	Cost	None	Loss of one day's earnings: **€1,000**	Loss of one day's earnings: **€1,000**	- Loss of one day's earnings: **€1,000** - Net repair: no cost
Difference in cost (A'-A) and (B'-B)		**€1,000**		None	
Total Cost per scenario		**€0**	**€5,474**	**€5,474**	**€2,279,154**
Estimated value of the coastal protection service in the event of a frequent storm (A'-A) and exceptional storm (B'-B)		**€5,474**		**€2,273,680**	

Key (reminder): A: frequent storm (two-year return period) with an effective coastal protection ecosystem service; A': frequent storm (two-year return period) without an effective coastal protection ecosystem service; B: exceptional storm (100-year return period) with an effective coastal protection ecosystem service; B': exceptional storm (100-year return period) without an effective coastal protection ecosystem service.

Estimation of the costs associated with railway closure

The Tarascon - Sète City railway line borders the Etang de Vic between the municipalities of Frontignan and Vic-la-Gardiole. The track is used for passenger transport (regional trains and high-speed trains, travelling at reduced speed across this stretch) and freight transport[29].

The stretch of railway track included in the study area is backfilled and not flooded, even under Scenario B'. There is consequently no material damage to account for in this type of storm.

With regard to potential operating losses, it is the wind associated with the storm rather than the flooding of the track which could lead to a prefectoral order to stop railway traffic, in order to prevent derailment or catenary wire failure. SNCF Réseau experts estimate the loss of company income at €15,000 for one-day closure between Montpellier and Sète. Finally, it is important to note that this is a low estimate of the total cost of line closure, to which the following should be added:

- The cost for railway companies of implementing replacement transport services for passengers;
- The cost of any itinerary changes for rail freight companies;
- The cost of refunding the end customers for train cancellations or increased journey times;
- The possible cost of disruptions to rolling stock and personnel.

[29] From 2020, the proposed new Montpellier-Perpignan line will unload the line Tarascon - Sète city from passagers related to high speed and freight traffic.

Finally, the savings made in variable operating costs for railway companies (tolls, energy, etc.) need to be deducted. As this additional data was not available in full at the time of the study, the estimated cost of railway line closure was maintained at €15,000 in Scenario B'.

<u>Estimation of the costs associated with road closure and cleaning</u>

The cost of closing and reopening a road is estimated at €1,000 (source: experts from the Hérault Department of Territories and Sea).

In Scenario B', the D114 South of Vic-la-Gardiole and the D116 would need cleaning before being reopened to traffic. This operation requires construction vehicles (tractor, dump truck, high-pressure cleaner, power generator) and their delivery to the site, at a cost of €800 per day. The workforce would consist of three employees, each at a daily cost of €250, for a total of €750 each day. Finally, the duration of this type of cleaning operation is estimated at two days, at a total cost of €3,100 (data source: Pôle Littoral - EID Méditerranée).

<u>Estimation of the cost of Aresquiers car park repairs</u>

The cost of Aresquiers car park repairs after flooding lasting a few hours (Scenario B') is estimated at €10,000 (experts from the municipality of Frontignan / the Thau basin urban area).

<u>Estimation of the costs associated with repairing beach infrastructure</u>

Sand fences[30] damaged following a 100-year storm with no coastal protection (Scenario B') would need to be repaired. The cost to repair sand fences is approximately €25 per linear metre (source: Pôle Littoral - EID-Méditerranée). Nevertheless, it is difficult to estimate the linear length of sand fencing that would need to be repaired in the event of Scenario B'. The annual rate of beach infrastructure repair is 2% and the average annual cost of repair of the whole infrastructure is €185,000 for an installed length estimated at 7,400 m (estimated via mapping). Considering that this type of storm would require the equivalent of an entire year's repair operations (source: experts from Pôle Littoral - EID Méditerranée), this item of damage can be estimated at €3,700.

<u>Estimation of the cost of a rehousing plan for residents of scattered dwellings</u>

According to INSEE[31], the average household in Villeneuve-lès-Maguelone is composed of 2.4 people. Satellite images show an estimated 50 scattered dwellings that would be threatened by sea flooding in Scenario B', requiring 120 people to be rehoused in the event of a 100-year storm with no coastal protection. However, in practice, around half of the population affected in this type of situation are housed with friends or family and are therefore not taken care of by the authorities (source: French fire service feedback document, 2012). Consequently, it is assumed that 60 people would need to be rehoused in the event of Scenario B'.

Emergency rehousing plans of this size generally consist of requisitioning rooms in local hotels. In Villeneuve-lès-Maguelone, the average price of an overnight stay is €65 (data: Booking.fr), which brings the total cost of the rehousing to €3,900.

<u>Note:</u> *this figure does not take into account the management costs of this type of rehousing plan, which are difficult to estimate.*

<u>Estimation of physical damage to scattered dwellings</u>

Valuation of physical damage to scattered dwellings is based on two reports from the European Centre for Flood Risk Prevention (CEPRI). In 2014, the CEPRI published a guide for the valuation of flood damage, resulting in the SIMUDOM model, summarised in Figure 31 below.

According to the CEPRI, the model is calibrated using data on the type of dwelling and typical furniture composition for each room (lounge, bedroom, kitchen, etc.), provided by INSEE. The cost of repair and replacement of items of furniture and property damage was identified using the BATIPRIX database and corresponds to the prices observed in supplier catalogues and the opinion of flood damage experts[32]. In addition, a 50% depreciation rate is applied to finishings (partitions, woodwork, electrics) and furniture. Their value is therefore half that of the new price. Finally, the probability of vulnerability is estimated using expert opinion and statistics, and varies for each building and furniture

[30] Fencing formed of vertical wooden slats, joined together by galvanised iron wire in order to fix the sand in place.

[31] Data from the 2013 census.

[32] The data uses national averages which do not take into account regional variations. Furthermore, the price of repairs may be higher in the event of an emergency situation due to high demand. The CEPRI therefore give a low estimate of the real costs of building damage.

item according to the water elevation and flood duration. Finally, please note that data taken from the initial CEPRI report (CEPRI, 2014a) is supplemented by specific observations of the damage caused by sea flooding[33] (CEPRI, 2014b). Salt water can cause greater deterioration to a building than the damage caused by freshwater. Salt corrosion continues even after the flooded systems have dried and may even require the replacement of entire partition walls (including metal reinforcements and electrical systems) if the water reaches the top of the skirting board.

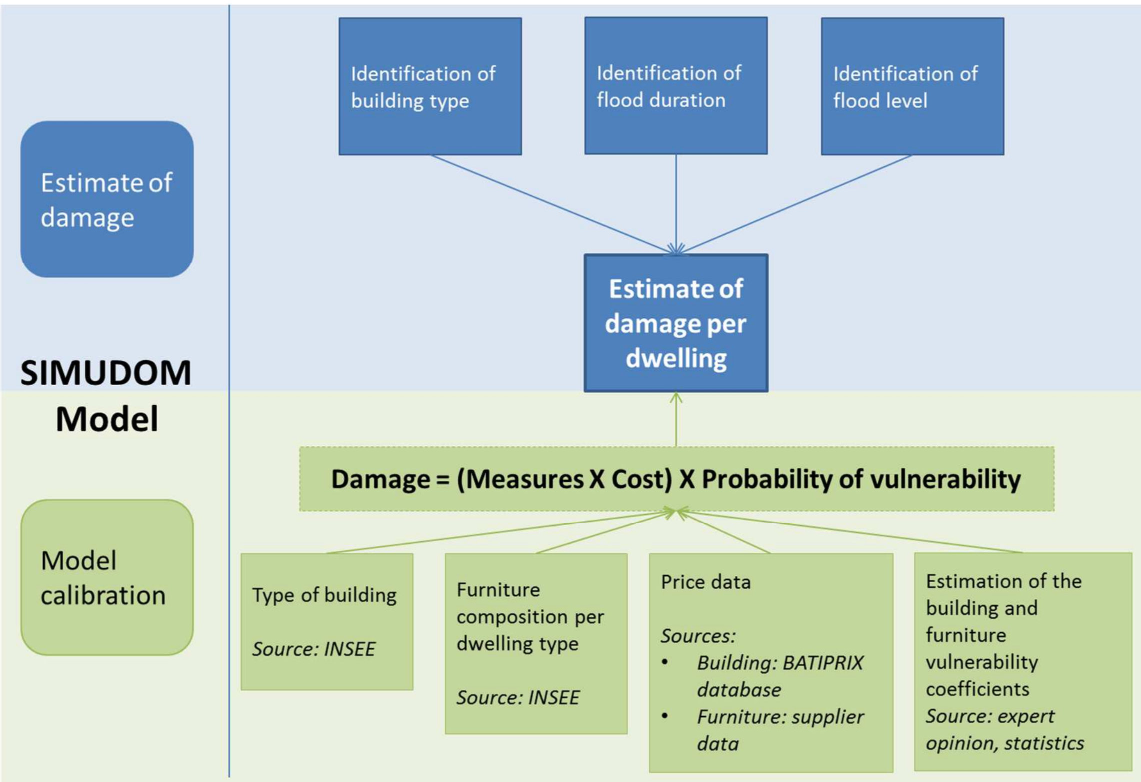


Figure 31: Functional diagram of the SIMUDOM model (Nomadéis illustration based on CEPRI, 2014)

The buildings in the areas flooded in the event of a one-hundred-year storm with no natural protection primarily consist of detached single-story dwellings (categorised "A1 - A3" according to CEPRI specifications). The duration of the simulated flooding is less than 48 hours (threshold adopted by the CEPRI to differentiate between short and long flooding durations), and the water elevation is 49 cm. The damage corresponding to these characteristics is given in Table 17 below.

	Saltwater flooding		
	Building	Furniture	**Total**
Damage for a 99 m² detached single-story dwelling (in €, 2011 rate)	16,420	9,740	**26,160**

Table 17: Damage to homes caused by saltwater flooding (according to CEPRI, 2014)

This gives the figure of €26,160 (2011 value), adjusted to €23,343 in 2016 for one dwelling[34]. With the assumption that 50 homes are affected by flooding, the total damage to scattered dwellings is estimated at €1,167,150.

[33] These observations were made following Storm Xynthia along the Charente-Maritime and Vendée coast in February and March 2010.
[34] The figure is converted using an online calculator available at http://france-inflation.com/calculateur_inflation.php, taking into account annual inflation between 2011 and 2016.

Estimation of the cost of a rehousing plan for residents living in shacks[35]

The shacks are mainly found in Les Aresquiers with approximately 40 homes and 100 people affected. Although the construction of these dwellings was originally informal, most have now been connected to the utilities network and approximately one half are used as primary residences (source: Pôle Littoral - EID-Méditerranée). 25 people would therefore need to be rehoused in the event of Scenario B', at a cost of €1,625.

Estimation of physical damage to informal dwellings

According to the scale described above, taken from the SIMUDOM model, physical damage caused by sea flooding following a one-hundred-year storm without coastal protection is estimated at €1,046,400 for the informal dwellings in Les Aresquiers.

Estimation of agricultural operating losses (fruit tree farming and other arable land)

Corn is the main crop grown in the areas flooded in the event of a one-hundred-year storm without coastal protection. The mean flood damage curves provided by the *Commissariat Général au Développement Durable* (CGDD, 2014) show the cost of corn crops at €325 per hectare. When applied to all affected areas (15 hectares), the total cost is estimated at €4,875.

According to the same source, vineyard areas (10 hectares) would experience losses of €1,000 per hectare in the event of Scenario B', representing a total cost of €10,000.

Finally, the "other farmland" category primarily consists of wildland and meadows, which are little impacted by short-term flooding.

Estimation of operating losses for tourism activity managed by "*Les Compagnons de Maguelone*"

Maguelone Island is home to a restaurant, souvenir and wine outlets, which would not be able to operate if access to the island was blocked for a day (Scenario B').

The restaurant's turnover is estimated at €130,000 each year, representing 20 meals at €20 each per day, over a 200-day opening period. The sale of beverages has an estimated annual turnover of €20,000 and the sale of souvenirs and wine is estimated at €30,000 (source: Pôle Littoral - EID-Méditerranée).

When applied to one day's operation, the loss of turnover in the event of a one-hundred-year storm without coastal protection is estimated at €356.

Estimation of the damage and operating losses associated with fishing

Regulated fishing activity is conducted on the Vic coastal lagoon. The loss of earnings in the event of Scenarios A', B and B', resulting in a one-day interruption to fishing activity, is estimated at €1,000 (source: *Comité Régional des Pêches*) [36].

In addition, the nets would be damaged and would need to be repaired in the event of a one-hundred-year storm without coastal protection. However, the annual depreciation of nets used on the site (trammel[37] and capéchade[38] nets) is close to zero as the fishermen often perform the repairs themselves.

Considering the various items of damage listed above, the following conclusion can be made (see Table 16):

→ **In the event of a biennial storm, the economic value of the coastal protection ecosystem service is estimated at €5,474.**

→ **In the event of a 100-year storm, the economic value of the coastal protection ecosystem service is much greater, at an estimated €2,273,680.**

[35] People living in shacks reside in the State public domain with a title of occupation which is no longer valid because it has expired and was not renewed. Even in case of natural disasters, public support of a resettlement plan is uncertain for these residents (source: EID).
[36] These estimations should be treated with caution as some of the site's fishing activity is informal.
[37] Nets fixed to the lagoon floor.
[38] Nets only used for Mediterranean lagoon fishing, consisting of fish traps attached to a fixed central net.

4.4. CONCLUSION AND RECOMMENDATIONS

In its current state, the Etang de Vic lagoon complex offers effective protection from coastal storms. Biophysical assessment of the ecosystem services shows that this protection reduces the impacts of a 100-year storm to those of a biennial storm (without coastal protection).

The estimation of the economic value of the ecosystem service (€5,474 for a biennial storm; €2,273,680 for a 100-year storm) may seem relatively modest[39], but it is important to consider the limitations inherent to the methodology applied:

- This study models the impact of a single storm episode, but it is the increased frequency of storms caused by climate change that could have greater consequences in the medium term (although this correlation has not been scientifically proven in this sector);
- Estimation of the value of the ecosystem service via the damage cost avoided method does not taken into account the risk aversion of economic players. It is therefore a structural underestimate of the willingness to pay to maintain the current level of natural protection.

Beyond the methodological constraints of the study, the order of magnitude of the result is primarily due to the area's management policy, implemented by the *Conservatoire du Littoral* (Conservatoire du Littoral, 2015). In order to preserve the Etang de Vic lagoon ecosystem, strict regulations limit anthropisation of the area and particularly, the establishment of economic activities or dwellings on the study site. Consequently, the final figure must not be interpreted as a sign of the limited economic value of the coastal protection service provided by the Vic coastal lagoon, but instead as the consequence of the natural preservation policy of one of the few remaining lagoon sites along the Languedoc coastline which has little artificial infrastructure.

More generally, in the light of storms and the rise in sea level, various works highlight the importance of reconsidering the development of Mediterranean coastal plains using a dynamic and adaptive approach, avoiding irreversible developments with adverse effects (Durand and Heurtefeux 2006, OZHM 2014). Minor protection measures (sand fences associated with revegetation) can be recommended to slow sandbar retreat and allow for the construction of a foredune to protect against storms, as on the Etang de Vic site (Durand and Heurtefeux, 2006). Finally, the MISEEVA project (BRGM, 2008-2011) estimated that the strategic retreat strategy for dealing with the rising sea level in Languedoc-Roussillon was half the cost of maintaining the current position[40].

[39] The result is consistent with that of the VMC/MISEEVA project (BRGM, 2011), which concludes approximately €1,000,000 damage for the case of no increase in the frequency of extreme events across the Palavasian lagoons.

[40] (Speech by Coralie Beltrame, MEDPAN conference on the socio-economic benefits of Coastal and Marine Protected Areas, Marseille 23-24 June 2015).

5. Valuation of Flood Control Service, Lonjsko Polje floodplains, Croatia

The purpose is to generate an economic valuation of flood control as it currently stands, an ecosystem service provided by the floodplains in the Lonjsko Polje Nature Park area, in the central Sava basin. (The Sava is a tributary of the Danube). The real volume of the retention area is determined from existing databases, populated with data from the local measurement stations, and the influence of this water storage capacity on downstream propagation is deduced from this information. The replacement cost method is then used for economic valuation, simulating the cost of installing infrastructure that could provide a flood control service equivalent to what is provided by the natural wetlands.

5.1. HYDROLOGY OF THE LONJSKO POLJE SITE

The central Sava plain, between Zagreb and Gradiška, features several floodwater retention areas:

- on the Odra (a right-bank tributary of the Sava, via the Kupa): Odransko Polje;
- on the Kupa: Kupčina;
- on the right bank of the Sava: Zelenik;
- on the left bank of the Sava (upstream to downstream): Žutica, Lonjsko Polje (11,500 ha), Opeka (5,700 ha), Trstik (2,100 ha), Mokro Polje (12,800 ha).

The Žutica, Lonjsko Polje, Opeka and Trstik retention areas do not lie on the course of the Sava, but the Lonja. The Mokro Polje area connects with the Sava via a spillway, and via stretches where the river is not fully contained within embankments. Various items of infrastructure have been built to control water flow in real time during high water episodes (embankments, canals, diversions, sluices, spillways, pumping stations, etc.). The artificial embankments limit the extension of the retention areas. The Lonjsko Polje retention area has more infrastructure than the Mokro Polje area. Most of this has been built since 2006. The most significant infrastructure includes the following:

- The Sava-Odra-Sava (SOS) diversion canal, diverting part of the Sava water flow into the Odra near Zagreb. The water flows back into the Sava via the Kupa at Sisak;
- A system of canals that cross all 5 left-bank retention areas in an upstream-downstream direction. These canals are fed from upstream by the Črnec and the Lonja. They also receive inflow from other left-bank tributaries of the Sava (Česma, Vlahinićki Potok, Gračenica, Repušnica, Kutinica, Ilova, Pakra, Subocka, Novska, Rajićka Rijeka, Sloboština). The downstream part of the Lonja-Strug canal joins the Sava downstream of Gradiška;
- The Prevlaka sluicegate that connects the Sava with the upstream end of the Lonja-Strug canal (max. discharge 600 m^3/s);
- The Trebez sluicegate that connects the Sava with the Lonja-Trebez canal (max. discharge 500 m^3/s).

The river's overall gradient is very low, approximately 0.07‰.

The Nature Park covers the Lonjsko Polje, Opeka, Trstik and Mokro Polje retention zones, a total retention area of 32,100 ha. The total park area is 50,600 ha (see Figure 33).

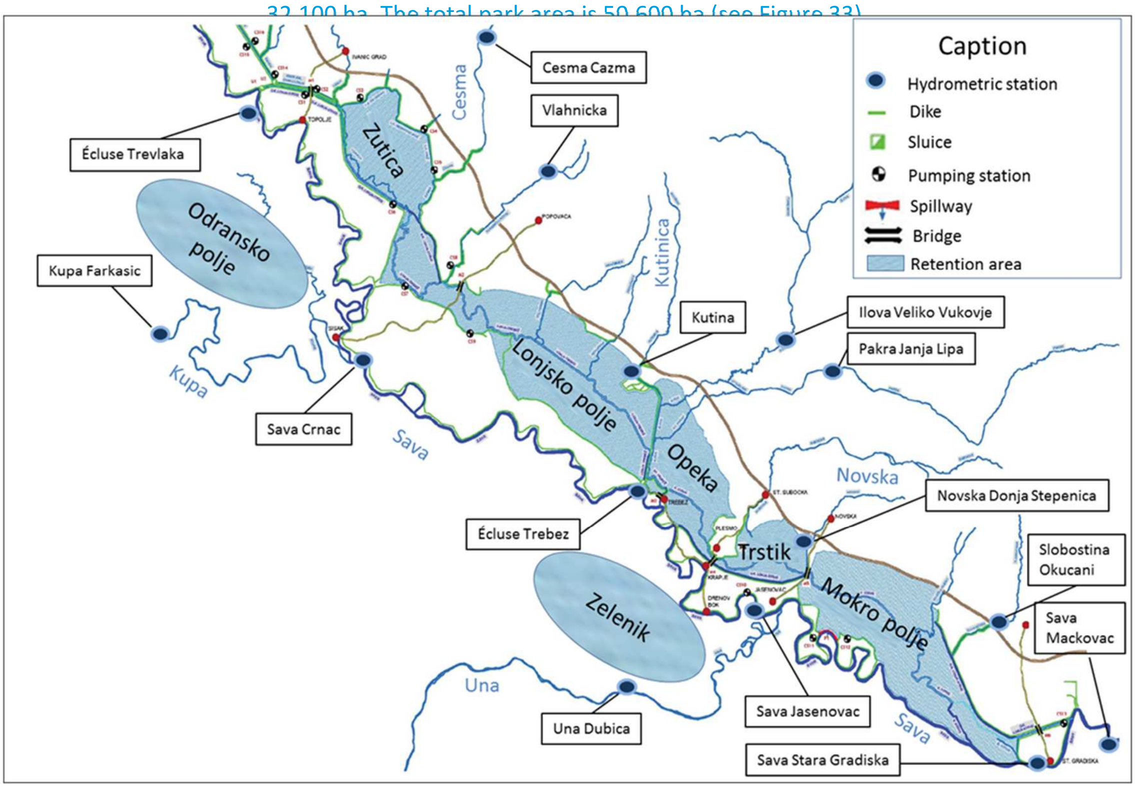


Figure 33The literature features two leading estimates of the Lonjsko Polje site potential retention capacity:

- According to the Ramsar Information Sheet for the site (Ramsar, 2012), the embankments around the Lonjsko Polje floodwater retention zone can retain up to 600 million cubic meters of water, to a maximum water level of 7.5 m ;
- According to a 2012 study by Croatian Waters (Croatian Waters, 2012), the maximum retention volumes (calculated from topographical data) and the corresponding areas are as follows:
  - Žutica: 237 million m³ (6,100 ha);
  - Lonjsko Polje: 1,160 million m³ (19,400 ha);
  - Opeka: 401 million m³ (9,100 ha);
  - Trstik: 222 million m³ (4,000 ha);
  - Mokro Polje: 1,250 million m³ (14,100 ha).

Figure 32: Map of the central Sava basin, the Lonjsko Polje Nature Park and its retention areas (source: Petricec, et al., 2004)

This study suggests that the total retention area in the nature park is 46,600 ha, and not 32,100 as mentioned above. The difference between the two figures may be because different filling heights were taken into account in the calculations.

The total theoretical capacity of the 5 retention areas would therefore be 2.88 billion m³ (elevation of 100 m). This total capacity can never actually be achieved, since the filling levels cannot go higher than 95.25 to 99 m (varying by the retention structure considered). The area is a dynamic storage system, where the water is moving, which generates differences in altitude from one point to the next. The actual maximum capacity of the 5 zones is estimated by Croatian Waters to be close to 1.5 billion m³. The most current and reliable modelling operations performed in 2012 (Croatian Waters, 2012) showed that for a 100-year flood, the real water storage capacity across the 5 zones was no higher than 870 million m³, since the retention areas would not be used to full capacity.

The Sava left bank retention system can be divided into two areas: the Lonjsko Polje system (Žutica and Lonjsko Polje retention areas) and Mokro Polje (Opeka, Trstik and Mokro Polje retention areas). The Lonjsko Polje retention can be artificially managed, in order to divert and store some of the high water flow from the Sava, but in the Mokro Polje area, storage and diversion phenomena cannot be controlled.

The other retention areas along the Sava (Zelenik, Odransko Polje, Kupčina and Jantak) have a volume of approximately 300 million m³ (Croatian Waters, 2012).

5.2. BIOPHYSICAL ASSESSMENT OF FLOOD CONTROL SERVICE

5.2.1. Scope and method

The biophysical assessment contained in this study covers the full network of retention areas within the Lonjsko Polje Nature Park and in its direct vicinity. There are two reasons for this choice:

- the Nature Park is a natural area that is recognised as a wetland area of international importance under the Ramsar Convention, and is managed locally as an integrated zone, particularly due to specific features of the Lonjsko Polje, Opeka and Mokro Polje retention areas. However, the park includes a system of waterways that is connected to other waterways beyond the park boundaries, and it would not be coherent, from a hydrological perspective to consider the park in isolation from the network of retention areas it belongs to;

- this limited scope enables economic valuation of flood control as an ecosystem service, using the replacement cost method. A valuation using the cost avoided method would need to cover all land areas affected by floods on the River Sava, which includes areas far downstream of the Lonjsko Polje Nature Park in Serbia and Bosnia; this would have made the exercise more complex than would have been possible to manage in this study.

There are two aspects to the flood control service provided by the site: reducing flood peak discharge and providing retention capacity in the area. We address the second aspect in this study, since it is easier to envisage replacement infrastructure to provide an equivalent service in the economic part of the study.

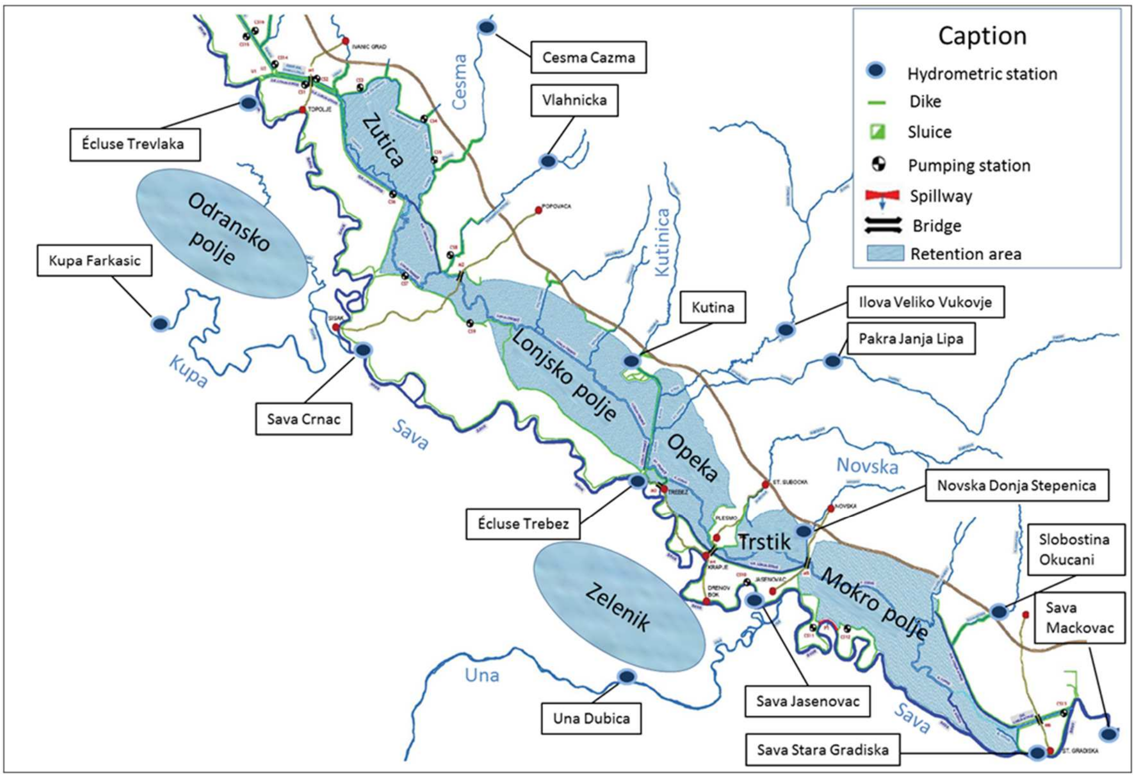


Figure 33: Map showing measurement station locations (adapted from Croatian Waters, 2012)

There are several methods that can be used to assess the effect of a retention area on river flow. Two approaches were considered for this project:

- A statistical approach to the flood discharge values upstream and downstream of the retention area. There is a certain relationship between flood peak discharge and river basin area. By studying the upstream and downstream discharge of characteristic floods (e.g. 10-year, 20-year, 50-year, 100-year flood), certain singularities can be found in the relationship, expressing the crest-reducing effect of the retention areas. However, the data required for this method was unavailable, so an alternative option was adopted;
- An **approach based on the measured discharge values during a specific flood** (selected option). By studying hydrographs (flowrate versus time) at the inlet and outflow from the area, the peak discharge and volume values during the event can be analysed. The hydrograph method takes the study area as an isolated "black box", and does not individually quantify the various hydro-physical phenomena that area involved in the retention service (see Figure 34).

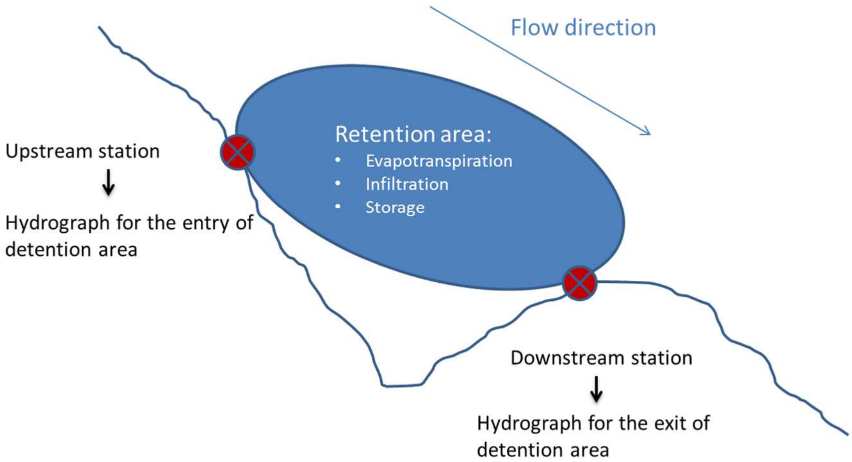


Figure 34: Diagram showing the hydrograph method: comparison of retention area input and output hydrographs

Choosing a representative flood

The reference flood needs to have a number of characteristics:

- The return period should be appropriate to the issue studied;
- Measured flow rates should fall within the measurement station calibration curve reliability range;
- There should be a large enough number of measurement points;
- The event should be sufficiently independent and isolated from previous and successive flood events;
- More generally, the reference flood should be well enough understood and documented.

In addition, in order to generate an economic valuation of flood control as an ecosystem service provided by the site, using the replacement cost method, the cost of infrastructure that would be large enough to protect against violent and sufficiently probable floods (100-year floods at least) should be assessed.

The **flood in the Sava river basin in September 2010** fulfilled all these criteria and was therefore chosen for the study.

2010 was a particularly wet year across Croatia; In September, rainfall was extremely heavy to the North of a line running from Zagreb to Daruvar. Rain fell especially hard between the 16 and 19 September, with the equivalent of more than a month's rainfall hitting already-saturated ground. Statistical analysis showed that the flood event on the upstream stretch of the Sava had the magnitude of a 100-year flood (ICPDR, 2010).

5.2.2. Estimating the retention potential of the Lonjsko polje floodplains

Data used

There are numerous measurement stations in and around the retention zones; however many of them unfortunately only measure water depth and do not calculate flow rate. The discharge data for the September 2010 flood was retrieved from 15 measurement stations:

	River	Station	Station position	Area of river basin monitored (km^2)
1	Sava to O/K. Lonja Strug	Prevlaka Sluice	Upstream	0
2	Sava	Crnac	Intermediate	22,852
3	Sava	Jasenovac	Intermediate	38,953
4	Sava to Lonja Trebez	Trebez Sluice	Intermediate	0
5	Kupa	Farkasic	RB tributary	8,992
6	Una	Hrvatska Dubica	RB tributary	9,368
7	Česma	Čazma	LB tributary	2,406
8	Vlahinićka	Vlahinićki Potok	LB tributary	13.68
9	Kutinica	Kutinica	LB tributary	55.33
10	Ilova	Veliko Vukovje	LB tributary	995
11	Pakra	Janja Lipa	LB tributary	559
12	Novska	Novska donja stepenica	LB tributary	4.78
13	Sloboština	Okučani	LB tributary	117
14	Sava	Stara Gradiška	Downstream	40,262
15	Sava	Mačkovac	Downstream	40,838

LB tributary: left-bank tributary; RB tributary: right-bank tributary;

Table 18: Measurement stations that generated the data used (source: Croatian Waters)

The map in Figure 33 shows the location of these stations.

Flow rate measurements were taken at three other stations, but they had no data for September 2010: Gračenica (measurements stopped on 19/07/2010), Subocka (measurements stopped on 31/12/2009) and Rajićka Rijeka (data missing for 2010).

Various comments should be made regarding the above table:

- The station at Prevlaka sluice only measures the flowrate diverted from the Sava to the Lonja Strug canal. Water only flowed through the sluice for a few days between 18/09 and 23/09. The highest measured flowrate was 445 m^3/s;
- The Crnac station on the Sava is downstream of the Prevlaka sluice and the confluence with the Kupa. It therefore does not measure the flowrate diverted via the Prevlaka sluice, but it does take into account the flowrate diverted via the Sava-Odra-Sava canal and the influence of the Odransko Polje retention area;
- The station at Trebez sluice only measures the flowrate diverted from the Sava to the Lonje-Trebez canal, or any flows in the opposite direction;
- It would appear that the Čazma station on the Česma can receive flows from the Zelina and the Lonja, via the Zelina-Lonja- Glogovnica canal;
- The Stara Gradiška and Mačkovac stations on the Sava are very close to one another, either side of the downstream outflow of the Lonja-Strug canal. When the flowrate measured at these two stations is compared, the difference was never more than 50 m^3/s.

Figure 35 below shows the daily variation in flow rate at these different stations.

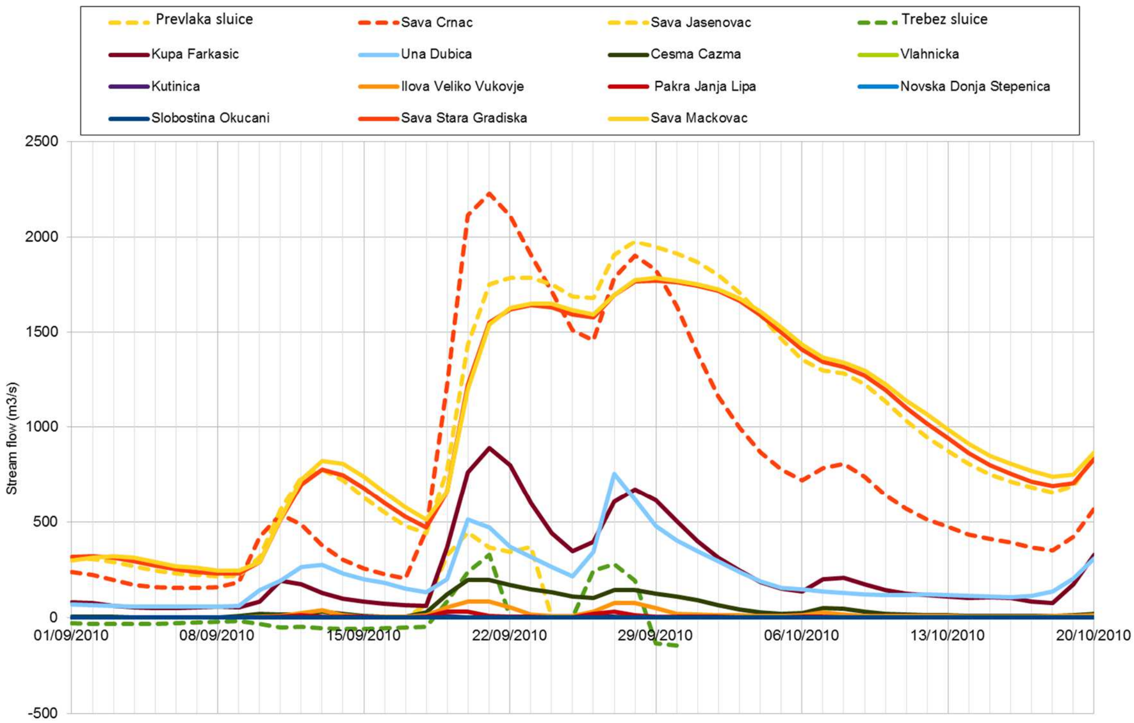


Figure 35: Daily variation in flow rate recorded by 15 measurement stations during the September 2010 flood

Three separate events characterise this flood:

- An initial small-scale flood occurred on 13 September and probably contributed to saturating the soil;
- The main flood event between the 19 and 21 September;
- A third flood between the 27 and 29 September, which was generally less intense than the second one, except on the Una and the two downstream stations on the Sava.

Results

By adding the flow rates on the Sava at Crnac and at the Prevlaka sluice, a flow rate value that is representative of the upstream discharge (including water flowing through the diversion canal to Odra) can be calculated. Lateral inflow is calculated as the sum of the flowrates from the Una and the left-bank tributaries (stations 7 to 13). The Mačkovac station gives the downstream flowrate. The total catchment area whose discharge is measured at Mačkovac is 40,838 km². The sum of the areas of sub-basins monitored by the other stations is 36,370 km², which does not include the areas covered by the Jasenovac, Kupa and Stara Gradiška stations, which are already included in the areas covered by other stations. The monitored area thus accounts for 89% of the river basin as a whole. A multiplying factor of 1.12 was therefore applied to the measured flow rates to calculate total inflow.

The area between the inlet stations (upstream and lateral inflow) and the Mačkovac station covers all 5 retention areas on the left bank of the Sava (Žutica, Lonjsko Polje, Opeka, Trstik and Mokro Polje) and the Zelenik retention area. The role of each specific retention area cannot be detailed on the basis of the data available; it is not even possible to distinguish the effect of the Žutica-Lonjsko Polje system from that of the Opeka-Trstik-Mokro Polje system. Additional flow rate measurements would have been required at various key points across these areas, to give this level of detail.

Figure 36 below compares the flow rates upstream and downstream of the retention areas.

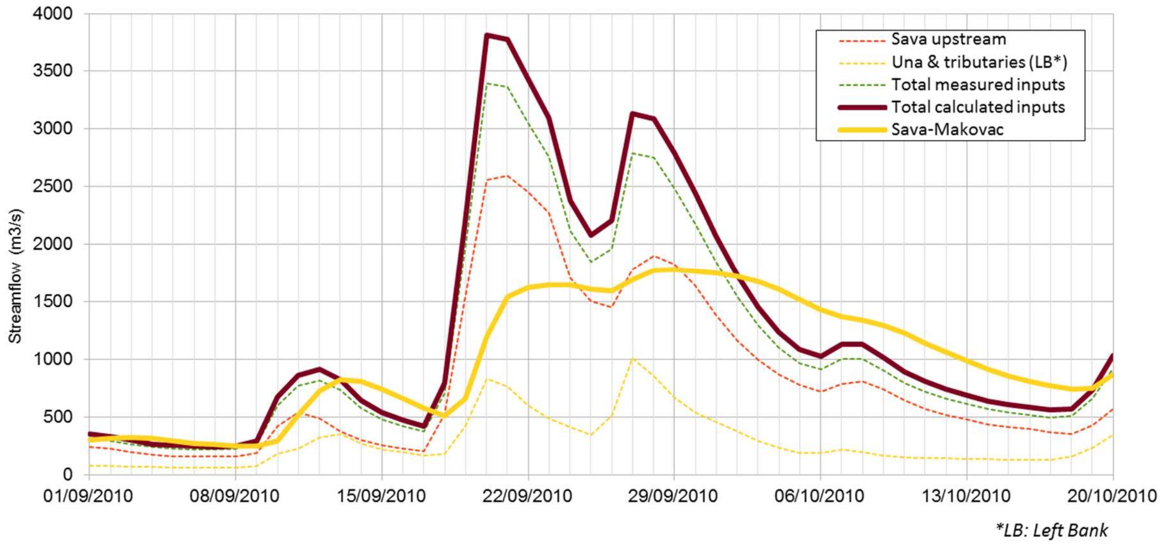


Figure 36: Comparison of flow rates upstream and downstream of the retention areas

The flood peak discharge is 3,810 m³/s at the inlet and 1,560 m³/s at the outflow (Mačkovac), which shows a crest reduction effect of 2,250 m³/s. The crest reduction was greater on the 20/09/2010 peak than on the later 28/09/2010 peak. This clearly expresses the fact that a large proportion of the retention capacity was already being used on 28 September. The volume of water stored during the event can be calculated using the difference between the inflow and the outflow graphs. Each flowrate differential is multiplied by the associated duration (24 hours in this case, since we are working on daily flowrates). All the calculated volumes are added together to give the total volume. The volume of water retained between 18 September and 2 October was thus calculated to be 1,430 million m³. Given the scale of the flood, the volume was stored not only in the retention areas, but also in the wider floodplains.

This 1,430 million m³ volume of water held during the 2010 flood can be compared with the 870 million m³ volume calculated using modelling studies in 2012 (Croatian Waters, 2012). Various factors may explain this significant difference:

- The scope of the two calculations was different (6 retention areas and wider floodplains in our case, 5 retention areas in the other case);
- The hydrological situation in 2010 may have been more unfavourable than the modelled situations;
- Uncertainty over measurement station output may be higher in very high-water situations, in the flow rate ranges where calibration curves are less well-established. Any uncertainties may be very significantly amplified by the differential calculation.

Despite all these reservations, it is clear that the retained volume in the 5 left-bank retention areas in the 2010 flood was close to 1 billion m³.

5.2.3. Biophysical assessment: conclusion

Evaluation of the functioning of central Sava retention areas was carried out based on flow rate measurements taken during a reputed 100-year flood in September 2010. The study area covers the Žutica, Lonjsko Polje, Opeka, Trstik, Mokro Polje and Zelenik retention areas, along with volumes retained in the wider floodplains.

According to this approach, the total volume retained during the flood was 1.4 billion m³, reducing daily peak discharge from 3,810 m³/s to 1,560 m³/s.

The proportion of this volume stored in the left-bank retention areas alone (i.e. excluding Zelenik and the wider floodplains) can be estimated as 1 billion m³.

The limitations of this approach are firstly that it is based on a single event, and it is difficult to assess how representative this event was, and secondly that it does not distinguish between the roles played by each different retention area, in particular those within the Nature Park. The result nonetheless remains consistent with the modelling result from 2012.

A more comprehensive approach would require other configurations to be studied, such as a 100-year flood before the hydraulic infrastructure was built, and 10-year, 20-year or 50-year floods, before and after the hydraulic infrastructure. This method could either use measurements taken during real events (possibly with some reconstitution of missing data using modelling) or statistical data.

Spatial analysis of the role of the different retention areas could be carried out either by hydraulic modelling of a transient regime[41], or by gathering flowrate measurement data from intermediate points that currently do not have this measurement capacity. This would require calibrating measurement stations that currently only measure water level.

5.3. ECONOMIC VALUATION OF FLOOD CONTROL SERVICE

5.3.1. Methodology

Two methods were considered for economic valuation of flood control as an ecosystem service: the cost avoided method and the replacement cost method.

The advantage of the cost avoided method is the ability to use real historical data to test how robust the results are. For instance, a report following the 1000-year flood that affected the Sava river basin in May 2014 (ISRBC - ICPDR, 2014) costed out the damage reported in Croatia, Serbia and Bosnia & Herzegovina[42]. However, the low likelihood of occurrence of this exceptional flood, with water rising higher than the historic levels of 1970 and 1974 in several places, means this is not a relevant reference scenario for a broader study.

There is also another argument against using the cost avoided method in valuation of the flood control service provided by the Lonjsko polje site. A significant fraction of the damage caused by the recent critical flood in 2014 (overall damage estimated to be €3,849 million) affected Serbia (40%) and Bosnia (33 %), which means that a cross-border assessment would be required, which goes beyond the scope of this report and in any case would make it very difficult to provide a comprehensive simulation of damage caused by a theoretical flood.

The replacement cost method thus appears to be the most appropriate in this case. It is the approach most frequently used for the economic valuation of a flood control service. For instance, of the seven valuations of this service surveyed by Aoubid *et al.* (2010), five used the replacement cost method.[43]

For Lonjsko polje Nature Park, the assessment sequence used was as follows:

1. Define the infrastructure required to provide a service equivalent to what is provided by the wetland in its current state;
2. Identify the unit cost of the relevant infrastructure (per linear metre or cubic metre of retained water). Given the lack of available data on the cost of similar infrastructure in Croatia, the figures used were taken from similar scale projects in other countries, and from the Quebec rainwater management reference report *Guide de gestion des eaux pluviales* (Quebec, MDDEFP - MAMROT, 2013);
3. Extrapolate the unit costs to the scale of infrastructure required, as determined in the first step;

[41] The approaches selected to assess the retention potential of the area are complementary to model-based simulation methods. The HEC Hydrologic Modeling System (HEC-HMS) is a tool that simulates the complete hydrological processes of a river system using input data such as rainfall, size of catchment area, etc. in order to forecast and facilitate management of flood events. It does not however output spatialised results. The HEC River Analysis System (HEC-RAC) takes into account terrain features using a spatialised grid system. However, it is time-consuming and complex to set up and it could not have been implemented for this study, even though it could have been useful to make up for missing measurement data using model output results.

[42] In Croatia alone, €153 million of damage was estimated to have been caused by the June 2010 flood (estimated return period between 20 and 100 years), and €32 million by the September 2010 flood (ICPDR, 2010).

[43] The use of one method rather than the other naturally does impact the order of magnitude of the estimated value. In a meta-study of 80 economic valuation studies of ecosystem services, Brander *et al.* (2003) showed that the replacement cost method generates the second-highest values, just behind the contingent valuation method.

4. Convert the calculated replacement cost[44], using the purchasing power parity index, to reflect socio-economic differences between Croatia and the Hungary.

Two main cost types were identified and estimated:

- Infrastructure construction costs;
- Maintenance costs.

In line with common practice for this type of infrastructure, the project lifetime used for cost discounting was taken as 100 years.

5.3.2. Choice of replacement infrastructure

With the retention area, the daily flood peak discharge in 2010 (100-year flood event) was reduced by 2,250 m^3/s and 1.4 billion m^3 of water was stored. The replacement cost method requires definition of the infrastructure that could replace the retention areas and achieve an equivalent result. This approach merely takes into account water-related aspects, regardless of the technical feasibility or any environmental impacts. Various types of infrastructure could be envisaged

- Building a canal to increase water removal capacity by 2,250 m^3/s. In order to avoid creating worse floods downstream, the canal would need to run all the way to the Danube (400 km) or possibly to the Black Sea (1,200 km), flowing through Serbia and Romania. With a 0.07‰ gradient, the canal would need to be 150 m wide and 12 m deep;

- Raising the banks of the Sava and the Danube to increase their transport capacity in high water situations. The length to be envisaged would be the same as in the previous scenario, or even longer if meanders are taken into account. Pumping stations would be required to raise the water from various tributaries to the elevation of the canalised river. Protection measures would be required to protect local communities in the event that the embankments failed. Considering a width of approximately 100 m, the banks would need to be raised by 6 to 7 m.

- Building pumping stations to discharge water into the Adriatic Sea (130 km away, drop approximately 400 m maximum). This would require at least two pipes of 10 m in diameter.

- Building a dam with a 1 billon m^3 reservoir (similar to the size of Lake Serre-Ponçon in France; see Figure 37). Since we are talking such a large capacity, it would need to be split over multiple sites, and water supply and outflow canals or possibly even pumping stations would be required.

Figure 37: Serre-Ponçon lake, France (source: Wikimedia Commons)

[44] World Bank data, International Comparison Program database. Construction costs data for the Hungarian man-made reservoir are provided in Euros, because the program was widely financed on European funds within the framework of JASPERS program.

All these examples are huge infrastructure projects that are technically complex and in some cases wholly unrealistic. They are mentioned for the purpose of estimating a replacement cost, and are not supposed to represent genuinely achievable projects.

For the replacement cost estimate, it was decided to consider the final option - to build man-made reservoirs. This choice was due to data availability, but also because it displays in the most visible form the infrastructure that would need to be developed to provide a service equivalent to the floodplains in their current condition.

5.3.3. Cost of replacement infrastructure

If retention reservoirs with a storage capacity of 1 billion m^3 were to be built, the overall capacity would need to be spread over several sites in order to control floods on the Sava (upstream of Zagreb, in particular) and on its main tributaries (Kupa, Kutinica, etc). The costs generated by the construction and maintenance of four reservoirs, each with a capacity of approximately 250 million m^3 will therefore be considered.

Construction costs

One recent flood management project in the Danube river basin, on the River Tisza, is an example that could be used to assess the reservoir construction cost. This area in Eastern Hungary is regularly affected by large-scale flooding due to a combination of rainfall and thawing snow (ICPDR, 2009). 661,000 people were endangered by these episodes, leading the JASPERS initiative[45] to classify flood protection along the Tisza river as a "priority axis", qualifying the projects for EU funding. Of the various infrastructure projects, the Hany Tiszasüly flood level reducing reservoir is closest to the dimensions considered for Lonjsko Polje, with a retention capacity of 247 million m^3, approximately one quarter of the total capacity required to provide a flood protection service equivalent to what is provided by the current Lonjsko polje site (JASPERS, 2010). It may therefore be assumed that all four reservoirs planned for the Lonjsko polje site would be equivalent to the Hany Tiszasüly reservoir.

The Hany Tiszasüly project, which was completed in 2013, is the closest to the reservoirs considered for the Lonjsko Polje site in terms of purpose (retention basin used for flood protection, with no hydropower) and dimensions. The costs of this Hungarian reservoir could therefore be used to assess the construction costs of each of the four Croatian reservoirs. The JASPERS 2010 Report states that the construction of the Hany Tiszasüly reservoir required a €103,381,697 investment. This figure may be considered the closest and most reliable approximation for the cost of equivalent infrastructure in Croatia. The main source of uncertainty and a potential difference with regard to the cost of the Hungarian project is the purchase price of land required for the reservoirs.

Furthermore, the different socio-economic contexts in Hungary and Croatia need to be taken into account; this could give rise to structural difference between the costs of similar projects in the two countries. In order to avoid this potential bias, the construction cost for the Hany Tiszasüly reservoir needs to be converted based on the purchasing power parity (PPP) between Hungary and Croatia. This indicator considers not only the Euro[46]-Croatian kuna exchange rate, but also the different amount of currency required in different countries in order to purchase the same "basket" of goods and services[47]. The kuna/euro PPP conversion factor is 4.434 and the exchange rate used to convert the amount back into euros is 0.134 euro per kuna (IMF data, 2016). The construction cost for each of the for retention reservoirs to be planned for the Lonjsko Polje site is estimated to be €103,381,697 x 4.434 x 0.134 = €61,424,856. The total construction cost would therefore be €61,424,856 x 4 = €245,699,422.

Maintenance costs

In order to estimate the total investment required to provide flood protection service by man-made means, the cost of maintaining infrastructure must be considered as well as the construction costs.

Unlike the construction costs, which are one-off "initial" costs, maintenance costs are incurred periodically throughout the lifetime of the infrastructure. In line with the recommendations set forth the UK report *Cost estimation for flood storage - summary of evidence* (Environment Agency, 2015), an average service life of 100 years was considered for the reservoirs, even though some components may have a shorter life.

[45] JASPERS (Joint Assistance to Support Projects in European Regions) is a joint initiative of the European Commission, the European Investment Bank and the European Bank for Reconstruction and Development, aiming to finance projects for the public good within the European Union.
[46] Currency of costs borne by European funds
[47] Source: INSEE.

The various maintenance items for retention reservoirs are summarised in the Quebec government's guide "*Guide de gestion des eaux pluviales"* (MDDEFP - MAMROT, 2013). Table 19 gives the maintenance frequency, unit cost and total cost for the infrastructure considered at Lonjsko polje for each of these items of maintenance. For debris removal, maintenance of aquatic plants and maintenance of open-air plants, the unit cost is multiplied by 22,280 ha corresponding to the total area of the four man-made reservoirs. For sediment removal and disposal, the unit cost is multiplied by total area (22,280 ha) and by the accumulated sediment quantity per hectare per year (2.8 m^3; cf. Ontario Ministry of Environment, 2003). This quantity of accumulated sediment per year is then multiplied by four, given that removal operations are carried out every 4 years.

Maintenance item	Maintenance interval (years)	Un it	Unit cost per year (EUR)	Total cost per year of intervention (EUR)
Debris removal	1	ha	978	21,788,325
Maintenance of aquatic plants	5	ha	1,711	38,129,569
Maintenance of open-air plants	5	ha	489	10,894,162
Sediment removal & disposal	4	m^3	154	38,434,605
Inspection	1		49	980 /196*

*5 inspections per year will be required for each reservoir in the first 5 years of operation, at an annual cost of €980. In subsequent years, one inspection per year is enough for each reservoir, at an annual cost of €196.

Table 19: Maintenance costs for retention reservoirs (EUR costs converted using PPP, calculated from MDDEFP - MAMROT, 2013)

Total cost

To calculate the full lifetime cost of the retention reservoirs, the annual costs have to be discounted, and added together to give the sum. Discounting is a way of taking into account the fact that there is a difference in perceived value between one euro in the future and one euro in the present. One simple way of conceptualising it is to consider that one euro in the hand today can be invested in the financial markets and earn interest. Next year, the euro invested today will have increased in "value", due to the compounded interest and will be "worth" more than one euro received at the end of the year.

The discount rate used to quantify the lower value of the future compared to the present is a key variable for assessing total project cost. In line with recommendations issued by the French Plan Commission, as reported by CEREMA (CEREMA, 2014), a discount rate of 4% was used for the first 30 years, followed by a decreasing rate that falls to 2% after 100 years. The general formula for calculating the total discounted cost is:

$$CT = C_0 + \sum_{t=1}^{100} \frac{C_t}{(1+r_t)^t},$$

where:

- C_0 is the initial cost (i.e. construction cost);
- C_t is the sum of maintenance costs incurred in year t;
- r_t the discount rate applicable in year t.

Costs are synthesized in the following table:

	Debris removal	Maintenance of aquatic plants	Maintenance of open-air plants	Sediment removal & disposal	Inspection	Total
Initial maintenance cost	21,788,325	38,129,569	10,894,162	38,434,605	980	109,247,641
Discounted maintenance cost for the 100th year	1,133,708	1,983,990	566,854	1,999,862	10	5,684,424
Sum of the discounted maintenance costs during 100 years	688,487,218	226,939,501	64,839,857	290,296,303	9,784	1,270,572,663
Construction cost						**245,699,422**
Total discounted costs						**1,516,272,085**

Table 20: Synthesis of discounted maintenance and construction costs for alternative man-made infrastructures

→ **Over 100 years, maintenance costs amount to €1,270,572,663. If we add an initial construction cost of €245,699,422, the total project cost for the four man-made retention basins to provide a flood protection service equivalent to what is provided by Lonjsko polje retention area in its current condition could be €1,516,272,085.**

5.4. CONCLUSION AND RECOMMENDATIONS

The Lonjsko polje floodplains provide a flood protection service, which currently requires human management of the retention potential in the natural areas. The site absorbs excess water when the Sava and its tributaries are in flood, protecting the downstream populations from potentially large-scale damage (even when the ecosystem service is provided, the estimated damage is significant).

A further biophysical assessment of the retention potential of various natural basins in the area provided additional understanding of the flood protection ecosystem service. Using available hydrographic data, it was estimated that the site can hold approximately 1 billion m^3 water in addition to the water volume present outside of flooding periods. InSAR[48] techniques can be used to survey the water coverage area in times of flooding, a useful addition to the analysis by comparing inlet and outflow hydrographs from the retention areas. These measurement-based approaches could benefit from being compared with simulation results. Models (HEC-HMS & HEC-RAS[49]) are being developed and in the future should enable the hydrological functioning of the area to be fully understood.

In order to give an economic valuation of the flood protection service provided by the retention area in its current condition, the cost of imaginary man-made infrastructure to provide an equivalent service was estimated. The relevant reservoirs would need to be extremely large, with a total capacity similar to that of the Serre-Ponçon reservoir in France, one of the largest in the Europe. The scale of the investment and the project itself would be huge. An investment of over €1,250 million would be required. Despite the uncertainties inherent in this type of exercise, this approximation nonetheless raises awareness of the value of the service provided.

In unspoiled environments, this value tends to implicitly highlight the water retention potential that is connected to the area of forest cover on site. This potential, in any catchment basin, is higher if there is greater forest coverage (European Environment Agency (EEA), 2016). It has been estimated that, in areas such as Lonjsko Polje, where forest cover is close to 70%, total water retention is 50% higher than in basins with 10% forest cover (EEA, 2016). Alluvial forests thus make a significant contribution to the effectiveness of service provision.

The limitations of current flood management methods, involving constantly raising the height of embankments, with the aim of channelling the flow of the Sava and its tributaries, can clearly be seen. If the natural way the area functions

[48] Interferometric synthetic aperture radar, abbreviated InSAR, is a satellite imaging technique that was developed in the 1990s and can detect centimetre or even potentially millimetre-scale variations in relief over areas of several km². Source: Carnec *et al.*, 2002.

[49] The HEC-HMS is an integrated model that uses various input data (catchment area, rainfall etc.) to output various discharge values, as a forecasting tool. HEC-RAS is a so-called "spatialised" model that incorporates terrain features in order to generate local results on a spatialised grid display. Models of both types are being developed by the Croatian, Bosnian and Serbian authorities, all of whom are affected by floods on the River Sava.

is artificially controlled in this way, the area may become submerged and no longer be able to effectively provide flood protection service. There may also be repercussions for other important services such as forestry (if the trees are submerged for longer, their timber may not be fit for use). An informed approach to floodplain functioning would recommend increasing the retention potential of natural retention areas, and optimising continuity between various retention areas.

It should be noted that, as this case study of a partially controlled system of flood diversion to natural retention areas illustrates, wetlands alone cannot provide total protection against all climate hazards. The best solution for adapting to and mitigating the consequences of extreme weather events is probably a combination of an ecosystem-based approach and a man-made technological approach. As the understanding and management of natural infrastructure improves, the balance is likely to tip in favour of the proper use of such natural environmental features (Plan Bleu, 2013).

Finally, enhanced international cooperation in the Danube region is vital in order optimise the flood control service in the face of observed and likely future increases in this phenomenon. Bodies such as the ISRBC (International Sava River Basin Commission) will probably play an important role (Babic, 2015[50]; Loczy 2013[51]).

[50] Marijan Babic, Croatian Waters. 23rd OSCE Economic and Environmental Forum SECOND PREPARATORY MEETING, Belgrade, 11-13 May 2015. The 2014 flooding disaster in Croatia – Experiences and lessons learned

[51] Denes Loczy 2013, Geomorphological Impacts of Extreme Weather Case Studies from Central and Eastern Europe

6. Valuation of carbon sequestration service, Burullus Lake, Egypt

The purpose is to generate an economic valuation of carbon sequestration as a global climate regulating service provided by Burullus Lake.

Burullus Lake is an "open" type coastal lagoon, with seawater inflow from the Bughaz El-Burullus channel that connects it to the Mediterranean Sea. Open lagoons usually feature significant variations in pH, salinity, oxygenation and temperature due to the seawater inflow and outflow. However, in the case of Burullus, this exchange is limited by large-scale inflow of fresh water from the drainage of agricultural land and from aquaculture farms, leading to desalination and eutrophication.

In this study, sediment and plant life (*Phragmites australis* population, dominant plant species on site) were the carbon storage compartments addressed in the biophysical analysis, for which data was available. A valuation of the carbon stock and carbon flow obtained was then calculated via the social cost of carbon method.

6.1. BIOGEOCHEMICAL CARBON CYCLE IN BURULLUS LAKE

Oceans are a major carbon sink that believed to absorb up to 41% of anthropogenic carbon emissions since the start of the industrial revolution (Khatiwala, *et al.*, 2009). Coastal wetlands play a role in this carbon sequestration by burying sediment containing high organic carbon concentrations.

In Burullus Lake, the main fluxes in the biogeochemical carbon cycle are as follows:

- carbon entering the lagoon ecosystem:
  - dissolution of atmospheric carbon dioxide in the water (inorganic carbon);
  - absorption of atmospheric carbon dioxide by green plants, chiefly *P. australis*;
  - carbon brought through wastewater inflow (9 agricultural drainage streams flow into Burullus Lake).
- internal flows within the lagoon ecosystem:
  - conversion of dissolved inorganic carbon (DIC) into dissolved organic carbon (DOC) by photosynthesis of phytoplankton and aquatic macrophytes;
  - sedimentation of organic matter from the decomposition of aquatic organisms.
- carbon exiting the lagoon ecosystem:
  - carbon dioxide emissions through plant respiration;
  - exploitation of reed beds;
  - fish caught and water taken from the lagoon to supply offsite aquaculture ventures.

The main fluxes are shown in Figure 38 below.

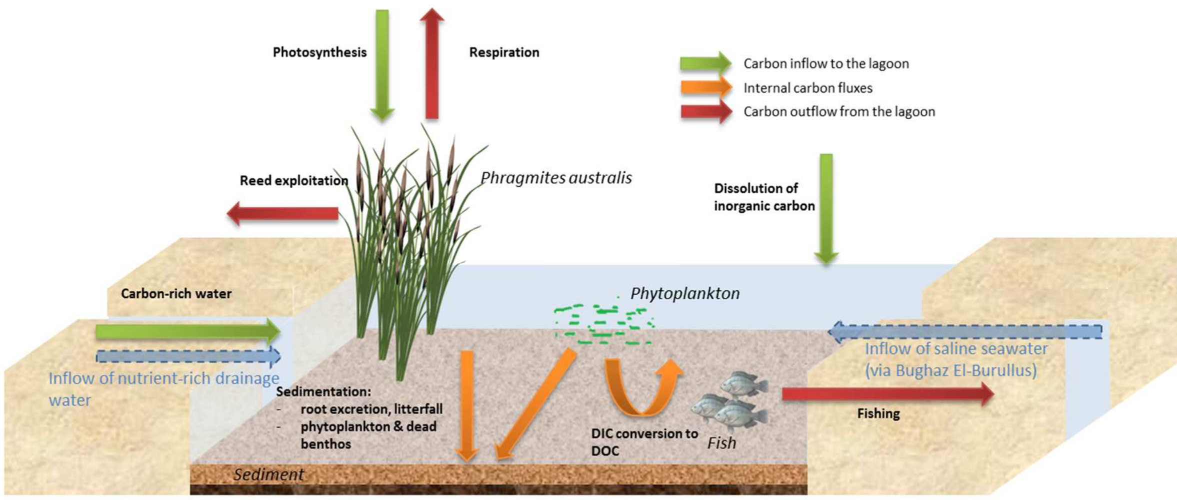


Illustration: Nomadéis

Figure 38: Main fluxes in the biogeochemical carbon cycle in Burullus Lake

Most carbon fluxes within the lagoon ecosystem vary significantly in time. The fluxes related to the reeds (*P. australis*) depend on the plant's life cycle, with a less active period from December to April, when the leaves, stems and panicles die and fall as litter, while the plant lives as rhizome form. Primary production is, therefore, at its maximum in the spring time growing season, with the highest carbon dioxide uptake. Some of the carbon absorbed by the reeds will then become a part of the sedimentary stock during the dormant period.

Phytoplankton photosynthesis, which transforms DIC into DOC, depends on multiple variables, including water temperature, salinity, nutrient-richness and turbidity. All of these factors are influenced the hydrological regime of Burullus Lake, strongly marked by management of agricultural drainage and wastewater inflow, via 9 different drains that feed into the lagoon - a total of approximately 3.9 million m^3 per year (El-Shinnawy, 2002). The biophysical characteristics of the lake are altered when the authorities decide to open the drain valves and allow this nutrient-rich water, loaded with organic matter, to flow in, chiefly when the levels of saline seawater inflow from the Bughaz El channel (to the East of the lake) are low. The impacts of this human management on carbon sequestration in the lake have been very little studied, because they are very complex. The inflow of drainage water tends to lead to eutrophication, which may promote phytoplankton proliferation, but also the development of green algae such as *Scenedesmus*, thus increasing turbidity. All things being equal, the proliferation of phytoplankton should stimulate photosynthesis and hence carbon sequestration; however, increased green algae has the opposite effect, limiting photosynthesis through reduction of light. In addition, the inflow of saline seawater raises the salinity gradient of water in the lagoon and lowers its temperature, at least in the eastern part. These two effects could limit phytoplankton photosynthesis and hence carbon sequestration in the El-Bughaz channel area[52]. The overall effect of human management of the lagoon's hydrological regime on carbon sequestration by phytoplankton is poorly understood, since the various effects of massive inflows from agricultural drainage (along with domestic and aquaculture wastewater) are complex and difficult to quantify.

Like many coastal wetlands, the carbon sequestration potential of Burullus Lake may be endangered by poor ecosystem management and poorly-informed usage of its resources. Duarte *et al.* (2005) calculated that loss of coastal plant-covered habitats may have caused the annual loss of up to 0.03 Gt of carbon sequestration by oceans and coastal wetlands at the start of the 21st century.

[52] See, for example, Watanabe *et al.* (2015) on the effects of salinity on carbon sequestration in a Japanese lagoon, and Ali *et al.* (2012) on variations in the phytoplankton population in Burullus Lake over time, as a function of salinity, turbidity and temperature.

6.2. BIOPHYSICAL ASSESSMENT OF CARBON STOCK AND NET FLUXES

Grey literature on the carbon cycle often differentiates carbon stores such as blue carbon, green carbon, brown carbon and black carbon. This categorisation may however cause some confusion when attempts are made to precisely define the scope of each compartment. Blue carbon, for instance, refers not only to dissolved carbon in water bodies, but also to all carbon stocks accumulated in organisms living in aquatic environments (Nellemann, *et al.*, 2009). Likewise, green carbon includes both plants and the soil of natural ecosystems (Keith, *et al.*, 2008). Brown carbon does not refer to soil organic carbon (SOC), but to greenhouse gases. Black carbon refers to solid particulate matter formed by the incomplete combustion of fossil fuels (Andreae, *et al.*, 2006). Instead of this classification, we have chosen instead to refer to different carbon storage compartments in an explicit manner, differentiated by their nature: plants, sediments, phytoplankton, etc.

The carbon sequestration service can be assessed using two approaches: a stock-based method (carbon accumulated in the area in the past) and a flux-based method (dynamic vision).

6.2.1. Quantifying the carbon stock

The two main carbon sequestration compartments on site, sediments and aquatic plant biomass (reeds) were used as the basis for estimating the current carbon stock in the lagoon.

Soil organic carbon (SOC) was assessed by updating results from a recent study (Eid and Shaltout, 2013), with the effects of changes in plant-covered areas between 2011[53] and the present day. Analysis of 60 samples taken in 2011 (6 sampling sites, with 10 samples per site) showed that the plant cover of an area had a significant effect on the estimated sedimentary carbon stock. Root excretion means that the areas of sediment with plants growing (vegetated areas) show higher levels of carbon transfer than bare areas. The authors used surface coverage data from 2005 to represent the plant cover associated with their sampling campaign from 2011. It must therefore be assumed that reed cover was equivalent at the two dates. However, the growth of *P. australis* fluctuates very significantly and is one of the major issues for managing this natural area. Thus, it is interesting to recalculate the carbon stock contained in the lagoon sediments in the light of more detailed and recent satellite imaging data on plant distribution.

<u>Carbon stock in sediments</u>

Eid & Shaltout (2013) used the following method to estimate the SOC stock in the lake sediments in 2011. After drying and stieving processes (Wilke, 2005), 60 samples were analysed, corresponding to 6 locations and depending on 4 depth layers (0 - 10, 10 - 20, 20 – 30 and 30 - 40 cm). Total SOC (Gg C) was calculated by multiplying the SOC mass per unit area of each zone (plant-covered and non plant-covered) by the surface area of the zone, as follows:

$SOC_t = \sum_{i=1}^{n} SOC_{mi} \times A_i$,

where SOC_{mi} is SOC per unit area in zone *i* (kg C.m^{-2}), A_i is the surface area of the zone of type *i* and *n* is the number of zones *(n=2)*.

Details of the calculations presented below allow reaching a total SOC stock of 3,375 Gg of carbon.

In addition, in our study, we determined the plant-covered and non-plant-covered areas present since 2011, based on maps from satellite images processing performed by the Tour du Valat. Plant densities were derived from average values of NDVI spectral index between winter and summer periods of each of the years analyzed between 2011-2015. Details of the method are presented in Appendix J. Figure 39 presents the areas with plant cover in 2015.

[53] Without more precise data, 2005 surface data provided in Shaltout, et al. (2005) were used to approximate 2011 surfaces.

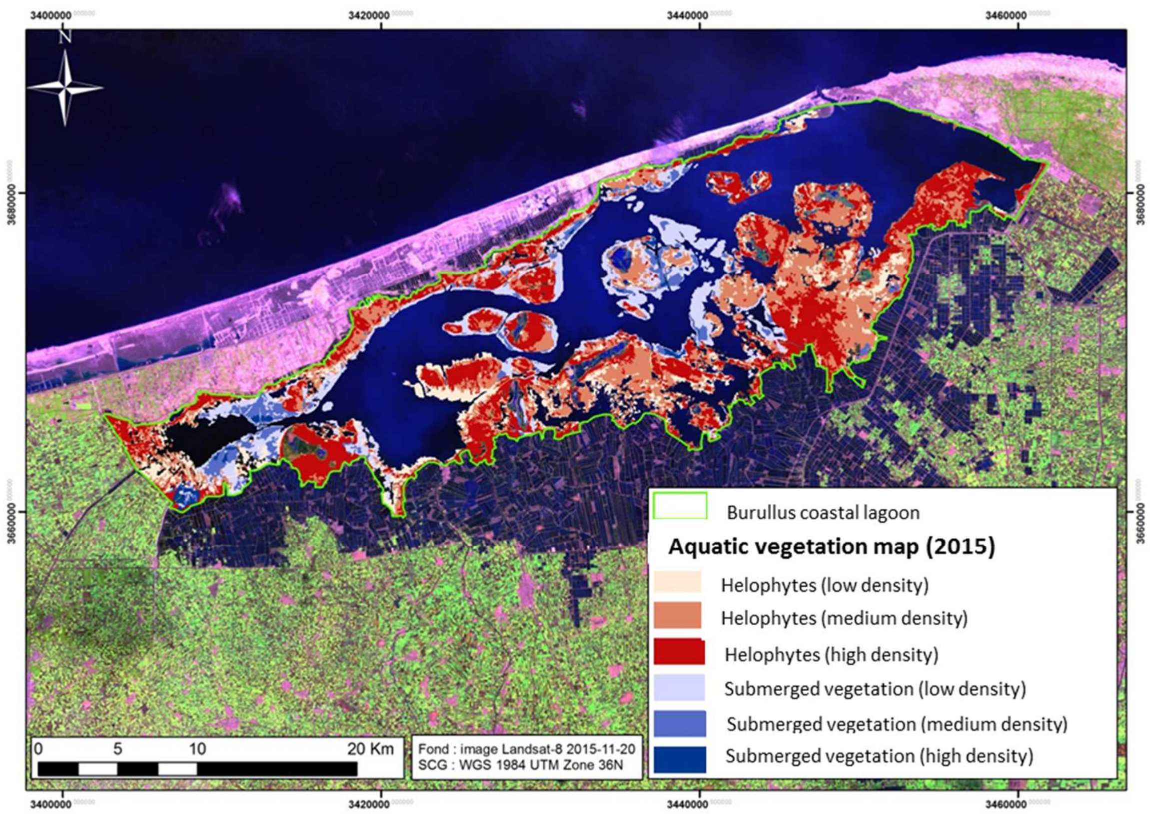


Figure 39: Map of Burullus Lake plant cover in 2015 from Landsat-8 images (Tour du Valat, 2016). Densities are defined by the normalized vegetation index NDVI: low density (<20%), medium density (20-30%) and high density (> 30%)

Table 21 presents the total surface area of zones with plant growth as determined through the mapping:

	Surface (ha)				
Type of plant cover	2011	2012	2013	2014	2015
Helophytes (low density)	4,110	3,770	2,720	2,966	3,048
Helophytes (medium density)	4,854	5,062	5,602	7,123	7,172
Helophytes (high density)	8,775	8,937	10,104	8,248	7,710
Total helophytes	17,740	17,768	18,427	18,338	17,929

Table 21: Surface area occupied by helophytes[54], by plant cover, from 2011 to 2015 (source: Tour du Valat, 2016)

Results of the calculation of the carbon stock in sediment are summarised inTable 22:

	Plant-covered zones	Non plant-covered zones	Total
SOC per unit area (kg C.m^{-2})[a]	9.3	7.4	
Estimated surface area (ha) - mapping	17,929	23,071	41,000
Percentage of surface area	44	56	100
SOC stock (Gg C)	**1,667**	**1,707**	**3,375**

[a] Source: Eid & Shaltout 2013

Table 22: Estimate of organic carbon stored in the sediment (SOC) in plant-covered and non-plant-covered areas of Burullus Lake in 2015

[54] A helophyte is a semi-aquatic plant, typically growing in marshes, whose roots are always under sediment, but whose stems, flowers and leaves are above the water level.

In our study, the carbon stock in the sediment in 2015 is estimated to be 3,375 Gg, while Eid & Shaltout (2013) recorded a stock of 3,181 Gg. The discrepancy is due to the difference between the areas defined as plant-covered and non-plant-covered: our study considered an area of 17,929 ha covered with helophytes (primarily *P. australis*), whereas Eid & Shaltout used surface data from 2005, where plant cover accounted for 8,200 ha[55]. According to their estimates, SOC per unit area was higher in plant-covered areas (9.3 kg C.m^{-2} compared with 7.4 kg C.m^{-2} for non-plant-covered areas). A larger plant-covered area thus naturally gives a higher total carbon stock in the sediment.

<u>Carbon stock in *Phragmites australis* biomass</u>

For carbon stored in plant biomass, we have considered in our study that helophyte coverage can be taken as equivalent to reed coverage (*P. australis*), for two reasons:

- It is the dominant angiosperm species in the lagoon (Eid & Shaltout, 2010), which quickly forms dense monospecific stands when conditions are favourable;
- There is no detailed data available on the exact distribution of other helophytes (*Typha* sp., etc.).

It should be noted that the local community uses the *P. australis* reeds as fuel (Shaltout & Khalil, 2005), which releases the accumulated carbon in the plant directly back into the atmosphere. This aspect is not, however, taken into account in our study.

The carbon content of *P. australis* was calculated by multiplying the dry matter mass per square meter by the carbon percentage in the above-ground parts (leaves, stems, panicles) and underground parts (rhizomes, roots) of the plant in the same area (source: Eid *et al.*, 2010). The mass of carbon per square metre was then split according to the three density thresholds defined above. The quantities of dry matter per square metre given by Eid & Shaltout were attributed to high density *P. australis* cover; the quantities for medium and low density areas were then deduced proportionally[56]. Finally the mass of carbon per square metre was multiplied by the surface area for each density category in order to estimate the total carbon mass.

	Mass (kg DM .m^{-2}	C content (%)	C mass per unit area (kg C .m^{-2})	Total C mass (Gg C)
	Low plant density			
Above-ground parts (leaves, stems, panicles)	0.83	0.43	0.36	10.89
Underground parts (rhizomes, roots)	0.25	0.44	0.11	3.30
Subtotal - Low density	*1.08*		*0.47*	***14.19***
	Medium plant density			
Above-ground parts (leaves, stems, panicles)	2.08	0.43	0.89	64.05
Underground parts (rhizomes, roots)	0.62	0.44	0.27	19.42
Subtotal - Medium density	*2.70*		*1.16*	***83.47***
	High plant density			
Above-ground parts (leaves, stems, panicles)	5.40	0.43	2.32	179.02
Underground parts (rhizomes, roots)	1.60	0.44	0.70	54.28
Subtotal - High density	*7.00*		*3.02*	***233.30***
Total				330.96

Table 23: Carbon stock in *Phragmites australis*

[55] There is another uncertainty with regard to the plant cover included in the “plant-covered” areas defined as such by Eid & Shaltout, which do not necessarily contain helophytes only.

[56] For example, to determine the mass of dry matter of the aerial parts of *P. australis* for medium density, we multiply the equivalent mass for a high density (5.4 kg DM.m^{-2}) by the ratio of medium and high densities (approximated by the center of each class, so 25/65).Selection of a proportionality factor to take into account the carbon content of various densities of *P. australis* adds an uncertainty to the overall estimate. Given the lack of specific data on this subject, a “default” value has been adopted.

→ **The carbon stock contained in the sediment and in helophytes biomass (regarded as *P. australis)* in Burullus Lake can be estimated at around 3,375 + 330.96 = 3,706 Gg or 3.7 million tons in 2015. Sediment accounted for 91% of the carbon stock.**

6.2.2. Quantifying carbon exchanges

In theory, the net ecosystem exchange (NEE) of the lagoon should be estimated on the basis of carbon dioxide and methane fluxes generated by all carbon cycle compartments in the lagoon (sediment, plants, phytoplankton, macroalgae, water column, etc.). However, in practice, due to lack of data availability on gas exchanges in the lagoon and the practical impossibility of new in situ measurements, it is impossible to make an all-encompassing estimate of carbon fluxes. Nonetheless, it can be expected (based on expert input) that in this type of environment, significant methane emissions are to be expected, which could reduce the sedimentary carbon stock.

- **Carbon sequestration potential in the sediment**

After estimating the carbon stock in the lagoon sediment in 2011, Eid & Shaltout (2013) also estimated the lake's potential annual carbon sequestration, as a function of plant cover. In ward carbon flux was updated based on variations in the plant-covered areas since this stock was assessed in 2011. The first 15 to 30 cm of soil are often used in the literature as a proxy for the carbon stock, in that they account for more than half of overall soil stocks (Walter, et al., 2015) (Jenkins, et al., 2013).

Note: *A carbon sequestration potential study of different zones in the Venetian lagoon (Doimi, et al., 2013) concluded that bottom-growing macroalgae played a significant role in CO_2 absorption in the sediment compartment, which suggests this compartment should be taken into account for Burullus Lake. However, the data required for this assessment could not be obtained for the Burullus site, and the sequestration coefficients reported in Italy cannot simply be transferred, since the two sites are different, with different plant and algae communities (chiefly* Ulva lactuca, Enteromorpha sp *and* Zoostera sp *in the Venetian lagoon, and* Potamogeton pectinatus *in Burullus Lake; Shaltout, et al., 2008). In addition, the macroalgae carbon sequestration potential is incorporated into the sediment compartment annually, and the carbon stock in sediment is already assessed. With a sedimentation rate of 4.7 mm per year (3.9 mm per year before the Aswan High dam was built in 1960 and 2.1 mm per year afterwards (Shaltout & Khalil, 2005, cited in Eid & Shaltout 2013) and samples taken at 40 cm depth, the sediment analysis in 2011 by Eid & Shaltout should reflect 85 years of carbonated deposits on the bottom of the lake, thus indirectly taking into account the contribution of bottom-growing macroalgae to carbon sequestration in sediment.*

Following on from Xiaonan et al. (2008) and Shaltout et al. (2013), the carbon sequestration rate in sediment for each type of zone *i* (CSR_i , g C.m^{-2}.yr^{-1}) is estimated from the soil density, sedimentation rate R (mm.yr^{-1}) and SOC percentage. Total carbon sequestration potential in the lagoon (CSP_t, Gg C.yr^{-1}) is then expressed as:

$CSP_t = \sum_{i=1}^{n} CSP_i \times A_i$ where CSP_i is CSP (Gg C year^{-1}) of the ith zone and A_i is area (m^2) of the ith zone.

Results are summarised in Table 24:

	Plant-covered zones	Non plant-covered zones	Total
Carbon sequestration rate in sediment (CSR, gC.m^{-2}.yr^{-1})[a]	14.9	8.6	
Surface area (ha)	17,929	23,071	41,000
Carbon sequestration potential in sediment (CSP, GgC.yr^{-1})	2.67	1.98	4.66

[a] Source: Shaltout *et al.*, 2013

Table 24: Carbon content of annual sedimentation

Carbon sequestration potential in *P.australis*

P. australis is a perennial species which survives winter as a rhizome. Seasonal variations in the quantity of carbon held in 1 m² of vegetation are therefore extremely significant. Photosynthesis, which is the main carbon sequestration mechanism, operates most intensively in the growing season (springtime). It does not make sense to estimate the net carbon exchange at a particular time of the year, or as a yearly average, if the aim is to assess overall contribution of the plant to carbon sequestration. The relevant variable is the annual quantity of atmospheric carbon taken up per square metre of *P. australis*. This corresponds to the annual carbon sequestration service provided by this reed.

In the absence of field measurements, the most reliable data on the carbon balance and dynamics for this species at the Burullus site are results from the model referred by Eid *et al.* (2010). This model, which was developed by Soetaert *et al.* (2004), was calibrated with field data from the site (samples taken at eight locations and five seasons for three of them). Carbon intake into the internal plant cycle generally took place through photosynthesis and rhizome mobilisation. Outgoing exchanges were generated by respiration and deposition of dead plant parts (panicles, leaves, rhizome and roots). Net annual carbon exchanges between 1 m^2 of *P. australis* (above-ground and underground parts) and the atmosphere can be estimated as follows:

C removed from the atmosphere by 1 m^2 of *Phragmites* in one year (g $C.m^{-2}.yr^{-1}$)

= C absorbed by photosynthesis (4,469 g $C.m^{-2}.yr^{-1}$) - C released through respiration (708 g $C.m^{-2}.yr^{-1}$)

= 3,761 g $C.m^{-2}.yr^{-1}$

This figure is comparable to those generated by Gonzalez-Alcaraz *et al.* (2012) in a study of the closest environment to Burullus Lake identified in the literature (Mar Menor lagoon in Spain, a brackish Mediterranean lagoon that had suffered eutrophication through the inflow of wastewater and agricultural drainage, with *P. australis* as the dominant species). In this environment, the annual net carbon exchange from the *P. australis* was 3,205 g $C.m^{-2}.yr^{-1}$.

Similarly for the carbon content estimate, the annual carbon exchange balance for 1 m^2 of plant cover was differentiated by density (low, medium, high density), with the value of 3,761 g $C.m^{-2}.yr^{-1}$ to high density. These values were then multiplied by the corresponding plant-covered surface area, to give and approximation of the overall atmospheric carbon sequestration potential of *P. australis* (see Table 25 below).

	per m^2 (g $C.yr^{-1}$)	Total (Gg $C.yr^{-1}$)
	Low reed density	
C absorbed by photosynthesis	687.5	21.0
C released through respiration	108.9	3.3
Annual C storage	578.6	17.6
	Medium reed density	
C absorbed by photosynthesis	1718.8	123.3
C released through respiration	272.3	19.5
Annual C storage	1446.5	103.7
	High reed density	
C absorbed by photosynthesis [a]	4469	344.5
C released through respiration [a]	708	54.6
Annual C storage	3761	290.0
Total (Gg $C.yr^{-1}$)		**411.3**

[a] Source: Eid, Shaltout *et al.* (2010)

Table 25: Annual net carbon sequestration by the *P. australis* reeds

There are three reasons that could explain the difference between annual net sequestration of atmospheric carbon by *P. australis* (411.3 Gg $C.yr^{-1}$) and the carbon content of annual sedimentation (4.66 Gg C. yr^{-1}):

- the slow rate of ligneous plant tissue decomposition (rhizome), whose organic carbon content may take several years to get into the sediment;
- the short lifecycle of non-ligneous tissue (leaves, panicles), whose carbon content is not fully incorporated into the sediment and may be eaten by detritivores. The rate of decomposition of such tissue seems to be particularly high in eutrophicated environments, which is the case for Burullus Lake (Eid, *et al.*, 2012);
- the pedons analysed by Eid & Shaltout contained no dead rhizomes or roots, with high concentrations of organic carbon.

- Net methane balance

Studies available on methane emissions in riparian environments dominated by *P. australis* show that the quantities of methane released represent a fairly small proportion of the overall carbon exchanges (3% to 5%, cf. Walters, 2010). In the absence of measurements from the Burullus site, and given the lack of certainty as to whether the figures obtained by eddy covariance in very different environments can really be extrapolated (from 0.4 to 31 mg $C.m^{-2}.ha^{-1}$ in Minnesota[57]; 0 to 163 mg $C.m^{-2}.h^{-1}$ in an Amazonian flood plain[58]), no net methane balance will be proposed for Burullus Lake.

6.2.3. Biophysical assessment: Conclusion

The ecosystem service of carbon sequestration in the Burullus lake is approached from two dimensions: the stock and fluxes. In terms of carbon stock, only the two most important compartments are studied, namely sediment and reed bed. The amount of carbon stored in sediments is assessed through measurements made by Eid & Shaltout (2013), and updated based on new maps. The evolution of the vegetated area leads to an estimate of carbon stock in the sediments of 3,375 Gg. The carbon in plant biomass is estimated by regarding all helophytes as *Phragmites australis* species. This assumption allows to assess the carbon stock in the dry matter of this type of reed, taking into account the different density classes identified by remote sensing methods. Given the observed surface in 2015, the carbon stock in helophytes is estimated at 330.96 Gg, and the total stock of carbon in sediments and plant biomass approached 3,706 Gg of carbon.

In terms of fluxes, the lack of data makes it impossible to provide an approximation of net ecosystem exchange (NEE), but only an estimate of net annual carbon flux generated by the reed bed (considered as *Phragmites australis*), and representing a net absorption of 411.3 Gg of carbon per year, together with the carbon content of the annual sedimentation (i.e 4.66 Gg of carbon per year). This approximation could be complemented by a study of other compartments' contribution to the lagoon carbon cycle (eg: phytoplankton), and characterization of methane fluxes.

6.3. ECONOMIC VALUATION OF CARBON SEQUESTRATION SERVICE

6.3.1. Social cost of carbon method

Various methods are used in the literature to value carbon, but the "social cost of carbon" method is the most appropriate for Burullus Lake site. Other alternative approaches have dissuasive limitations:

Clean Development Mechanism

The CDM is open to Kyoto Protocol Annex I countries, and is a means for developing countries to finance greenhouse gas prevention or reduction infrastructure in their territories. In return, the credits purchased by "Annex I" financing countries are deducted from their emissions reduction targets.

Joint Implementation

The principle of JI is similar to that of the CDM (investors buy carbon credits to improve their emissions status, and thus finance clean infrastructure), but in this case, the projects are put in place in developed countries. Most of such projects have been carried out in former Soviet Union countries.

- The market price method requires a relevant carbon market price to be chosen and justified, but Egypt is not currently member of a zone that operates any such mechanism[59]. The country is officially listed as a "non-Annex I" party to the Kyoto Protocol (2005) and can thus participate in the Clean Development Mechanism (CDM) and in Joint Implementation (JI) projects (see below). Until the Paris Agreement enters into force, Egypt is therefore not bound by any greenhouse gas reduction targets. Consequently, and despite the fact that Egypt has expressed

[57] Crill, et al., 1988
[58] Devol, et al., 1988
[59] There are currently national carbon markets (Switzerland), international markets (European Emissions Trading Scheme, ETC) or regional markets (Alberta Province, Canada).

intent to create a carbon market under its national emissions reduction strategy[60], application of a specific market price is not justified. It further appears unsatisfactory to choose a mean or median price based on analysis of world carbon markets, since the prices have been so erratic.

- In countries that have instituted a carbon tax, a carbon stock can be valued on the basis of the tax rate set by Law; however, Egypt has not put in place this type of fiscal mechanism, and it would seem that the carbon market solution is preferred as the future mechanism for meeting emissions reduction targets (INDC Egypt, 2015).
- The replacement cost method would involve estimating the cost of an investment that could store a carbon quantity equivalent to the quantity emitted if the whole lagoon carbon stock were to be released into the atmosphere. However, no existing or planned carbon sequestration and storage projects in North Africa could provide a relevant benchmark for estimating the cost of an infrastructure designed to provide a service equivalent to that provided by the wetland[61].

The method selected is thus the social cost of carbon method. This theoretical cost represents the loss of utility caused by the emission of an extra ton of carbon when the pollution level is optimal (i.e. resulting from the optimisation of a growth trajectory), taking account interest rates and population growth rates, among other things. This idea was popularised in the Stern Report (Stern, 2006), and has been widely used in literature on the valuation of ecosystem services[62]. There nonetheless remain some academic debates about details of the assumptions used (cf. Economic valuation of carbon stock and next fluxes).

Table 26 summarises the potential methodologies and their respective characterisations.

Method	Limitations and characteristics
Market price	Egypt is not part of a mandatory market scheme.
Carbon tax	Does not exist in Egypt.
Replacement cost	No existing project that could be used as a relevant benchmark.
Social cost (selected method)	Most reliable method, despite precautions being required in choosing the static and dynamic parameters.

Table 26: Methodological options for economic valuation of the carbon sequestration service provided by Burullus Lake

The carbon stock and net fluxes are valued, in the first case to quantify the theoretical immediate cost of loss of the ecosystem service, and in the second to estimate the value of the service that would potentially be lost every year.

6.3.2. Determining the social cost of carbon

Social cost of carbon (SCC) refers to the cost, in terms of economic damage to the community, of the emission of one extra ton of carbon into the atmosphere, as compared with a reference emissions trajectory, (for example, corresponding to a business-as-usual scenario based on current demographic and economic trends). In more precise terms, SCC is the change in the discounted utility value of consumption per additional tonne of CO_2 equivalent emitted, expressed in terms of current consumption:

$$SCC(t) = -\frac{\partial W}{\partial E(t)} / \frac{\partial W}{\partial C(t)},$$

where SCC(t) is the social cost of carbon in year t, W is the wealth accumulated over the period in question, E(t) is the quantity of greenhouse gas emitted in year t and C(t) is the aggregate consumption in year *t*. The numerator expresses the marginal impact of the emissions on wealth in year *t*, and the denominator expresses the effect of an additional unit of aggregate consumption in year *t*, taken as a non-discounted value.

[60] “A national market for carbon trading may be established. This national market may further be developed into a regional market, which can attracting foreign direct investment in national carbon credit transactions, especially in the Arab and African region” (INDC Égypte, 2015).
[61] The replacement cost method has been used for economic valuation of natural water purification services (Gren, 2013) or extreme weather event protection services (Sathirathai, 1998), but it would appear that it has never been used for carbon sequestration services.
[62] Voir par exemple Canadian Boreal initiative, 2005.

Most estimates of the social cost of carbon come from simulations using one of three models: DICE, PAGE and FUND (Nordhaus, 2014). These models are referred to as Integrated Assessment Models (IAM) and all have a geophysical part that estimates climate sensitivity (i.e. the relationship between the quantity of greenhouse gas emissions and global warming) and an economic part which expresses global warming in terms of economic damage. These all use four main stages:

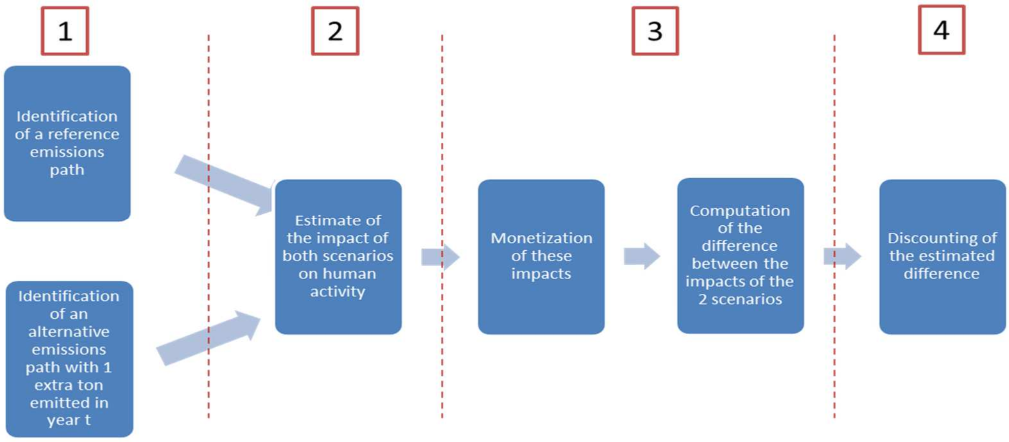


Figure 40: Sequence used in Integrated Assessment Models (IAM) to estimate the social cost of carbon (Illustration: Nomadéis)

Differences between social cost of carbon estimates are primarily due to choices made in calibrating the assumptions at the different stages above, in particular the discount rate chosen. This key variable expresses the relative value a society confers on the future, in comparison to the present, in other words the importance that closeness in time has for a variable. A three percent discount rate, for instance, means that society gets utility of a value equivalent to €100 in year *t* and €103 the next year (*t+1*). The discount rate is determined based on ethical factors, but also based on past observation; there is no established general rule[63]. In order to understand the importance of this parameter, the difference between social cost of carbon estimates with different discount rates can be seen. The Stern report (Stern, 2006) adopted a very low discount rate (0.1%), which gave an estimated SCC of \$89/t CO_2^{-eq} in 2015, whereas calibrating the model with a 1.5% discount rate would give an SCC of \$20/t CO_2^{-eq} (Nordhaus, 2007).

It is therefore important to be aware of the intrinsic limitation of SCC estimates using IAM simulations. The output values depend heavily on the assumptions used, but it is not always possible to satisfactory justify these assumptions (Pindyck, 2013). Table 27 summarises the assumptions required at each stage of simulation with an IAM model:

Steps	Assumptions
1	• Future climate policies and their effects on greenhouse gas emissions • Population growth/variation • GDP growth/variation • Technological advances
2	• Geophysical equations transposing emissions quantities into temperature changes • Effect of global warming on human activities
3	• Estimate of a damage function in order to monetise the effects of climate change
4	• Choice of discount rate

Table 27: Calibration assumptions for Integrated Assessment Models

[63] For example, in the so-called "Ramsey growth model", discount rate R must verify the equation $R = \delta + \eta g$, where δ is the rate of pure preference for the present, η is the risk aversion coefficient and g is the growth rate of consumption.

In this context, given the number of different estimates available in the literature, some authors[64] have sought to use meta-analysis techniques to propose a unified SCC for public policymakers. Nordhaus (2014), though, shows that this approach is rather unconvincing because meta-analysis should use independent sources; in this case, however almost all SCC estimates were based on one of the three main models (DICE, PAGE or FUND). The US Interagency Working Group on Social Cost of Carbon (2010) published a reference report[65], which adopts a range of €9.6 and €49.1/t CO_2^{-eq}, corresponding to discount rates of 5% and 2.5% respectively[66]. In line with this range, **it is proposed in this study to adopt a social cost of carbon of €30 per tonne of CO_2 equivalent (€110 per tonne of carbon)**[67].

6.3.3. Economic value of carbon sequestration service

→ **Taking a carbon price of €30 per ton of CO_2 equivalent (€110 per ton of carbon), the carbon storage service provided by the Burullus site can be valued at approximately 100 x 3,706,000 = €407,660,000**

→ **The sequestration of atmospheric carbon by *P. australis* can be valued at 110 x 411,300 = €45,243,000 per year.**

→ **Every year, sedimentation captures an organic carbon content that can be assessed at 110 x 4,660 = €512,600.**

6.4. CONCLUSION AND RECOMMENDATIONS

The carbon cycle in the lagoon involves multiple compartments (plants, sediments, phytoplankton, etc.) that initiate different carbon fluxes. The atmosphere and immediate lagoon environment are also external compartments that interact with the lagoon ecosystem. In Burullus Lake, high human impact levels, affecting the hydrological regime and potentially causing eutrophication, influence these interactions.

The study site is extremely large, as it represents the biggest Mediterranean reed bed. Biophysical assessment of the carbon sequestration service is affected in two ways by the scale of the study site: the size of the site needs to be borne in mind when apprehending the orders of magnitude of the results, and any synthetic approach is, by necessity, based on simplifications. This study estimated the contribution to the carbon cycle of two main compartments: sediment and the *Phragmites australis* reeds. The carbon stock and carbon fluxes were estimated for both these compartments.

It should however be remembered that these biophysical results, and hence the estimated economic value, need to be supplemented by taken into account other carbon cycle compartments in the lagoon, especially phytoplankton and macroalgae.

A more comprehensive carbon balance should also include methane emissions from the site, which would have to be measured by installing the appropriate sampling equipment.

Finally, the influence of certain key biophysical parameters on the carbon sequestration dynamics such as the influence of salinity and water temperature is still poorly understood and could justify further research.

Nonetheless, even based on current knowledge, it is already clear that the estimated economic value of the carbon sequestration service provided by Burullus Lake is extremely high. This conclusion, which was reached despite the fact that a "reasonable" social cost of carbon[68] was used, should promote further research to enhance current knowledge on the way that different carbon cycle compartments function within the lagoon[69], and should be an incentive to ensure this ecosystem service is not neglected in decisions made with regard to local conservation, that may relate to controlling the hydrological regime or managing the reed population.

[64] See for example (Tol, 2008).
[65] Figure updated in 2013 after the 2010 report.
[66] The limits of this range were defined by comparing simulations using the three main IAMs.
[67] This value is also consistent with the figure of €26.3/t CO_2^{-eq} used by the World Bank in project assessments (World Bank, 2014).
[68] i.e. higher than the current carbon price on the European market (€9 per tonne of CO_2), but lower than the price reported in some countries (e.g. €130 per tonne of CO_2 in Sweden). Source: WTO, 2015
[69] Useful initiative could include regularly mapping/monitoring the plant-covered area, and measuring organic carbon inflow from drainage water flowing into the lagoon.

7. Valuation of carbon sequestration service, Yeniçağa peatlands, Turkey

The purpose is to generate an economic valuation of carbon sequestration as a service provided by the Yeniçağa peatlands, by quantifying the carbon stock and net fluxes (CO_2 and CH_4). If the peatland was overexploited[70], the wetland would no longer be able to provide both aspects of carbon sequestration: firstly, the accumulated carbon stock would be released and secondly, the zone would no longer be able to play its dynamic role as a carbon sink (flux-based approach). The marginal abatement cost of carbon method was used to estimate the economic value of the ecosystem service.

7.1. BIOGEOCHEMICAL CARBON CYCLE IN PEATLANDS

Although peatlands only account for 3% of global land surface, and are mainly found in the Northern hemisphere, they hold up to 33% of the world's soil organic carbon (SOC) (Gorham, 1991). Well-conserved peatlands operate as carbon sinks. Protecting these special wetland areas is therefore a significant issue in attempting to limit human greenhouse gas emissions (GHG) and thus to restrict global warming.

Peatlands play a key role in the biogeochemical carbon cycle (Figure 41) because of their high carbon sequestration potential. Firstly, they form and store organic carbon as peat and secondly, they are involved in significant CO_2 fluxes (incorporating atmospheric inorganic carbon and storing it in organic form through photosynthesis, releasing nocturnal inorganic carbon via plant biomass and the methane-producing activities of microorganisms).

The Yeniçağa peatland is a carex peatland (*Carex limosa L.*), also known as a fen peatland[71]. It is groundwater fed from an aquifer close to the surface. The "non-specialised" plant life that has developed there is dominated by cyperacae, common colonising species such as sedges (*Carex paniculata, Carex elat,* etc.) (Sumer, 2002).

Peat soils are generally near saturation (between 70% and 90% water), fairly acidic and with low oxygenation, which leads to low levels of decomposition of dead organic matter by bacteria. 10% of the carbon dioxide fixed by photosynthesis in the plant biomass cannot be released into the atmosphere. The short term effect is significant accumulation of plant biomass, and in the longer term, peat formation. On average, a peat bog forms over thousands of years, with 5 cm peat formed per century. The peat contains between 70% and 100% dry organic matter, unlike mineral soil, whose dry organic matter fraction is no higher than 10% to 15% (Burt, *et al.*, 1993).

Saturated peatlands create anaerobic conditions, and when they have drains, they also feature high methane production by archaea. These microorganisms are associated with the fermentation of organic matter, a process which takes around ten days.

However, once the maximum organic carbon storage capacity of the peat has been reached, carbon capture falls to near zero in peatlands, and peat formation activity stops. The importance of this type of peatland is therefore related to the way it stores and prevents the release of a large carbon stock captured during the peat formation phase, rather than acting as a "carbon sink" in the strict sense.

[70] Two types of use coexist: the peat can be drained and used *in situ* for agriculture and forestry; off site, the peat is primarily used as a fuel or as horticultural compost.

[71] Fen peatlands, otherwise known as carex peatlands or sedge peatlands are the first stage of peat formation, following the gradual infill of a depression with non-specialised plants such as sedges and weeds. Slightly acidic rainwater begins to collect on the surface of the carex peatland, and sphagnums (peat mosses) begin to grow. This second stage is referred to as living peatland. When the peat becomes so thick that it prevents the mosses from drawing up water, plants that generally prefer dry environments move in. This starts to form a domed-shape and is called a bog. Source: Pôle-Relais Tourbières.

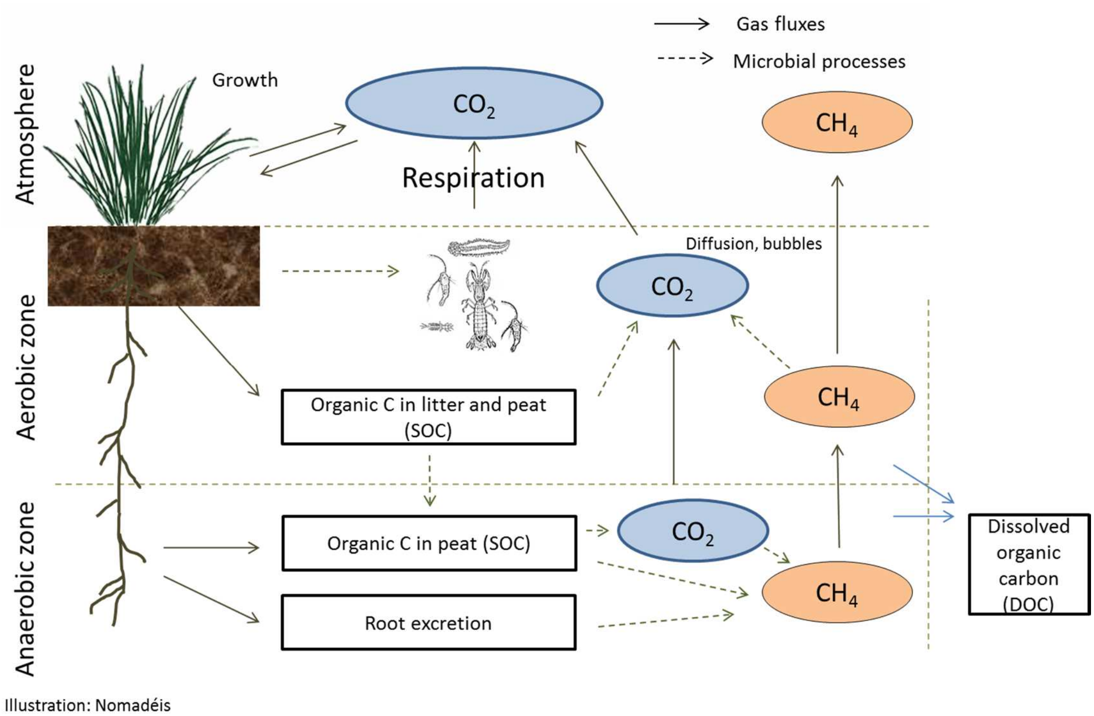


Figure 41: Main carbon fluxes and stocks in a peat bog (adapted from Rydin & Jeglum, 2006 and Parish *et al.* 2008)

In addition, any drains dug into the peat (at Yeniçağa, there are 8 drains across the site), bring the groundwater closer, and cause the peat to become oxidised in contact with air. This leads to an increase in soil-to-atmosphere CO_2 emission and a reduction in the carbon stored in the soil as peat (Rawlins, *et al.*, 2010). Drainage changes biochemical factors such as temperature, redox potential and the quantity of degradable organic matter. It also leads to a reduction in methane-producing activity by bacteria (Blodau, 2002). Several studies all seem to point to the same conclusion, that in general, in a drained peatland, CO_2 emissions increase (Moore and Dalva, 1993; Silvola *et al.*, 1996) and CH_4 emissions fall (Glenn *et al.*, 1993; Moore and Dalva, 1993; Martikainen *et al.*, 1995; Nykänen *et al.*, 1998). Drainage reduces the thickness of the anaerobic zone, where methane is produced and increases the aerobic zone, where CO_2 emissions are produced and CH_4 is consumed. In addition, the lower the anaerobic zone is in the peat profile, the lower the quality of the substrate for methane-producing microorganisms. Lai's literature review (Lai, 2009) provides a very clear explanation of the methane production process in peat bogs. When organic soil is drained, natural methane production is reduced. The soils even become methane sinks when methanotrophs dominate the methane cycle.

In the Yeniçağa peatland, there are areas where peat is extracted, and drained areas that are used for agriculture. This modifies the carbon cycle compared to that of a peat bog with no human influence. The carbon dioxide and methane emissions are also influenced by subsoil clay layers (with near-zero emissions potential, (GIZ, 2010)), and drainage ditches. The configuration of the Yeniçağa peatland is shown in Figure 42.

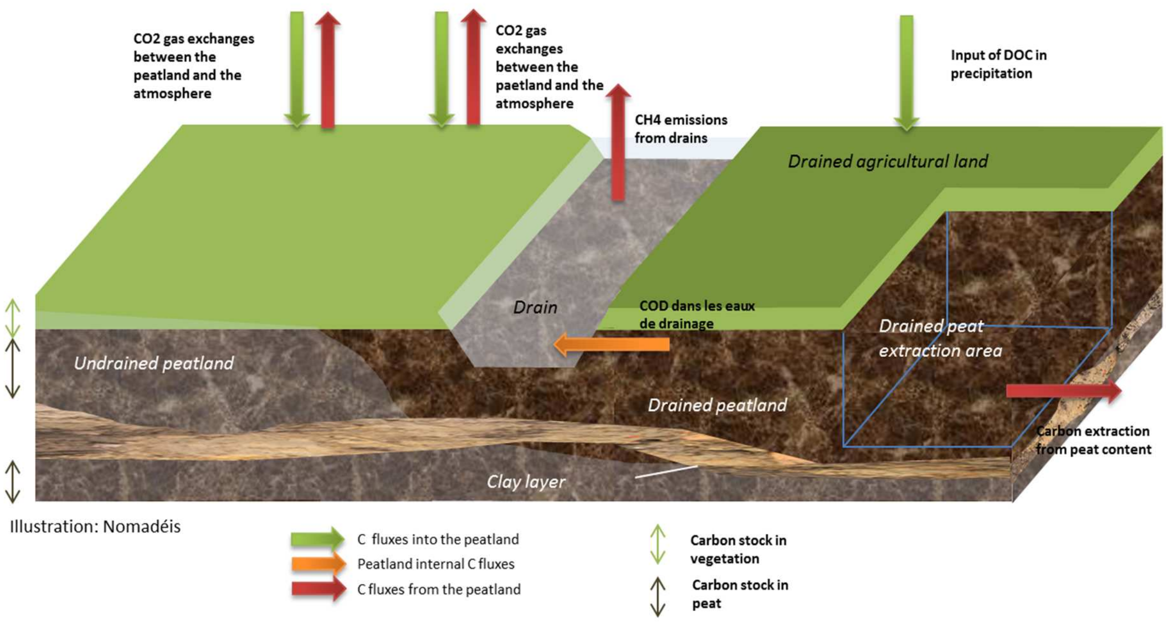


Figure 42: Main carbon fluxes and stocks in the Yeniçağa, Turkey

<u>Sources of carbon emissions to the atmosphere</u>

- CO_2 emissions to the atmosphere;
- Dissolved organic and inorganic carbon in rainwater (DOC);
- CH_4 emissions from underground plant biomass (roots);
- Carbon extraction as peat for human use.

<u>Sources of carbon storage in the ground</u>

- Capture and storage of CO_2 fixed by plant photosynthesis;
- Consumption of CH_4 produced by methane-producing bacteria by methanotrophs;
- Inflow of dissolved organic carbon in rainwater.

7.2. BIOPHYSICAL ASSESSMENT OF CARBON STOCK AND NET FLUXES

7.2.1. Quantifying the carbon stock

Any comprehensive estimate of the carbon stock in the peatland ecosystem should theoretically include stocks stored in two compartments, the soil and plant biomass.

With respect to the soil, in our study, the carbon stock was estimated on the basis of experimental data from research carried out between 2009 and 2013 on the Yeniçağa site (Tubitak project No. 109Y186), coordinated by Prof. F. Evrendilek of Abbant Izzet Baysal University in Bolu. The two studies complied by Prof. Evrendilek's team (Dengiz, et al., 2009) (GIZ, 2010), have been compared with respect to their own measurements (Evrendilek, et al., 2011), giving an estimate of between 2,040 ± 126 $t.ha^{-1}$ and 5,520 ± 238 $t.ha^{-1}$ for the carbon stock in the soil per unit area, depending on the depth interval adopted[72].

Evrendilek et al. (2011) conclude that the Yeniçağa peatland contains between 2,040 and 5,520 tonnes of carbon per hectare, a total estimated potential of between 0.65 and 1.77 million tonnes of carbon in 2009.

The main parameter that needs to be taken into account to generate an up-to-date and reliable estimate of the carbon stock is variation in the surface area exploited since the 2009 assessment. Peat extraction in new areas since 2009 will

[72] The mean minimum depth of peat at the Yeniçağa site is 1.7 m and the mean maximum depth is 4.6 m according to Evrendilek *et al.*, 2011.

have reduced carbon stocks on the site, and therefore needs to be taken into account in the 2016 assessment of carbon stock in the peatland.

The **carbon stock in plants will not be estimated in this study** for the following reasons:

- There is no data to estimate the area currently occupied by various plant species on the Yeniçağa site;
- According to Gorham's estimates (Gorham, 1991), the carbon stock in plant biomass only accounts for 1.5% of the total stock in the peatland. In acknowledgment of the low significance of this compartment, previous studies have decided to leave it out of peatland carbon stock estimates (Canadian Boreal Initiative, 2005). Furthermore, the carbon density of plant biomass can vary by a factor of 20 depending on the nature of the plants (from 342 g/m^2 for herbaceous plants to 6,210 g/m^2 for stands of trees). The species mentioned in Sumer's study (Sumer, 2002), would seem to suggest that the site is in the lower part of the range[73].

Consequently, it must be remembered that the calculation of carbon stock in the peatland soil is a slight underestimate of the total carbon sequestration potential of the peatland.

The organic carbon stock in the soil by unit area was estimated using the following equation (Evrendilek, et al., 2011):

$$SOC\ stock\ (tC.ha^{-1}) = depth\ (m) \times density\ (t.m^{-3}) \times SOC\ (\%) \times 10{,}000(m^2.ha^{-1})$$

where:

- *depth is the mean depth of the layer, i.e. thickness of the peat*[74]*;*
- *density is the result of* $\frac{mass\ of\ homogenous\ material}{volume}$*;*
- *SOC (%) is the fraction of organic carbon in the soil.*

Given that an estimate of the carbon stock per hectare was available, the current area of the Yeniçağa was estimated. Since 2009 (when the peatland surface was 320.3 ha) new areas have been used for peat extraction, except in 2010 when extraction was banned. Peat exploitation resumed in 2011 at a pace of approximately 1.5 ha/yr (Table 28).

Year	New areas exploited[75]
2009	1.5 ha
2010	0 ha
From 2011 to 2016	1.5 ha per year
Total new area exploited since 2009	10.5 ha
Total area currently and formerly exploited for peat extraction (2016)	31.72 ha

Table 28: Variation in areas exploited for peat extraction on the Yeniçağa site. Total area currently and formerly exploited for peat extraction is the sum of areas exploited before 2009 (21.22 ha) and areas exploited since 2009 (10.5 ha)

Since 2009, 10.5 additional hectares of peatland have been used for peat extraction. The updated unexploited peatland area adopted for the total carbon stock calculation therefore corresponds to the area of the peatland in 2009, less the new areas exploited from 2009 to 2016, giving 320.3[76] $- 10.5 = 309.8$ hectares.

Given the lower and upper bounds for soil carbon content per hectare (2,040 and 5,520 t C.ha^{-1}) calculated by Evrendilek *et al.* (2011), the total carbon stock in 2016, as calculated from the unexploited peatland area, is between $2040 \times 309.8 \times 10^{-6} = 0.632$ and $5520 \times 309.8 \times 10^{-6} = 1.710$ million tonnes of carbon (between 2.319 and 6.276 million tonnes of CO_2[77]).

[73] *Phragmites australis* and *Carex pseudocyperus* in the red beds*; Alopecurus arundinaceus, Juncus compressus, Bidens tripartite, Chenopodium album* and *Equisetum palustre* in overgrazed areas and *Cirsium canum, Orchis laxiflora, Euphorbia palustris, Senecio paludosus* and *Teucrium scordium* in drained marshy areas.

[74] Measurements taken or reported by F. Evrendilek *et al.* were performed down to a depth of 30 cm. This proxy is acknowledged in the literature (Jenkins *et al.*, 2013); carbon content decreases very quickly after this initial layer.

[75] There are two peat extraction businesses on the Yeniçağa site. The legal limit for new peat extraction areas is 2 ha per year, but this limit is not fully reached.

[76] Source: Evrendilek *et al.*, 2011

[77] One tonne of carbon can be converted into carbon dioxide tonnes by multiplying the former by the mass ratio (carbon to carbon dioxide) per unit (mole). The conversion factor is therefore 44/12=3.67.

7.2.2. Quantifying carbon fluxes

The carbon dioxide (CO_2) and methane (CH_4) fluxes between the peatland and the atmosphere were estimated separately and then aggregated using the global warming potential (GWP) coefficient to provide an estimate of peatland net ecosystem exchange[78] (NEE) in CO_2 equivalent.

In both cases, emissions were estimated with no distinction made between different sources (soil/biomass).

1. Assessment of carbon dioxide fluxes

For the undrained areas, a flux tower in the northern part of the zone (meadow area, see Figure 43) was used to measure variations in CO_2 flux as a function of various hydrological and atmospheric parameters using the eddy covariance method. The flux tower measurements are report in Evrendilek's study (Evrendilek, 2014) and can be extrapolated to all undrained peatland areas to provide an estimate of their CO_2 NEE.

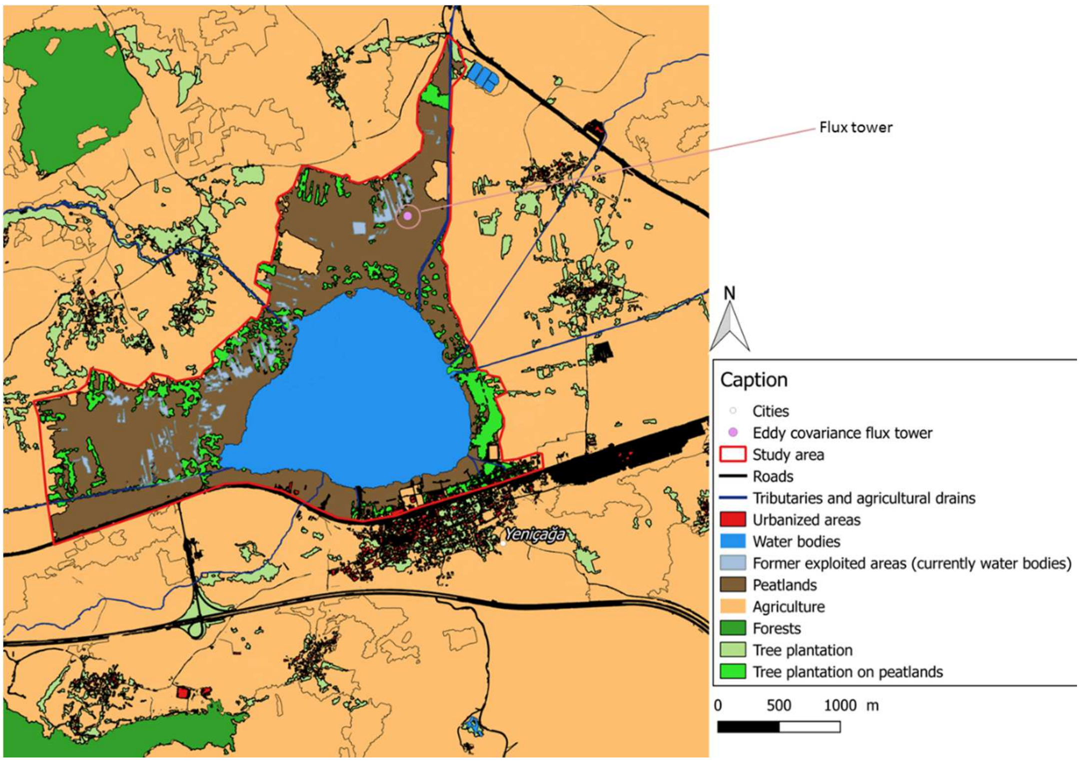


Figure 43: Yeniçağa site land use map, based on data from Tubitak project No. 109Y186 in 2009 (sources: F. Evrendilek, 2014; Plan Bleu, 2016)

Flux tower data from July 2010 to February 2014 (Evrendilek, 2014) highlighted alternating periods during which the area operates as a carbon sink (plant growing season from April to September) and periods during which the area emits CO_2. This seasonality is also affected by extreme events such as floods, droughts and fires (which are rare on the Yeniçağa site, with only two occurrences reported during the measurement period). These flux tower measurements are relevant to the undrained areas[79], and can therefore be extrapolated to the corresponding areas within the peatland perimeter, a total of 309.8 ha.

On average over the three years of measurements, the land within the flux tower measurement zone acted as a net CO_2 sink (-0.22 mg $CO_2.m^2.s^{-1}$ annual mean). The mean flux in growing season is -0.28 mg $CO_2.m^2.s^{-1}$; outside this period, the fluxes are lower and estimated to be +0.05 mg $CO_2.m^2.s^{-1}$ [80].

[78] Net ecosystem exchange (NEE) is the difference between the quantity of carbon taken up by photosynthesis (gross primary productivity) and the quantity of carbon released back into the atmosphere by all the respiration in the ecosystem (Chapin, *et al.*, 2006) (Moureaux, *et al.*, 2008).
[79] It is not entierly clear whether the area the flux tower is installed in (2x2km) should be considered drained or undrained, since it is an area that has been developed; nevertheless, the fact that the area functioned, on average, as a carbon sink over the three years suggests that it should be considered undrained.
[80] Evrendilek's 2014 study has been adopted rather than Evrendilek's 2013 study (which came to a conclusion of mean annual net CO_2 emissions of -0.04 mg $CO_2.m^2.s^{-1}$), since although both pieces of work used redundant data, the latter had a shorter measurement period (590 days instead of 3 years).

According to this emissions-per-unit-area data (converted into CO_2 per hectare per year as -69.388 t.CO_2.ha^{-1}.yr^{-1}) and based on the surface area reported above, the undrained areas represent a net sink of approximately $-69.388 \times 309.8 = -21{,}496$ t CO_2 per year.

The results of the extrapolation were supplemented by data for the drained areas, for which the IPCC CO_2 emissions coefficient was applied (IPCC, 2014). This method takes into account both the CO_2 emissions from drained soils and the emissions from the drainage water.

For drained soils, the IPCC reports unit area carbon dioxide emissions coefficients of 19.45 and 10.28 t.ha^{-1}.yr^{-1} for drained agricultural land and drained peat extraction areas respectively. The corresponding surface areas in the scope of the study are as follows:

- 42 ha of drained agricultural land;
- 31.72 ha of drained peatland.

In total, the drained areas of the Yeniçağa peatland emit approximately $(19.45 \times 42) + (10.28 \times 31.72) = 1{,}143$ t CO_2 per year. However, this figure should be revised to take account of the subsoil clay layers under the peatland, which have a near-zero emissions potential. In accordance with DKM recommendations (GTZ, 2010), a 30% reduction coefficient was therefore applied to the CO_2 emissions, giving a final total of 800.03 tonnes CO_2 per year.

Finally, dissolved organic carbon (DOC) fluxes were estimated using IPCC coefficients (IPCC, 2014), and applied to an area corresponding to a 2-metre wide strip of land either side of all the drainage ditches on site. The emissions coefficients were calculated using the following formula:

$$EF_{DOC} = DOC_{Natural\_flux} \times (1 + \Delta DOC_{drainage}) \times Frac_{DOC-CO_2}$$

where:

- EF_{DOC} is the DOC emissions factor for a drained site (t C. ha^{-1}.yr^{-1});
- $DOC_{Natural\_flux}$ is the DOC flux for an undrained site (t C. ha^{-1}.yr^{-1});
- $\Delta DOC_{drainage}$ is the proportional increase in DOC flux on a drained site compared with an undrained site;
- $Frac_{DOC-CO_2}$ is the conversion factor for the proportion of DOC converted to CO_2 following export from the site.

For peatlands in temperate zones, the IPCC reports values for the following parameters that give a DOC emissions factor for a drained site EF_{COD} estimated as 0.31 t C. ha^{-1}.yr^{-1} or 1.11 t CO_2. ha^{-1}.yr^{-1}.

The area to which this coefficient was applied is approximated as a 2-metre strip either side of each drainage ditch (with the exception of the outflow from Lake Yeniçağa). The length of the drains was calculated using the map shown above, and the area of the corresponding strips around the drains was obtained by multiplying the drain length in metres (i.e. two strips of 2 m wide either side). The areas in question are specified in Table 29:

Drain	Length (km)	Land strip surface area (ha)
Kinali	0.217	0.087
Aksu	0.152	0.061
Findikh	0.391	0.157
Kirenli	0.217	0.087
Ömerli	0.152	0.061
Kaymaz	0.261	0.104
Güzveren	1.413	0.565
Kuziviran	0.217	0.087
Total	**3.02**	**1.209**

Table 29: Surface area of the 2 m wide strips of land either side of the drains within the study zone (source: calculated from F. Evrendilek, 2014 and Plan Bleu, 2016)

Consequently, the estimate for carbon dioxide emissions from the strips of land either side of the drains is $1.11 \times 1.21 = 1.34$ tonnes per year. When revised with the 30% reduction coefficient for the subsoil clay, this gives estimated emissions for 0.94 t CO_2 per year from these strips of land.

Note: *Dissolved inorganic carbon (DIC) is the least-studied variable in the literature on carbon fluxes. Research on the subject* (Worrall, *et al.*, 2003) *tends to show that it only accounts for a small proportion of exchanges. This fraction will therefore not be considered in the rest of this study.*

Type of land	Emissions factor by unit area (CO_2 $t.ha^{-1}.yr^{-1}$)	Surface area (ha)	Reduction coefficient applied for the clay layers	Total (CO_2 $t.yr^{-1}$)
Drained agricultural land	19.451	42.0	30%	**571.86**
Drained peatland	10.276	31.72	30%	**228.17**
Undrained areas	-69.388	309.8		**-21,496.40**
Strips of land emitting DOC	1.109808	1.21	30%	**0.94**
Total		**383.5**		**-20,695.43**

Table 30: Summary of CO_2 emissions from the Yeniçağa in its current state (2016)

→ **In total, the Yeniçağa site in its current state is a net carbon dioxide sink with $-21,496 + 800.03 + 0.94 = -20,695.43$ tonnes of CO_2 sequestered per year.**

Net carbon dioxide emissions if the whole area were totally drained

In order to fully grasp the carbon sequestration service provided by the Yeniçağa site in its current state, the net carbon dioxide fluxes in/from the area can be simulated for a hypothetical scenario in which it were totally drained for agricultural usage (current legislation places very strict limits on use of the peat).

By using the emissions coefficients by zone described above, and considering a drained area of 351.8 hectares (the current drained agricultural areas plus the areas that are not currently drained), the area would become a net emitter of carbon dioxide, releasing 5,019.24 tonnes of CO_2 per year[81].

Type of land	Emissions factor by unit area (CO_2 $t.ha^{-1}.yr^{-1}$)	Surface area (ha)	Reduction coefficient applied for the clay layers	Total (CO_2 t.yr-1)
Drained agricultural land	19.451	351.8	30%	**4,790.28**
Drained peatland	10.276	31.72	30%	**228.02**
Strips of land emitting DOC	1.109808	1.21	30%	**0.94**
Total		**384.73**		**5,019.24**

Table 31: Summary of CO_2 emissions from the Yeniçağa site if the whole area was drained (hypothetical scenario)

→ **In total, in the hypothetical scenario that the whole Yeniçağa site was drained, the whole area would become a net carbon dioxide source, with $4,790.28 + 228.02 + 0.94 = 5,019.24$ tonnes emitted per year.**

→ **It can thus be seen that the Yeniçağa, which is currently a carbon dioxide sink, would no longer play a carbon sequestration role if the whole area were to be drained; instead it would become a net CO_2 source (**Figure 44**).**

[81] The usage of the fictive drained areas is considered as agricultural, since the current legislation strictly limits the peat extraction on new areas.

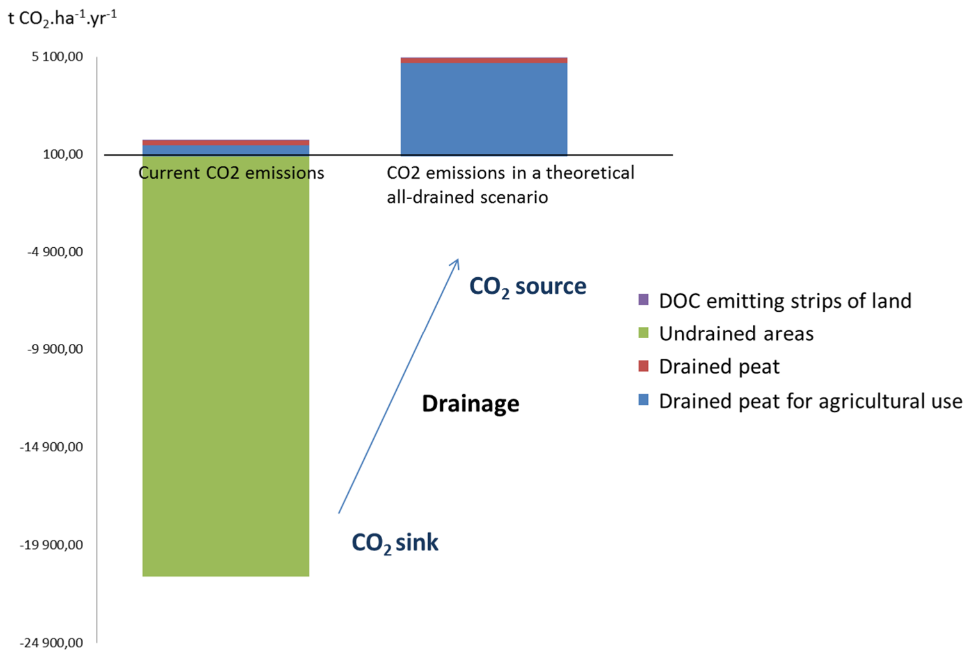


Figure 44: Comparison of net CO_2 emissions from the Yeniçağa site in its current state (2016) and in the hypothetical scenario whereby the whole area was drained

2. Assessment of net methane flux

For budgetary reasons, the flux tower on the Yeniçağa site does not measure methane flux. It is more difficult to measure greenhouse gases produced by bacteria than to measure greenhouse gases produced by plants (e.g. CO_2 or water vapour), even under ideal meteorological conditions.

In order to estimate methane emissions from the Yeniçağa site, a distinction is made between drained and undrained areas. For the undrained areas, data has been transferred from a California peatland, studied by Baldocchi et al. (2011). For the drained areas, the IPCC method was used (IPCC, 2014), which identifies emissions coefficients for drained soils and drainage ditches. The IPCC reference coefficients were applied to surface areas calculated on the basis of mapping data.

In the literature, the closest site to Yeniçağa in terms of climate conditions is the Sacramento-San Joaquin Delta peatland in California. Table 32 summarises their similarities and main differences.

Characteristics	Yeniçağa	Sacramento-San Joaquin
Similarities		
Latitude	40.77115	38.575764
Mean annual temperature	13.6°C[a] /10.4°C[b]	15.6°C
Mean annual precipitation	538[a] mm / 542.2[b] mm	325 mm
Mean annual evapotranspiration	1200[a] mm / 818[b] mm	2190 mm
Drainage	Partial	Partial
Type of peatland	Fen peatland	Fen peatland
Depth of water table	65 to 132 cm (Dengiz, 2009)	50 to 70 cm
Differences		
Altitude	990 m	-10 m
Type of climate	Temperate	Temperate / Mediterranean

[a] according to GIZ 2010 (period covered: 1975-2006); [a] according to Evrendilek 2013 (period covered: 2010-2013)

Table 32: Comparison of the geoclimatic characteristics of the Yeniçağa peatland in Turkey and the Sacramento-San Joaquin peatland in California (sources: GIZ, 2010; Evrendilek, 2013; Baldocchi *et al.*, 2011)

Methane fluxes on the Californian site were measured by laser spectroscopy over an undrained area from April 2007 to August 2010, and analysed using the eddy covariance method (which was also applied on the Yeniçağa site for measuring CO_2 flux) (Baldocchi, *et al.*, 2011). The mean annual methane emissions rate was estimated to be 8.77 g C $m^{-2}.yr^{-1}$ (114.01 kg methane per hectare per year[82]), with significant variation between emissions measured in the daytime (4.2 g C $m^{-2}.yr^{-1}$ on average) and night-time emissions (13.1 g C $m^{-2}.yr^{-1}$ on average).

Based on this study, **methane emissions from the 309.8 ha of undrained land on the Yeniçağa site can be estimated as $\mathbf{114.01 \times 309.8 = 35.32}$ tonnes of methane per year.**

For the drained areas, the IPCC recommends using coefficients of 1.8 and 6.1 kg $CH_4.ha^{-1}.year^{-1}$ for drained agricultural land and drained peatlands respectively.[83] On the Yeniçağa site, there are 42 ha of drained agricultural land and 31.72 ha of drained peatlands. When the IPCC coefficients are applied to these areas, the **methane emissions from drained areas can be estimated at $\mathbf{1.8 \times 42 + 6.1 \times 31.7 = 0.27}$ tonnes of methane per year.**

The water in the drainage ditches on the Yeniçağa site also emits methane. The IPCC recommends that drains in agricultural land should be differentiated from drains in peat extraction areas and that methane emissions coefficients of 527 and 542 kg $CH_4.ha^{-1}.yr^{-1}$ respectively should be applied to the surface area of these drains.

The distribution of each type of drain by usage was estimated using mapping[84], giving an estimate of 0.39 ha for drains on agricultural land and 0.82 ha for drains in peat extraction areas.

Drain	Length (km)	Land strip surface area (ha)	Drain surface area (ha)	
		Total	of which agricultural land	of which drained peatland
Kinali	0.217	0.087	0.043	0.043
Aksu	0.152	0.061	0.030	0.030
Findikh	0.391	0.157	0.000	0.157
Kirenli	0.217	0.087	0.000	0.087
Ömerli	0.152	0.061	0.015	0.046
Kaymaz	0.261	0.104	0.000	0.104
Güzveren	1.413	0.565	0.283	0.283
Kuziviran	0.217	0.087	0.022	0.065
Total	**3.022**	**1.209**	**0.393**	**0.815**

Table 33: Surface area of drains through agricultural land and drained peatland areas (source: calculated from F. Evrendilek, 2014 and Plan Bleu, 2016)

The **drains are responsible for the emission of approximately $\mathbf{527 \times 0.393 + 542 \times 0.815 = 0.65}$ tonnes of methane per year.**

→ **In total, taking into account the drained and undrained areas, methane emissions for the Yeniçağa in its current state can be estimated as $\mathbf{35.32 + 0.27 + 0.65 = 36.24}$ tonnes per year.**

Net methane emissions if the whole area were totally drained

In the hypothetical scenario that the whole area was drained for agriculture, it can be estimated that the methane emissions from the Yeniçağa site would be reduced to $1.8 \times 351.8 + 6.1 \times 31.7 + 0.65 = 1.48$ tonnes per year.

→ **In the hypothetical event that the whole area was to be drained, methane emissions would be reduced to net emissions of 1.48 tonnes CH_4 per year.**

→ **If the whole area were drained, it can be seen that the methane emissions from the Yeniçağa site would be reduced (Figure 45).**

[82] One tonne of carbon can be converted into methane tonnes by multiplying the former by the mass ratio (carbon to methane) per unit (mole). The conversion factor is therefore 16/12=1.33.
[83] Coefficients for a temperate or boreal zone, relatively nutrient-poor.
[84] The approximate percentage of the drain through agricultural land and drained peatland was estimated from map on Figure 43 above. The drain surface area was then calculated on the basis of an average width of 1m for each drain, and the land strip surface areas was calculated on the basis of a width of 2m for the land strips on each side of the drains.

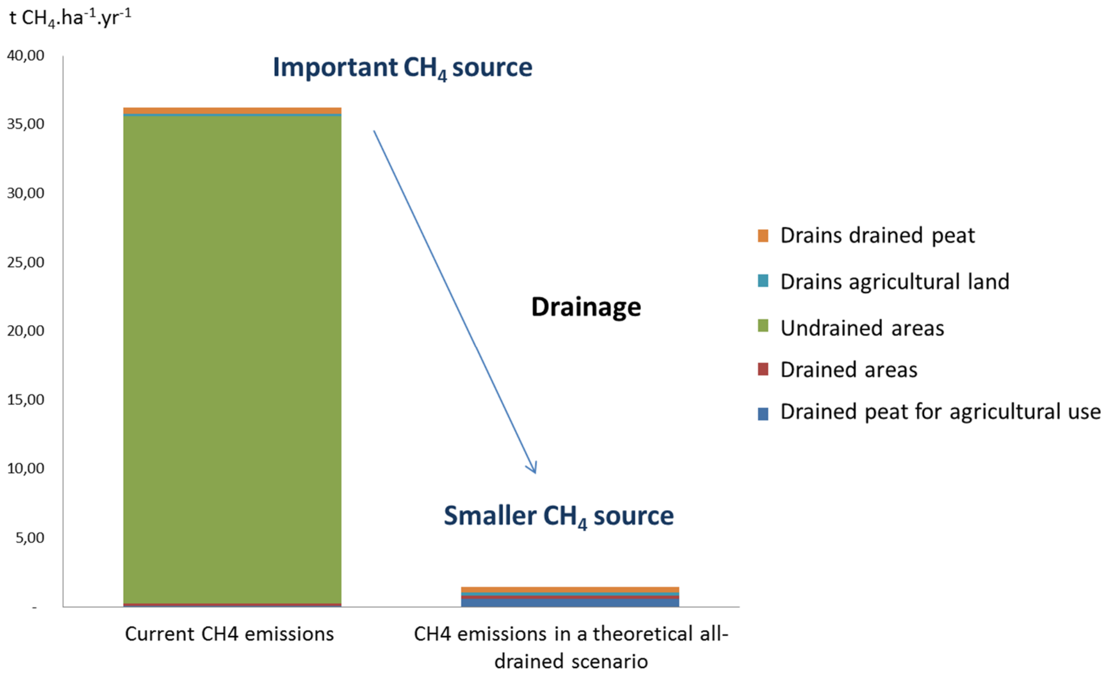


Figure 45: Comparison of net CH_4 emissions from the Yeniçağa site in its current state and in the hypothetical scenario whereby the whole area was drained

3. Assessment of total net emissions in CO_2 equivalent

The total carbon balance for the Yeniçağa requires the net carbon dioxide and methane fluxes to be converted into a single common unit, tonne CO_2 equivalent (t CO_2^{-eq}).

The IPCC recommendation for this conversion is to use the global warming potential (GWP).[85] The GWP of methane (CH_4) compares the radiative forcing[86] of the gas with the radiative forcing of carbon dioxide over a certain period of time, generally 100 years. Despite is widespread use, GWP has certain limitations:

- GWP does not take account of the different levels of the gases in the atmosphere over time, only their respective radiative power. This is problematic because the radiative power of methane is significantly higher than that of carbon dioxide (0.97 W.m^{-2} versus 0.48 W.m^{-2}, IPCC 2014), but its concentration in the atmosphere varies very differently over time. Methane remains in the atmosphere for an estimated 12 years, whereas carbon dioxide remains in the atmosphere for up to 100 years after emission (IPCC, 2014).
- the link between radiative forcing and concrete climate change related damage has not been clearly established (IPCC, 2009). In particular, there is a time lag between radiative forcing and temperature change (Dufresne, 2009);
- the choice of a 100-year time horizon for PWG calculation is arbitrary and does not match the typical timeframes that are used when discussing climate policies (Boucher, 2010).

Because of these various limitations, a range of alternatives to GWP can be used to aggregate different greenhouse gases. Boucher (2010) mentions the following two options:

[85] Global warming potential (GWP) is an indicator that seeks to measure the cumulative effect of all greenhouse gases using a single unit. Conventionally, it is limited to direct greenhouse gas, i.e. the six gases covered by the Kyoto Protocol (CO_2, CH_4, N_2O, CFC, HFC, SF_6). This indicator is expressed as "CO_2 equivalent" since, by definition the greenhouse effect attributed to CO_2 is given the reference value of 1, and the other substances are expressed relative to CO_2 (Source: INSEE).

[86] On a global scale, radiative forcing refers to the rate of energy transfer from Earth to the upper layers of the atmosphere per unit area, expressed in Watts per square metre (IPCC, 2007).

- Global temperature change potential (GTP) expresses the change in global mean surface temperature caused by emissions of a gas (Kelvin.kg^{-1}) over a specific time span. The GTP of a gas is normalised against the GTP of carbon dioxide. The relative advantage of GTP over GWP is that it makes a direct link between greenhouse gas emissions and warming. However, the values used depend heavily on the time horizon used and the assumptions adopted regarding the way the deep ocean absorbs and releases energy from the initial radiative imbalance (GWP does not rely in such assumptions). Consequently, GTP calculations entail more uncertainties than GWP calculations (Shine, et al., 2005);
- Global damage potential (GDP), an indicator developed by Tol et al.(2008) comes out of a programme seeking to minimise the discounted cost of climate change adaptation. The relative GDP of two gases is calculated as the ratio between the respective cost of emissions reductions for each gas, based on the emissions strategy set out following the optimisation calculation. In particular, Tol et al. show that GWP is a special case of GDP, if certain assumptions are adopted[87].

Table 34 shows the conversion coefficient values given by each method for a 20-year and a 100-year time horizon.

	GWP		GTP		GDP[88]	
	20 years	100 years	20 years	100 years	20 years	100 years
CO_2	1	1	1	1	1	1
CH_4	72[89]	25[23]	57[90]	4[24]	82[91]	21[27]

Table 34: CH_4 and CO_2 conversion factors by method

For this study, a 100-year time horizon was chosen in order to use the same framework as the IPCC. Upper and lower limit values are given for CO_2 equivalent, calculated using the 100-year GTP and GWP values respectively. Having mentioned all the methodological precautions required, the net greenhouse gas balance for the Yeniçağa in carbon dioxide equivalent - in its current state and in the hypothetical scenario that the whole area were drained are summarised in Table 35 below.

	Lower limit (100-year GTP)		Upper limit (100-year GWP)	
	CO_2	CH_4	CO_2	CH_4
Current net balance(t CO_2-eq)	-20,695.44	36.24	-20,695.44	36.24
	-20,550.48		**-19,789.47**	
Hypothetical net balance (t CO_2-eq)	5,019.24	1.48	5,019.24	1.48
	5,025.14		**5,056.14**	

Table 35: Summary of the biophysical assessment of carbon sequestration potential in the Yeniçağa peatland

7.2.3. Biophysical assessment: conclusion

Carbon sequestration service provided by Yeniçağa peatlands has a static dimension (stock) and dynamic dimension (annual sequestration). Analyses performed by Evrendilek, et al., (2011), allowed estimating that the amount of carbon stored in the peat was between 0.632 and 1.710 million tonnes in 2016.

The net carbon emissions depend on the drainage of the area, occurring for agricultural or extractive purposes. If the area acts as a net carbon sink in its current state (absorption between 19 789.47 and 20 550.48 tons of carbon dioxide equivalent per year, according to the clustering coefficient of retained carbon dioxide and methane), the area is likely to become a net carbon emitter in case of drainage of all surfaces (up to 5 056.14 tonnes of carbon dioxide equivalent emitted per year, in the worst scenario).

The net carbon emissions in a fictive state of total drainage highlights the importance of careful management of the wetland, which takes into account all ecosystem services provided by a site in good conservation status - including carbon sequestration service.

[87] Finite time horizon, zero discount rate, greenhouse gas concentrations that do not vary over time and cost of climate change effects taken proportional to radiative forcing.
[88] With a zero discount rate.
[89] Source: IPCC, 2007
[90] Source: Shine *et al.*, 2005
[91] Source: Boucher, 2010

This conclusion is all the more valid here as this study probably underestimated the potential for sequestration site Yeniçağa:

- Lake Yeniçağa sediments were not taken into account, while the water reserves of carbon storage potential can be significant[92];
- Organic carbon stored at more than 30 cm depth was not considered here, but should be added as, in calcareous soils, inorganic form of carbon from carbonates ($CaCO_3$)[93].

7.3. ECONOMIC VALUATION OF CARBON STOCK AND NET FLUXES

7.3.1. Greenhouse gas abatement cost valuation method

Not all the various carbon sequestration valuation methods can be applied to the Yeniçağa peatland. Turkey is in an unusual situation with respect to the market price and carbon tax methods. It has a special status in the regime that has existed since the Kyoto Protocol entered into force (2005). Turkey is officially listed as an "Annex I" party and can thus theoretically participate in the Clean Development Mechanism (CDM) and in Joint Implementation (JI) projects. However, a decision made at the 7th Conference of the Parties to the United Nations Framework Convention on Climate Change, which entered into for on 28 June 2002, released Turkey from the obligation to pursue greenhouse gas emissions reduction targets and suspended it from participating in the CDM and JI mechanisms. Despite a stated intention to implement a national carbon market (INDC[94] Turkey, 2015), it is not yet relevant to use the market price method to value the carbon sequestration service provided by the Yeniçağa peatland.

Although Turkey is not part of any mandatory carbon trading schemes, it is nonetheless the third-largest player in the voluntary carbon market (VCM, see below), with $207m credits traded since 2007, corresponding to 31.7 Mt CO_2-eq. (EcosystemMarketplace, 2015). Most of the projects financed in Turkey with VCM credits are mid-capacity hydropower plants and wind farms (Ciner, *et al.*, 2014). However, it does not seem altogether appropriate to use the price of a tonne of carbon on the VCM, since the carbon offset in this way is carbon from the countries buying the credits, and not carbon from Turkish emissions (Turkish investors buying credits on the VCM).

Voluntary Carbon Market (VCM)

The VCM, like the CDM and JI is a platform for trading carbon credits, but it is based on voluntary offsetting. Projects proposed for funding are certified under two independent schemes (Gold Standard and Verified Carbon Standard). The USA ($656m), Brazil ($233m) and Turkey ($207m) are the leading countries in total trades over the last 11 years, with a 14% increase seen in 2014. (EcosystemMarketplace, 2015)

The Table 36 below summarises the potential methodologies and their respective characterisations.

Method	Limitations and characteristics
Market price:	
- mandatory scheme	Turkey is not part of a mandatory market scheme
- voluntary (VCM)	Turkey benefits from this market, but probably not for offsetting its own carbon emissions
Carbon tax	Does not exist in Turkey
Replacement cost	No relevant reference project
Social cost	Global cost, not specific to Turkey
Marginal abatement cost (option adopted)	Method most appropriate to the Turkish context, taking into account the INDC targets

Table 36: Methodological options for economic valuation of the carbon sequestration service provided by the Yeniçağa peatland

[92] "The role of inland waters in the global carbon cycle and climate forcing can be modified by human activities, including the construction of basins that accumulate large quantities of carbon in sediments and emit large amounts of methane in atmosphere" (Tranvik al., 2009)

[93] The latter two stocks are less well characterized than surface organic carbon stocks, but they are considered to have very long residence time in soils (higher than the millennium) and thus participating less in carbon flow, especially to the atmosphere. Source: Walter et al, (2015).

[94] Intended Nationally Determined Contributions (INDC): At the Paris 2015 Climate Change Conference (COP21), each country was required to publish its nationally-determined contribution (INDC), which was each country's greenhouse gas emissions reduction commitment for the 2025-2030 period, with the goal of limiting global warming.

Instead of adopting a social cost of carbon method in the same way as for the Burullus Lake study, the selected option was to value the carbon sequestration service using the **greenhouse gas emissions marginal abatement cost.** Abatement cost refers to the cost of implementing a greenhouse gas emissions reduction policy, as compared with a "business as usual" scenario (BAU). The "marginal" aspect means that the abatement cost of one additional tonne of carbon dioxide (CO_2) equivalent is assessed. In order to quantify the cost of such policies for Turkey, a study by the EBRD (EBRD, 2011) has prioritised investments to reduce Turkish emissions according to their economic interest at different carbon price levels (Figure 46). The part of the bar chart which corresponds to a positive carbon price covers projects theoretically undertaken once the carbon price reaches a given level. The projects with a negative carbon cost are calculated differently: the height of each bar corresponds to a comparison between a scenario with constant energy intensity and a scenario with lower energy intensity, thanks to the project. The following formula is used:

$$Value\ of\ one\ tonne\ of\ carbon = \frac{Quantity\ of\ emissions\ abated\ by\ the\ project\ in\ question}{Total\ project\ cost\ (construction\ \&\ operation) - cost\ of\ current\ technology}.$$

The width of the bar for each project shows the total quantity of abated emissions that are saved.

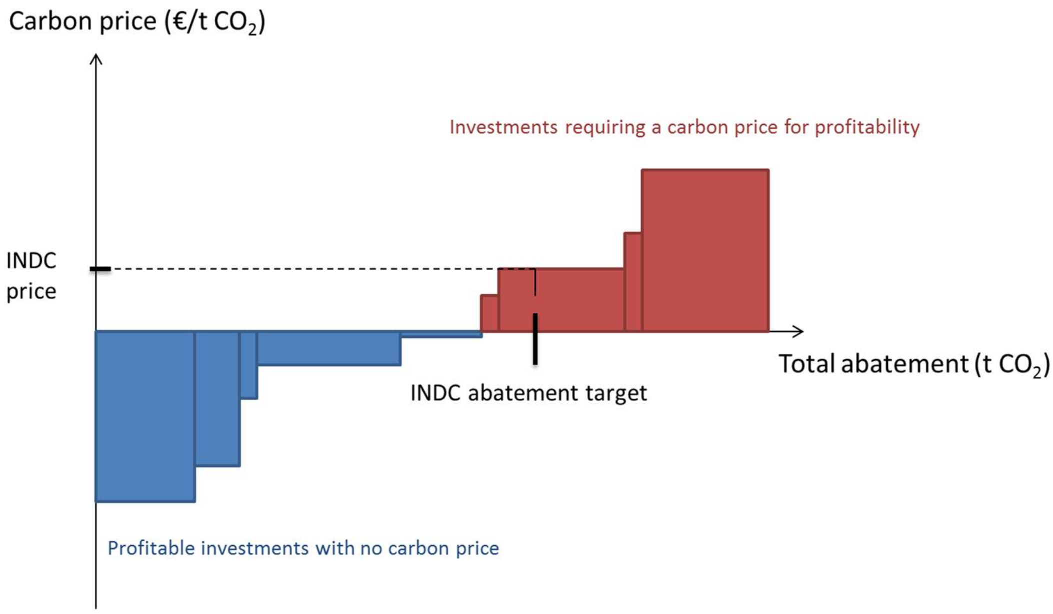


Figure 46: Example of the carbon marginal abatement cost graph

In order to define the carbon price used in the economic valuation of the service provided by the Yeniçağa peatland, the measures described in Turkey's INDC were compared with the "planned policies" scenario described by the EBRD (Table 37), and the corresponding carbon price was deduced from the official emissions reduction target (21% cut by 2030, as compared with a business-as-usual trajectory). This price was then applied to the estimated carbon stocks and fluxes for the Yeniçağa peatland.

7.3.2. Establishment of the carbon price

The EBRD study (EBRD, 2011) takes into account all sectors that are relevant in reducing the country's energy intensity (construction, power, transport, manufacturing, etc.), considers two time horizons (2020 and 2030) and analyses three reference scenarios in calculating the abatement cost:

- A *status quo* scenario which assumes no new climate policies are implemented in Turkey; the policies implemented 2011 would continue as they are until 2030;
- A *planned policies* scenario, which considers the implementation of projects planned or announced by the Turkish government by 2011;
- An *enhanced policies* scenario, which describes the possible measures that could be taken to enhance Turkish climate policy beyond the objectives and means announced in 2011.

Each aspect of climate policy was examined, comparing the plans described in Turkey's INDC (Turkey, 2015) with the hypothetical EBRD scenario with which it shares the most characteristics (Figure 47).

The *Planned policies* scenario is the closest to the Turkish INDC, so the corresponding carbon marginal abatement graph was used to determine the carbon price. Turkey's official target is to reduce its greenhouse gas emissions by 21% in 2030 compared with a "business as usual" scenario. This would represent an abatement of 246 Mt CO_2-eq. When this quantity of abated carbon is applied to the marginal abatement graph for the *Planned policies* scenario, the price of one tonne of carbon in order to make the necessary investments is found to be €26[95].

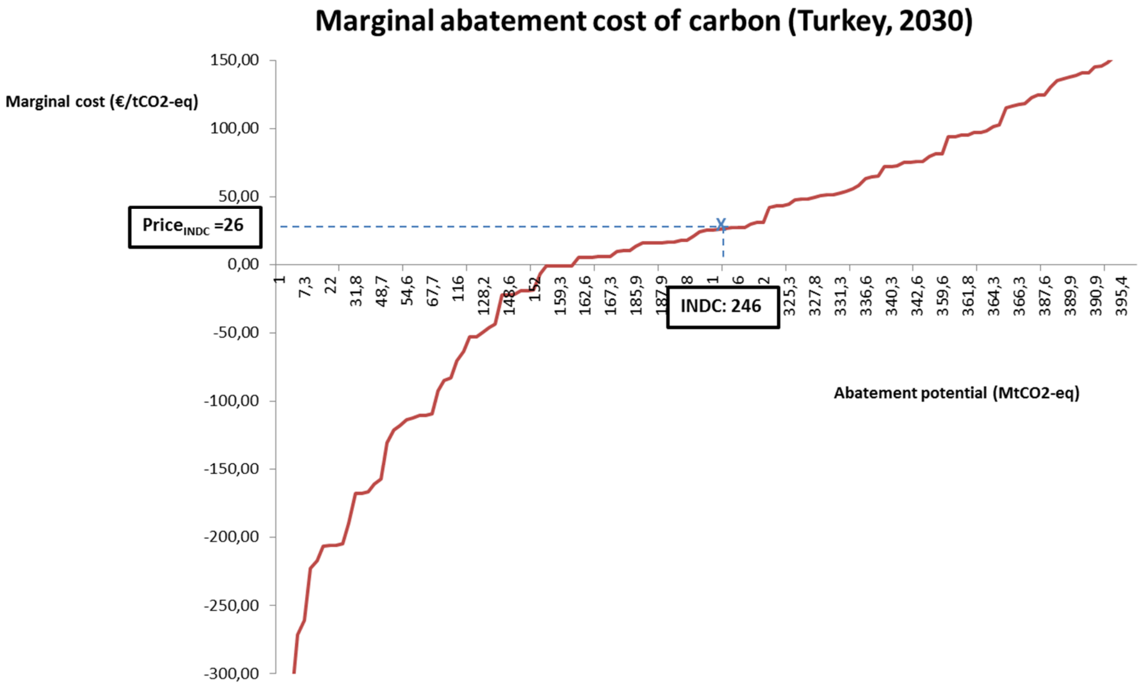


Figure 47: Carbon price established using the marginal abatement cost method
(source: calculated by Nomadéis from EBRD data)

[95] Original data in 2011 euro value, adjusted for inflation to 2015 euros.

	Status quo	Planned policies	Enhanced policies	INDC Turkey (by 2030)
Fossil fuels	• Free lignite supplied to poor households • Coal mines subsidised	• Reduced public support for the mining sector (coal), but no impact on prices (imported coal dominates)	• Free lignite supply programme suspended • Increased gas demand, covered by imports	• Renovation of existing state-owned powerplants
Market structure	• Gas market dominated by BOTAŞ • Gradual liberalisation of other markets	• Liberalisation of gas market • Gradual liberalisation of other markets	• Same as *Planned policies*	• Not discussed
Energy security	• Gas plants limited to 30% of total electricity generation • All lignite reserves are explored	• Gas plants limited to 30% of total electricity generation • All lignite reserves are explored	• No more official target	• Not discussed
Renewable energies	• Subsidies kept at 2011 levels • No state support for hydropower investments • Limited development of wind power	• Increase in subsidies • Improved cross-border power grid to allow imports of hydropower from Georgia (5 TWh/yr)	• Higher subsidies than in *Planned policies* scenario • Power generation sector included in the European Emissions Trading Scheme The carbon price is €40/tCO_2 **or** investment subsidies are granted for renewable energies (20% of initial cost)	• Increase solar power generation capacity to 10 GW • Increase wind power generation capacity to 16 GW • Use the full hydropower potential of the territory
Nuclear power	• No state-sponsored development programme, private investment possible	• Public contracts to develop a nuclear power industry (10GW by 2030)	• Same as *Planned policies*	• Build one nuclear powerplant (Akkuyu; 4.8 GW)
Construction	• Limited improvement in energy efficiency. • Development of urban gas networks • Development of air conditioning to levels observed in Southern Europe (30% of households)	• Strengthen legislation on insulation, heating meters and condensing boilers	• Public subsidies for building renovations • Tightening energy efficiency standards • Energy audit services	• Adopt energy efficiency standards for new buildings • Renovations to existing buildings • Energy audit and certifications
Transport	• High fuel taxes • Road transport dominant	• Same as *Status quo*	• Same as *Status quo*	• Reduce share of road transport in favour of rail and sea transport • Build high-speed rail networks • Reduce the average age of the national vehicle fleet
Waste	• No improvement in waste treatment	• No improvement in waste treatment	• Adoption of efficient waste treatment technologies	• Study the possibility of using waste as a power source, recycling
Other		• Improve energy certification processes	• Introduce energy benchmarks in industry	• Agriculture: rehabilitate pastureland, adopt reduced ploughing techniques

Table 37: Comparison of EBRD reference scenarios and Turkey's INDC proposal. The light blue boxes are the closest measures to those described in Turkey's INDC on each topic

7.3.3. Economic value of carbon sequestration service

→ **Taking a carbon price of €26 per tonne of CO_2 equivalent, the carbon sequestration service provided by the Yeniçağa site can be valued at approximately 26 x 20,550.48 = €534,313 per year.**

→ **In the hypothetical scenario that the whole area were drained, the economic cost of the net carbon emissions from the site is estimated at 26 x 5,025.14 = €130,654.**

→ **The virtual cost of poor management of the area, leading to overexploitation, could theoretically lead to economic losses of approximately €664,967 per year, corresponding to an annual cost per hectare of 1,734 euros.**

7.4. CONCLUSION AND RECOMMENDATIONS

In its current state, the Yeniçağa site functions as a carbon sink, but this function would be endangered if the area was more intensively drained in the future. The biophysical study of the carbon sequestration ecosystem service provided by the Yeniçağa peatland could benefit from being supplemented by on-site methane flux measurements, since the data transfer from a Californian peatland limits the robustness of this assessment. In addition, it might be considered that the results presented here underestimate the carbon sequestration potential of the area[96].

In this context, it seems pertinent to protect the Yeniçağa peatland as much as possible from potential overexploitation, either for peat extraction or agriculture. Several peatland conservation plans have been successfully implemented, including in Turkey. For instance, the Akgöl site in Konya province, Turkey was reflooded from September 2011, which has prevented 3000 tonnes of annual carbon emissions (DKM, 2012)[97]. The "*Adaptation to Climate Change and Protection of Biodiversity through Conserving and Sustainable Use of Wetland in Turkey*" project, run jointly by the Ministry of the Environment, Turkish Forests and GIZ from 2009 to 2013 has helped raise local awareness of the issues around peatland conversation, in Akgöl and Yeniçağa.

Uncertainty over the future economic benefits of peat exploitation in Yeniçağa[98] is an additional factor that should encourage conservation. As long as they preserve the carbon sequestration potential of the peatland, alternative projects for the site, in particular tourism-based initiatives, could be developed.

More generally, it has been shown that peatland restoration, alongside innovative land use practices, reduces carbon emissions, supports wetland ecosystem services and biodiversity, and generates additional income from peatland resources such as reeds or alder forests (Förster, J. mainly based on Schäfer (2009)-TEEBweb.org). In some cases, such as the Levresses peatland in Frasnes, France, restoration of previously exploited peatlands can involve closing up drainage ditches, reducing the impact of these ditches on the hydraulic function of the area and on the greenhouse gas emissions of the peat system (source: feedback from *Conservatoires d'espaces naturels* and *Pôle relais tourbière*s). However, this type of policy decision often requires support from cost-benefit type economic studies.

[96] This underestimation can be explained by two possibilities: vegetation and lake sediments were not taken into account, and a lower evapotranspiration on the California site was used to transfer data on methane flux.
[97] This measure was put in place in Akgöl peatland case, particularly to fight peat fires, rare in Yeniçağa peatland.
[98] In 2010, GIZ estimated that peat exploitation in Yeniçağa would be economically viable for a 10 or 20 year period, i.e. until 2020-2030 (GIZ, 2010).

8. Conclusion

The final economic value assigned to an ecosystem service should be systematically interpreted in its context, which does not allow the comparison between several assessments. Thus, the study reached the following monetary values, reflecting the specificities of the studied sites and approaches applied, and complement similar exercises already carried out worldwide (Appendix H):

Site & service studied	Considered surface (ha)	Economical method	total value (€ or €/year)	Unit value (€/ha or €/ha/year)
Etang de Vic (France) - coastal protection	1,900	Avoided damages costs	2,273,680 €	1,197 €/ha
Lonjsko polje floodplain (Croatia) - flood control	22,280 (artificial retention basins)	Replacement costs	1,516,272,085 €	68,055 €/ha
Burullus lagoon (Egypt) - carbon sequestration	41,000	Social cost of carbon	45,755,600 €/year	1,116 €/ha/year
Yeniçaga peatland (Turkey) - carbon sequestration	383.4	Marginal abatement cost of carbon	664,967 €/year	1,734 €/ha/year

We should note that the economic value of a service does not always explicitly reflect the effectiveness of the management or protection status enjoyed by the sites, and can confound interpretation of the service importance.

Moreover, the value depends on the robustness of the biophysical assessment conducted upstream, whose accuracy is influenced by the data availability, uneven between sites.

For the extreme events considered (100-year return period flood or storm), some economic values such as assessed on the Vic lagoon site may seem low. However, this site is managed in an exemplary manner by the Conservatoire du Littoral to conserve its natural character. The result thus reflects the low level of anthropisation, which decreases the estimated value of any impacts, but at the same time shows how effective this buffer area is in providing storm protection. On the other hand, higher values as the one assigned in the case of the Croatian floodplain, can be explained by the valuation method applied and the corresponding time horizon: the replacement cost method used for this valuation is known to identify higher costs than other methods such as the cost avoided method (Plan Bleu, 2013), and is obtained through long term discounted maintenance costs (100 years), which influences the value obtained.

The Egyptian and Turkish studies required some data transfer from other sites, which may introduce a bias into the valuation of the carbon sequestration service. This service was valued using two different methods, each of which gave a different price for a tonne of CO_2. In addition, economic valuation of services such as carbon sequestration can be maximised by the presence of human activities and do not take into account conservation efforts, as mentioned above. The methods used here, however, conclude to similar order of magnitude in the values obtained for Yeniçağa peatland, whose exploitation is strictly limited but where a fictive scenario is considered, or for the overexploited Burullus Lake. The importance of carbon sequestration service can be maximized by the human activities, not reflecting conservation efforts, as mentioned previously.

Despite their specificities, the estimated values range from around €1000 $ha^{-1}.yr^{-1}$ to more than €68,000.ha^{-1}, which reflect the effective value of each service, in their specific context. These values are expressed per unit area during specific extreme events such as floods and storms, or with an additional time dimension for carbon sequestration service.

This study highlights the value of natural and preserved wetlands as efficient green infrastructures adaptation to climate change. Among all adaptation measures illustrated in this report, we note the importance of regulating human exploitation of these fragile environments (peatland, coastal lagoon) to limit the release of greenhouse gases;

maintaining mobility areas around coastal systems forming barriers against storms, while encouraging the sedimentary circulation, or the interest to preserve and ensure a cross-borders management of large and well-connected floodplains to ensure population safety against floods. These low costs solutions compared to equivalent human-made are enhanced by the cost that society should support in their absence.

The study also highlights the utility and diversity of wetland functions, in particular the regulating services they provide.

These services are often poorly understood and associated with complex mechanisms that are difficult to assess using market-based approaches. They nonetheless need to be taken into account in policymaking in the same way as services that traditionally influence decisions (provisioning or recreational services), which generate easily demonstrable benefits that can be assessed in monetary terms. The monetary value assigned to the three services studied herein thus highlights how important it is to take them into consideration in a context of climate change, within a common framework that includes market-related services.

9. Limitations and overall prospects

The state-of-the-art performed at the beginning of the Med-ESCWET project and the feasibility study that identified the ecosystem services to be studied highlighted the fact that there are very few studies of this type in the literature on Mediterranean wetlands. This report's biophysical assessment and economic valuation of ecosystem services in relation to climate change should thus be taken as an exploratory study, which has been carried out rigorously, but without claiming scientific precision. It is based on a combination of biophysical and economic analyses, adapted to different environments and contexts. It is useful to reiterate some methodological choices that were made. These choices highlight both the usefulness and the limitations of this project, and call for prudence in interpreting and comparing results from the study:

- **An interdisciplinary approach, service by service:** the study analysed three different ecosystem services, requiring expertise from various different scientific disciplines. Although all ecosystem services were described, in order to properly understand the way each environment functions, only one service was assessed for each site;
- **A regional, multi-site approach:** the Med-ESCWET project chose to study 4 sites in the North, East and South of the Mediterranean; the projects were different in nature, in hydrogeological and hydrobiological function, in size, level of development and anthropisation. Results from the studies are not consequently comparable amongst themselves.
- **An assessment approach using partial data:** the studies performed for the Med-ESCWET project are based on data acquired for other previous research programmes that had different objectives. Data was therefore only partially available and had to be supplemented by estimates, updates and sometimes by data transfers from other sites.

Despite these limitations, this unprecedented exercise has generated some useful and pertinent lessons in terms of methodology and observations, above and beyond the numerical results for the 4 assessments. Indeed, these values are not an end in itself but rather a means to reach a compromise in decision making. The idea was to enable ecosystem services to be compared with other economic sectors in investment-related discussions or in activity planning / strategy-making processes (Emerton and Bos, 2004, cited in Plan Bleu, 2013).

In the Med-ESCWET project, each of the four study sites was valued with a focus on a single ecosystem service, which therefore does not address the issue of the total economic value (TEV) of the site or the complex interactions between different services.

This choice nonetheless highlighted the role of these areas in combating climate change, both in terms of adaptation and mitigation. Very often, the vulnerability of these wetlands to climate change is the key issue emphasized. Conventional approaches encourage global efforts to combat climate change in a very marginal way, but do not push national and local authorities and site managers to get involved in this struggle. The Med-ESCWET project, on the other hand, does contribute to this commitment. The role of green infrastructure in climate change adaptation was illustrated in the project case studies, by the variety of situations and wetlands encountered. This emphasizes the importance of better regulating human usage of these fragile environments in order to limit greenhouse gas releases, of allowing transit areas for coastal systems that provide a storm barrier while promoting sedimentary circulation, and the relevance of conserving large, well-connected floodplains in a coherent manner across borders, in order to ensure flood protection for local populations.

The Med-ESCWET project has also reaffirmed the need to ensure all local biophysical assessments and economic valuations are understood in their context, in order to ensure that the ensuing results and recommendations are properly interpreted. This vision of the issues related to an ecosystem service provided on the scale of each zone could also be broadened:

- **In its biophysical scope:** analysis of each service helps understands the mechanisms of service provision in a site-specific context, with its own combination of multiple phenomena, some of which attenuate and others accentuate the service. It would, for instance, be counter-productive to recommend peatland reflooding, without taking into account the potential feedback reactions (i.e. basing such a decision solely on the carbon dioxide balance in the area, when methane release could easily offset the carbon dioxide sequestration).

- **In its geographical scope:** analysis of each service shows a correlation between the size of each site and the scale of services provided, but also its integration in the way a much larger and more complex environment functions. It is difficult to isolate the role of each wetland within the ecosystem it is part of, as a whole. For instance, besides the lack of available data, the complex hydrographic network of the Sava and the different flow dynamics under various scenarios limit the ability to assess the way the flood control service is provided by each wetland in the river basin.
- **In its anthropic scope:** analysis of each service highlights the importance of human factors both in biophysical assessment and economic valuation. It would be wrong to fail to take account of the negative or positive influence of current and past activities on or around the sites. For instance, the inflow of urban and agricultural wastewater that drains into Burullus Lake contributes significantly to carbon sequestration in the sediment. Conversely, the relatively low levels of development around the Étang de Vic limits the economic impact of coastal storms that were modelled for the project.
- **In its timescale scope:** the Turkish and French case studies both highlight the fact that long-term processes are important parameters in regulating service provision (restoration of peatlands after several decades of exploitation or the cumulative impact of successive storms on a coastal lagoon); these long-term aspects could not always be included in our analysis. However, plausible scenarios based on actual extreme events (100-year flood on the Sava) or realistic assumptions (simulations of sea flooding caused by a 100-year storm) were used to study the importance of certain services. Approximations could be used to express the time scale, in the dynamic description of the carbon sequestration service. It should also be noted that the economic value assigned to a service at a particular moment in time does not adequately reflect the effectiveness of management measures or the overall protection status a site enjoys; it is therefore important to present this economic value in context.
- **In its economic scope**: the analysis especially highlights a duality in the valuation of carbon sequestration services, whereby the effects of global warming are cross-border, but the costs of mitigation schemes depend on local economic contexts. The valuation process can thus use either a global assessment method (social cost method used for the Burullus Lake site) or a more local form of assessment (abatement cost method use for the Yeniçaga site). More broadly, the analysis shows the diversity of the valuation methods that can be used and the significant impact they have on estimating the value of services provided, regardless of the outcome from the biophysical analysis. This comment implies that current debates on the relevance or hazards or a monetary approach to non-traded environmental goods and services that have no market price are legitimate. It should nevertheless be stated that in the Med-ESCWET project, the valuation of ecosystem services provides a key argument in favour of environmental protection in public and private planning and policymaking that might affect wetlands; this is particularly relevant to sites that do not enjoy an excellent legal or regulatory protection framework. Although there is general acknowledgment of the role played by natural wetlands in protection from extreme climate events, it is rare to see this reality included in adaptive management policies, due to a lack of sufficient scientific data. This argument is particularly useful for demonstrating that protecting wetlands is a lower-cost solution than building artificial infrastructure that would be assumed to provide equivalent services.

The project has sought to take a pioneering approaching, providing examples of methodologies that could be applied to other sites. However, it is important to emphasize that the results and recommendations are mainly relevant on a local level. Firstly, the management history of the study sites, their biophysical (in particular climate-related) features and their social and economic contexts are site-specific parameters; it would be difficult and even dangerous to generalise conclusions and apply them to other sites. Secondly, the way this project combined biophysical assessments and economic valuation required individual methodology choices for each study area. The aim of providing a valuation to reflect the service provided as accurately as possible played a key role in defining the scope of the study and the scenarios chosen, in order to ensure that the biophysical analysis generated results that could be used for the valuation method adopted. The combinations adopted for this project differ for each area, and other combinations could probably have been used if other sites or services were to have been studied. This means that if other services were analysed in the same areas using different methods, the results could vary significantly. Using these results in practice will hence require in-depth understanding of the methods used, if the valuations are to be used intelligently in local policymaking. Any interpretation of these results must be undergirded by close collaboration between policymakers and scientists.

The economic valuation of climate change adaptation and mitigation services considered here represents the start of an approach that has not been widely developed in the Mediterranean region and could feed into subsequent broader valuation studies. While bearing in mind the hazards of improper generalisation, as mentioned above, estimates of the TEV of wetlands could help ensure a better understanding of environmental management, via cost-benefit studies for site managers and policymakers, for instance. This last point highlights one of the majors difficulties encountered in many combined science/public policy projects such as Med-ESCWET - it is very rare and difficult to get scientists engaged with such strategies.

In concrete terms, the results of this study could also help in the development of impact indicators focused on ecosystem services provided by Mediterranean wetlands, as initiated by Tour du Valat. Developing such indicators (e.g. role of wetlands in water supply, drought and flood reduction, or water purification) would help provide an inventory of the various, sometimes poorly understood, environmental protection roles played by Mediterranean wetlands.

Finally, the Med-ESCWET project has emphasized the way ecosystem service valuation can be useful in policymaking. Despite its limitations, this type of exercise has already steered some concrete decisions, as described by the TEEB[99]. Several initiatives that are currently underway on different scales (Ecopotential[100], EFESE[101], Nile-Eco-VWU[102]) are also using a similar approach. In this context, the Med-ESCWET analysis of pilot sites has contributed to better understanding of wetlands and the ecosystem services they can provide within the Mediterranean region, which boasts exception biodiversity, but which is under substantial anthropological pressure.

[99] TEEBweb.org

[100] Ongoing European project on potential ecosystem benefits from various protected areas (mainly in Europe), based on earth observation (remote sensing and field measurement) methods. http://www.ecopotential-project.eu/

[101] French Evaluation of Ecosystems and Ecosystem Services http://www.developpement-durable.gouv.fr/Evaluation-francaise-des.html

[102] “Nile Ecosystems Wetlands Valuation and wise-Use” (Nile-Eco-VWU): regional project to develop and test integrated tools for ecosystem services valuation and assessment that can be applied at local and regional scales within the Nile Basin. http://www.nile-eco-vwu.net/home

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Appendix A: Questionnaire template sent to local experts/managers

Name / Surname:

Position:

Organisation:

Country:

E-mail:

Telephone:

Name of the proposed Mediterranean wetland:

Country:

Location:

☐ Coastal ☐ Inland ☐ Close to an urban area ☐ Rural

Surface area:

1/ Does this site have one or more special protection or conservation status(es)?

☐ Yes ☐ No

If yes, which ones (e.g. Ramsar)?

2/ What organisation/agency is responsible for site management?

……

Is there a management programme? ☐ Yes ☐ No

If yes, which one?

3/ Is this body:

☐ National ☐ Regional ☐ Local?

4/ Organisation's contact details:……………………………………………………………………………………………………

5/ Have the ecosystem services provided by this site already been identified?

☐ Yes ☐ No

If yes, which ones? (see Appendix I)

……

……

6/ To your knowledge, have studies been carried out into the ecosystem services provided by this site?

☐ Yes ☐ No

If yes, which? ……

7/ Does this site provide the following climate change adaptation ecosystem service(s)?

☐ Flood regulation ☐Carbon sequestration

☐ Protection from extreme climate events ☐ Low water replenishment

8/ Do these services have a proven impact on the surrounding populations?

☐ Yes ☐ No

9/ In your opinion, what ecosystem services could this site provide? (e.g.: regulating, provisioning, cultural services.) (See Appendix I).

……
……

10/ Is there a national legal framework for protecting areas that play an important role in preventing flooding or extreme climate events?

☐ Yes ☐ No

If yes, which? ………………………………………………………………………………………

11/ What pressures is the site facing?

☐ Urban expansion ☐ Unsuitable land use

☐ Pollution ☐ Hunting/fishing

☐ Artificial water management infrastructure (dams)

Other: ……………………………………………………………………………………………

12/ Who uses the site?

☐ Farmers ☐ Residents

☐ Tourists ☐ Fishermen/hunters

Other: ……………………………………………………………………………………………

13/What data is available or easily accessible regarding this site? (tick available/accessible data):

Biophysical data

☐ Site surface area (ha)

☐ Topography (slope)

☐ Average water depth (if applicable, in m)

☐ Soil type (composition, thickness, texture)

☐ Site treatment and operation techniques (soil enrichment, pastureland, drainage, harvests)

☐ Type, size and frequency of surface water flows

☐ Source of surface water ☐ Water saturation level

☐ Erosion/sedimentation

☐ Flooding frequency (no. of floods per year), duration and water elevation

☐ Change of land/soil use

☐ Surface area of wetlands and vegetation cover in areas subject to extreme climate events

☐ Surface area of wetlands capable of storing water on sites affected by drought (% of total)

☐ Loss of wetlands significant for water storage (e.g. drained wetlands)

☐ Duration of the low water period

☐ Water flow resulting from the replenishment-storage cycle (mm per day; m^3/m^2)

☐ Quantity of carbon present in the biomass (soil, plants)

☐ Quantity of carbon sequestered by wetlands (t/ha)

☐ Carbon density of the top 15 centimetres of soil (t/ha)

☐ CH_4 and N_2O fluxes on the relevant sites (estimated in CO_2-eq)

☐ Flowrate of the watercourse supported by a wetland (if applicable)

☐ Mean annual and monthly rainfall

Economic data

☐ Construction or maintenance costs of artificial infrastructure that replaces a degraded or lost service (embankments, dams, etc.)

☐ Economic losses due to flooding

☐ Economic losses due to drought

☐ Number of people and economic activities dependent on ecosystem services

☐ Demand from populations for an artificial alternative (e.g. construction of a dam)

Populations living in areas facing drought

14/ In what ways do you consider the economic valuation of ecosystem services to be useful?

☐ Awareness raising for the population

☐ Support for decision-making

Other: ………………………………………………………………………………………

15/ Do you know the local experts working on the proposed site?

☐ Yes ☐ No

If yes, please supply the name, position, organisation/institution and contact details for each of them.

Mr / Mrs	First name	Surname	Position	Organisation	E-mail	Tel.

Please contact Plan Bleu for any questions:

Mrs Juliette Balavoine, jbalavoine@planbleu.org , +33 (0)4 92 38 71 34

Appendix B: Categorisation of ecosystem services (MEA France)

15 Provisioning services (production of goods)	15 Regulating services (production of services)	13 Societal services (production of services)
Food crop support	Contribution of pollination to food production	Source and support of artistic inspiration
Energetic crop support	Biodiversity and ecosystems: reciprocal maintenance	**Living environment/ amenities:** - Landscape (aesthetic sense) - Qality of the olfactory environment - Quality of the sound environment
Aquaculture	**water cycle regulation:** Flood control - Waste purification and treatment (water auto-purification) - Drought effects mitigation - Prevention of geomorphological desorders (banks erosion, lacks of material in some area..)	**Patrimonial:** - Value of biodiversity and Heritage (protected sites, protected and emblematic species) - Specific human communities
Professional fishing (marine and freshwater fishing, beach fisheries)	**Soil regulation:** - Erosion and mudslide control - Avalanches control	**Recreational:** - Hunting - Recreational fishing - Outdoor sport - Tourism and nature recreation - Hydrotherapy and thalassotherapy
Land picking (vegetable)	**Regulation of chemical elements cycle :** - Maintenance of soil quality - Recycling of organic debris **Species regulation:** control of : - Parasites and pathogens - Pest and invasive species	**Educational/ scientific:** - Research supports - Development of educational knowledge
Extraction and using of mineral products (salt, granular ressource.)	**Climate regulation:** - Purification and maintenance of air quality - Global climate regulation - Local climate regulation	
Fibers and others minerals		
Wood harvesting		
Living tank		
Water transport (river and maritime)		
Freshwater storage/ groundwater recharge : Supply of water for : - Domestic use - Production of bottled water (mineral and spring water) - Agricultural use - Industrial use - Energy production		

Appendix C: Questionnaire into the ecosystem services provided by the pilot sites

The inventories of ecosystem services were created in a participatory manner by sending an online questionnaire (Google Forms) to the participants of each site's kick-off workshop. A score of 1 to 5 was allocated, reflecting the probability of each of the 13 services considered existing. For each service, this total score was obtained by taking the average of all the scores submitted, weighted by the degree of certainty of the respondents and rounded to the closest whole number.

(Example of a questionnaire for the Etang de Vic coastal lagoons)

Enquête: Evaluation des services écologiques fournis par les lagunes côtières de l'Etang de Vic

Dans le cadre du projet Med-ESCWET sur "L'évaluation économique des services écologiques rendus par les zones humides méditerranéennes", nous cherchons à analyser la probabilité d'existence et l'intensité de 16 services écologiques fournis par les zones humides (e.g. séquestration du carbone, purification de l'eau).

D'après votre connaissance des lagunes côtières de l'Etang de Vic, merci d'attribuer pour chaque service écologique mentionné un score de 0 à 5 tel que:
Score 0 = le service écologique n'est PAS rendu par les lagunes côtières de l'Etang de Vic
Score 5 = le service écologique est rendu avec une forte intensité par les lagunes côtières de l'Etang de Vic

Comme il est probable que vous connaissiez mieux certains services écologiques que d'autres, merci de préciser dans un second temps, si vous êtes sûr(e) ou non de la notation que vous avez attribuée.

Merci beaucoup pour votre participation!
L'équipe Med-ESCWET

*Required

Civilité *

- M.
- Mme

Organisation: *

Merci d'attribuer un score de 0 à 5 à chacun des services écologiques listés:
Score 0 = Service écologique NON rendu par les lagunes côtières de l'Etang de Vic; Score 5 = Service écologique rendu avec une forte intensité

	0 (Non rendu)	1	2	3	4	5 (rendu avec une forte intensité)
Séquestration du carbone						
Protection contre les évènements climatiques extrêmes (inondation, sècheresse, tempête, tsunami..)						
Régulation du climat local						
Epuration						
Soutien d'étiage						
Contrôle de l'acidifcation des sols						
Lutte contre l'érosion						
Maîtrise des crues						
Contrôle de la salinité						
Maintien de la qualité de l'air						
Ressources en eau						
Productions aquacoles et piscicoles						
Productions agricoles végétales et animales (biens alimentaires et énergétiques)						
Extraction de matériaux et autres agro-ressources						
Aménités environnementales						
Loisirs et activités récréatives						

Merci de préciser si vous êtes sûr(e) ou non de votre notation:

	Je suis sûr(e) de ma notation	Je ne suis pas certain(e)
Séquestration du carbone		
Protection contre les évènements climatiques extrêmes (inondation, sècheresse, tempête, tsunami..)		
Régulation du climat local		
Epuration		
Soutien d'étiage		
Contrôle de l'acidifcation des sols		
Lutte contre l'érosion		
Maîtrise des crues		
Contrôle de la salinité		
Maintien de la qualité de l'air		
Ressources en eau		
Productions aquacoles et piscicoles		
Productions agricoles végétales et animales (biens alimentaires et énergétiques)		
Extraction de matériaux et autres agro-ressources		
Aménités environnementales		
Loisirs et activités récréatives		

Submit

100%: You made it.

Never submit passwords through Google Forms.

Appendix D: Fact sheet on the ecosystem services provided by the Vic coastal lagoon, France

Etang de Vic

WATER RESOURCES

DESCRIPTION

The lagoons have a limited use for the water supply of populations due to their salinity. Thanks to their retention capacity, they are primarily a water resource that contributes to correct ecosystem function and maintenance of its biodiversity. The annual water balance of Etang de Vic and its catchment area is positive (run-off and precipitation offset evaporation), but June, July and August are deficient.

FISHERY AND AQUACULTURE PRODUCTS

DESCRIPTION

The lagoon is a source of fish and shellfish. The main fish and crustacean species fished are eels (29,904 eels fished in 2012), sea bass, big-scale sand smelts, mullets, prawns and breams. Clams and mussels are the main shellfish species fished. 10 commercial fishing stands and 40 clam fishing stands are in place. Etang de Vic is part of the Palavas fishing organisation ("*prud'homie*"), which includes 67 skippers, 20 of whom fish in the Palavasian lagoons. The most common fishing techniques are "*capétchade*" and "*globe*" net fishing. Hook-and-line fishing, angling and fixed net fishing using gillnetting or trammel nets are also practised during the summer period.

CONTRIBUTING ELEMENTS

- Etang de Vic and Etang de Pierre-Blanche;
- Canal du Rhône à Sète

BENEFICIARIES

- Fishing professionals (within a *prud'homie*) in agreement with the *Conservatoire du Littoral*.

PRESSURES

Potential unauthorised catches via recreational fishing. Algal bloom phenomena ("*malaïgue*") during the summer season.

CROP AND ANIMAL AGRICULTURAL PRODUCTION (food and energy)

DESCRIPTION

Agricultural activity is present across 36% (≈141 ha) of the study site's land area. This activity includes various practices: pastureland (10% of agricultural plots), wildland (10%), meadows (7%), cash crops (5%), market gardening (3%), vineyards (1%).

CONTRIBUTING ELEMENTS

- Meadows and salt marshes around the lagoon

BENEFICIARIES

- Farmers
- Local population

PRESSURES

Rise in sea level and increase in soil salinity.

EXTRACTION OF MATERIALS AND OTHER AGRORESOURCES

The Etang de Vic lagoons are not exploited for their material resources.

GLOBAL CLIMATE REGULATION: CARBON SEQUESTRATION

The limited contribution to this service comes from plant biomass (main production of saltwater marshes and meadows), animal biomass via the calcification and sequestration of calcium carbonate (inorganic carbon) and the storage of organic carbon in sediments.

LOCAL CLIMATE REGULATION

DESCRIPTION

The water surfaces mitigate temperature variations due to the thermal inertia of water, which heats up and cools down more slowly than air. However, this service is limited by the shallow depth of Etang de Vic and Etang de Pierre-Blanche. The lagoons also increase the air humidity via evaporation, making the lagoon banks cooler than inland areas.

CONTRIBUTING ELEMENTS

Permanent water bodies: Etang de Vic and Etang de Pierre-Blanche.

BENEFICIARIES

- Local population

PRESSURES

Increase in local drought phenomena

WATER PURIFICATION

DESCRIPTION

This service primarily consists of the purification of effluents and the balance of matter carried by rainwater run-off and water courses. The wetlands' hydroperiod (characterised by water masses remaining in the wetlands for long periods), biotic components (vegetation and microorganisms) and abiotic components (sediments) purify transiting water via retention and the elimination of pollution (organic matter, nutrients such as nitrogen and phosphorus, metal elements). In addition, this service is supported by the reduced inflow of domestic pesticides ("*vert demain*" programme implemented by many surrounding municipalities). Gradual improvement of the water quality has been observed in the water column and in phytoplankton communities since construction of the Montpellier Sea Outfall in December 2005. At the same time, a significant decrease in phosphorus in sediments was observed between 2006 and 2011. Provisional diagnostics of the chemical status of Etang de Vic as per the WFD are poor and the target of reaching good status has been pushed back (2021-2027) (2015).

CONTRIBUTING ELEMENTS

- Vegetation, microorganisms and sediments in the salt marshes and meadows, Etang de Vic, Etang de Pierre-Blanche and canal;
- Vic-la-Gardiole lagoon treatment plant (in 2012 and 2013, the total nitrogen and phosphorus yields exceeded 80%).

BENEFICIARIES

- Farmers in the catchment area;
- Populations of "shacks" and "huts" in Les Aresquiers (domestic wastewater discharge);
- Local populations who benefit from the Mireval wastewater treatment plant and the Vic-la-Gardiole treatment basins.

PRESSURES

Etang de Vic has a high concentration of pesticides and insecticides due to their past use and it also receives current farm inputs (transfer via run-off and soil leaching in the catchment area). Blackwater tank discharge from pleasure boats; Domestic wastewater discharge from the "shacks" and "huts" in Les Aresquiers; Phosphorus-rich discharge from the former Montpellier treatment plant into the River Lez, which flowed into the lagoon via the *Canal du Rhône à Sète* until 2006; Pollutants stored in sediments which could later be released into the environment (e.g. in the event of dredging along the lagoon bed or agitation of the water column); The low inflow rate promotes the concentration of pollutants at the expense of water replenishment.

LOW WATER REPLENISHMENT

Its position at the foot of the catchment area means that this service cannot be provided.

FLOOD CONTROL

DESCRIPTION

Flood control is an especially important service during "*épisodes cévénols*" flood events

CONTRIBUTING ELEMENTS

- Etang de Vic and Etang de Pierre-Blanche;
- Saltwater meadows and marshes;
- Floodable farmland to the north of the site.

BENEFICIARIES

- Transport professionals and users of the railway and the *Canal du Rhône à Sète*;
- Skippers and farmers;
- Seaside resort workers (sandbar's sea front);
- Neighbouring urban populations along the coast.

PRESSURES

An increase in run-off from the catchment area due to increased soil impermeability caused by growing urban development.

COASTAL PROTECTION

DESCRIPTION

The main service provided is protection from coastal storms, specifically erosion, sea flooding and the retention of saltwater inflow via the channel.

CONTRIBUTING ELEMENTS

- Saltwater meadows and marshes;
- Etang de Vic and Etang de Pierre-Blanche;
- Dune ridge.

BENEFICIARIES

- Transport professionals and users of the railway and the *Canal du Rhône à Sète*;
- Skippers;
- Seaside resort workers;
- Farmers on the northern banks;
- Neighbouring urban populations along the coast.

PRESSURES

The presence of dams along the River Rhône reduces flowrates and sediment flows upstream and within the wetlands. In addition, the coast's natural sediment dynamics are disrupted by the presence of solid structures at each end of the site, installed to combat coastline retreat (coastal erosion). The fastest erosion rates can be observed on the southern and central parts of the site, and are occasionally greater than 1 m per year. Natural fragmentation of the coastline is another pressure. Dune vegetation can be damaged by visitors, especially in the summer season, despite routes being clearly defined (sand fences and paths, notices).

MAINTENANCE OF AIR QUALITY

In theory, vegetation that traps air particles has an impact on maintaining air quality. However, no local study has demonstrated the importance of this service on the Etang de Vic site.

ENVIRONMENTAL AMENITIES

DESCRIPTION

The site's major environmental amenities are primarily based on its aesthetic value and landscapes, the heritage value of Maguelone Cathedral, the site's fauna and flora, and the conservation of ancestral fishing practices. This service is promoted by on-site preservation efforts thanks to an effective management plan led by the *Conservatoire du Littoral*.

CONTRIBUTING ELEMENTS

- Several remarkable natural areas have been identified for their ecological interest and landscapes (ZNIEFF, classified site, Palavasian Lagoons RAMSAR site, etc.). The Habitat Directive highlights the site's role in the reproduction of waders and shorebirds. The former Villeneuve salt pans and the Villeneuve-lès-Maguelone peninsula provide the site with a heritage value. Heritage and traditions are also remarkable values in Etang de Vic and Etang de Pierre-Blanche thanks to ancestral fishing practices such as "*capétchade*", angling and net fishing.

BENEFICIARIES

- Local and tourist populations

PRESSURES

Degradation of the environment due to high visitor numbers in summer (trampling, dropping rubbish, etc.).

RECREATION

DESCRIPTION

Recreational activities in this area primarily consist of outdoor activities, hiking, horse riding and cycling, seaside resort and river tourism activities and hunting.

CONTRIBUTING ELEMENTS

Hiking, horse riding and cycling areas have been developed in the neighbouring wetlands. These areas are a waterfowl habitat where hunters use decoy techniques and shoot during early morning and late afternoon "flights". There are 6 hunting grounds along the northern bank to the north-east of Etang de Vic, 4 along the canal bank, only one of which is in active use, and 12 along the Etang de Pierre-Blanche bank. Only 3 hunting grounds remain open all year round and only 5 are in regular use (more than 5 to 10 nights per year). Recreational fishing is practised on the sandbar beach and along the *Canal du Rhône à Sète*. The sandbar's sea front is home to swimming, canoeing, kayaking and kite-surf activities. Etang de Vic is part of a sea canoe and kayak trail. An average of five canoes travel across the lagoon each week and pleasure boating represents a total of 1,200 barges each year.

BENEFICIARIES

Professionals and users of seaside resorts (Palavas Kayak de Mer, Echappée Verte), ecotourism (bird observation), tourist boat rental and outdoor sporting activities, hunters (sea hunting association, Villeneuve-lès-Maguelone sea hunting association and Vic-la-Gardiole hunters and owners syndicate) and recreational fishermen; Local populations.

PRESSURES

Damage to landscapes in the event of excessive visitor numbers in summer.

Appendix E: Fact sheet on the ecosystem services provided by Lonjsko polje floodplain, Croatia

WATER RESOURCES

DESCRIPTION

The water supply for Ljubljana, Zagreb and Belgrade, among other towns, primarily depends on water resources from the wetland, which provided drinking water for 1 million people in 2001. The wetland has two aquifers, Lonja (100 m) and Sava (70 m). Two springs within the park area, Drenov Bok and Osekovo also supply local people with water.

CONTRIBUTING ELEMENTS

- The alluvial plain allows standing water to gradually seep down into the water table. Infiltration from the River Sava only occurs in periods of high water

BENEFICIARIES

- Local population

PRESSURES

Site hydrology has been influenced by the embankments and sluices that have been built (Gugic, 2004); a difference of a few centimetres between high and low ground can change the hydrological regime in the area and the water supply it provides.

FISHERY AND AQUACULTURE PRODUCTS

DESCRIPTION

The wetland is home to 27 fish species, making it the largest spawning grounds in the Danube river basin. In periods of high water, populations migrated from the rivers to breeding grounds such as the Lonjsko Polje and Mokro Polje retention areas, which have higher temperatures. The park is an important area for traditional fishing and angling, providing a wide variety of fish (carp, catfish, perch).

CONTRIBUTING ELEMENTS

- The aquatic environment is species-rich because of nutrient inflow from tributaries of the Sava; stagnant water in the retention areas.

BENEFICIARIES

- Fishermen

PRESSURES

Spawning grounds invaded with vegetation, especially *Amorpha fruticosa* (invasive species).

CROP AND ANIMAL AGRICULTURAL PRODUCTION
(food and energy)

DESCRIPTION

Traditional agriculture is the main activity of the local community (grazing, fodder, hay-making). The area provides pasturleand for cattle, horses and pigs, helping preserve a diverse landscape. No sheep species present, because of excessive parasite transmission. Traditional farming practices include several indigenous species such as the Posavac horse, Slavonian-Syrmian Podolia cattle, Posavina geese, Turopolje pigs and Slovenian blackbelted pigs. These hardy species are well-adapted to extreme outdoor conditions, have low dietary requirements and are particularly docile. Part of the Lonjsko Polje forest, near the grazing grounds is also dedicated to animals (cattle, pigs and horses) and is a protected area. This area is next to the pastureland. The only human interventions are allowed are culls on "health" grounds. This area allows pigs to breed and spread (wild and semi-wild pigs), since acorns are a part of their diet. Grazing also encourages the formation of small ponds, where many amphibians lay.

CONTRIBUTING ELEMENTS

- Meadlowlands (covering 4,593 ha – 10.1 % of the park) used for hay-making and pastureland; oak and ash forest areas left "fallow" for cattle.

BENEFICIARIES

- Farmers
- Local population

PRESSURES

Several elements affect agricultural production, primarily low water and drought issues. In addition, the pasturelands are covered with false indigo (*Amorpha fruticosa*), cocklebur (*Xanthium strumarium*) and ragweed (*Ambrosia artemisifolia*), which are invasive species. There are also tensions between farmers and the bodies running livestock resource selection programmes and with hunters and poachers who threaten unguarded livestock. The lack of standardisation and marketing of agricultural produce from the area also causes economic pressure. The issue of state-owned farmland not yet been resolved.

EXTRACTION OF MATERIALS AND OTHER AGRORESOURCES

DESCRIPTION

Forestry is an important economic activity on the site. There are only two other forests that are as big in Europe: Eastern Croatia and the Landes Forest in France. 68% of the Park is covered with oak and ash forests, and the majority of this is open for forestry usage (there is only 10% of the forest where exploitation is banned for conservation reasons). The exploitation rate, which is adapted to growth rate, enables sustainable timber harvesting. The wood is sold as raw timber. Oak is the highest-value wood.

CONTRIBUTING ELEMENTS

- Alluvial forests.

BENEFICIARIES

- Local and national populations

PRESSURES

Increase in level and duration of forest flooding due to higher embankments, may be damaging to commercial wood types, especially oak; Ash dieback (fungal disease) recently reported (last two years).

CARBON SEQUESTRATION

DESCRIPTION

The service is primarily provided by the forest, which covers approximately 70% of the site, via humus formation and accumulation and by plant photosynthesis.

CONTRIBUTING ELEMENTS

- Alluvial forests (poplar, ash, oak); soils

BENEFICIARIES

- World population

PRESSURES

Recent ash dieback due to fungal disease

LOCAL CLIMATE REGULATION

DESCRIPTION

The water surfaces mitigate temperature variation due to the thermal inertia of water, which heats up or cools down more slowly than air. 70% of the wetland is forest-covered, and the trees exchange water with the atmosphere, contributing to air humidity.

CONTRIBUTING ELEMENTS

- Bodies of water; alluvial forests

BENEFICIARIES

- Local population

PRESSURES

Droughts

WATER PURIFICATION

DESCRIPTION

The natural retention areas also purify stagnant water by sedimentation, and the soils and forests provide a significant quality gain between surface water and groundwater (one quality category higher in the local standards).

CONTRIBUTING ELEMENTS

- Soils and forests

BENEFICIARIES

- Local population (drinking water supply from boreholes)

PRESSURES

Pollution due to nutrition inflow from the Sava (approximate phosphorous releases of between 1.79 and 6.89 kt/yr and nitrogen releases of between 37.86 and 85.59 kt/yr (Ramsar Information Sheet); organic pollution from wastewater in the Sava river basin (population 9 million); organic pollution from industry (1,096 businesses surveyed in power generation, chemicals, metalwork, paper and timber); pollution from hazardous substances (metal, oil, emerging substances, pesticides, etc.).

LOW WATER REPLENISHMENT

DESCRIPTION

Drought issues are increasingly frequently reported. Artificial low water replenishment is provided by the flood protection system, based on the natural retention capacity on the site. This service can however have a negative interaction with the flood protection service, for instance in the event of flash floods during a period of drought. In this case, the water has been maintained at a certain level in order to maintain usages, which prevents optimum retention of flood water.

CONTRIBUTING ELEMENTS

- Retention areas in the nature park; aquifers.

BENEFICIARIES

- Local population
- Farmers
- Forestry operators

PRESSURES

Canalisation of the rivers.

FLOOD CONTROL

DESCRIPTION

Croatia is heavily affected by flooding, which can occur at any time of year due to flood water inflow either from rainfall or snow thaws. Artificial infrastructure has been built to enhance natural flood protection capacities following the severe flooding in 1964. The Lonjsko Polje retention area is the largest retention in the Sava central basin (26,600 ha), which an estimated maximum capacity of 634 million m^3. The restoration measures implemented aim to increase the size of the floodplains and widen the river bed.

CONTRIBUTING ELEMENTS

- 4 retention basins (the main two being Lonjsko Polje and Mokro Polje); embankments to the North, South, East and West of the Lonjsko Polje retention area; alluvial forest that reduces flood peak discharge; traditional grazing practices that preserve an open environment that favours retention of water within the retention basins.

BENEFICIARIES

- Mainly the population of Central Posavina and downstream countries (Serbia and Bosnia & Herzegovina)

PRESSURES

Natural flood protection is threatened by intensive agriculture and road and home building in the floodplains. In addition, the installation of artificial flood protection systems (embankments) has affected the natural hydrological regime of the area. Finally, if the alluvial forest is too dense, it can hinder the proper flow of flood water from upstream to downstream and saturate the upstream retention areas.

COASTAL PROTECTION

DESCRIPTION

The inland location of the site means this service is not considered.

MAINTENANCE OF AIR QUALITY

DESCRIPTION

High levels of plant life on site, in particular the forest, contribute to this service by trapping particulate matter from the air on their foliage.

ENVIRONMENTAL AMENITIES

DESCRIPTION

The environmental amenities provided by the site are mainly the possibilities the biodiversity offers for teaching, research, preserving genetic resources, gathering medicinal plants, animals and marketing local produce. The RAMSAR zone includes 3 bird reserves, which are a priority area in the "European Biodiversity and Landscape Strategy" and a key site in the "Danube River Basin programme". These programmes highlight the major significance of the area for many protected species: common spoonbill (*Platalea leucorodia*), white-tailed eagle (*Haliaeetus albicilla*), lesser-spotted eagle (*Aquilla pomarina*). 58 mammal species, 16 amphibian species, 10 reptile species and 27 fish species are found on the Lonjsko Polje site. The site is also a refuge for migratory birds from Northern Europe, chiefly waterfowl such as ducks, herons, spoonbills, storks, terns, waders and cranes. The area provides favourable habitats to animal and plant species that are rare or endangered in Europe. It is home to more than two-thirds of Croatia's bird species (250 species), including 138 species that breed in the Lonjsko Polje park, for instance the white stork (*Ciconia ciconia*).
The park's alluvial forests are among the world's last remaining common oak (*Genisto-elatae-Quercetum roboris, Carpino betuli-Quercetum roboris*) and ash forests (*Leucoio-raxinetum angustifoliae*), highlighting changes in the genetic make-up of both species .
Environmental amenities are also based on the local population's traditional lifestyle, since the wetland offers a strong natural, cultural and landscape heritage. This heritage draws on centuries of traditional agriculture, grazing (a tradition going back 250 years) and forestry. Today's landscape reflects the linear development of rural villages along the Sava from the 17th to 19th centuries, and the former communications routes and territorial borders. Approximately 1/3 of current buildings on the site are traditional wooden homes (600 houses). This architectural heritage is classified as UNESCO world heritage.

CONTRIBUTING ELEMENTS

- Oak and ash forests; alders; aquatic environments; wet meadows; pastureland.

BENEFICIARIES

- Local and world population; businesses in tourism.

PRESSURES

Poorly maintained, demolished or badly restored historic buildings; illegal export of materials; poorly developed local government; abandonment of traditional construction techniques; lack of skilled labour for restoration of architectural heritage; land registry not updated and not kept in digital form.

RECREATION

DESCRIPTION

The park is seen as a recreational area for 1.5 million people who live near the wetland. The forests, meadows and aquatic environments allow a wide range of wild birds and mammals to thrive. This rich biodiversity is a draw for tourists, and tourism is a major economic activity in the area. 13,000 people, mainly Croatians, Germans and French, are estimated to have visited the park between April and October 2015. The aim is to increase visitor numbers to 25,000 per year. The visits are mainly day trips (3-day stay max). Visits focus on discovering the natural environment, cultural and traditional heritage. Sustainable tourism is developing, organised by "Lonjsko Polje Nature Park Public Service". The activities on offer include boat trips, bird-watching, walking, cycling and horseriding (on Posavina horses). Some traditional homes have been restored to become tourist accommodation. The main attraction is the Čigoć "Stork Village" (one of 16 European villages to be awarded this mark). An annual Stork Day is organised on the last Saturday of June. These tourist activities receive financial backing from the local authorities and Tourism and Culture Ministries. They are mainly run by people who have recently moved in or back into the area from elsewhere.
The site is also a popular fishing and hunting ground. The hunting societies sell annual licenses. There are rules to regulate hunting, and culls are sometimes organised in compliance with the nature protection laws. Hunting generated nearly €68,000 per hectare in 2001.

CONTRIBUTING ELEMENTS

- Biodiversity, natural landscapes, traditional buildings

BENEFICIARIES

- Local and tourist populations; businesses in tourism.

PRESSURES

Biodiversity threatened by poaching (hunting that is illegal because of the means used, the time of year, species hunted and quantities caught); lack of infrastructure

Appendix F: Fact sheet on the ecosystem services provided by Burullus Lake, Egypt

WATER RESOURCES

DESCRIPTION

Because of the high salinity gradient within the lagoon, the western part of the lagoon is used for freshwater supply for aquaculture and irrigation for agriculture in the area. Some local communities abstract water from the lagoon for domestic use.

CONTRIBUTING ELEMENTS

- Bodies of water
- Irrigation canals

BENEFICIARIES

- Fish farmers
- Farmers using irrigation

PRESSURES

Discharge of agricultural drainage water, water from (legal and illegal) fish farming ponds and domestic wastewater threatens the water quality in the lagoon.

FISHERY AND AQUACULTURE PRODUCTS

DESCRIPTION

Lake Burullus is a major fishing and aquaculture site, with a very productive nursery (mullet, tilapia, prawns, crabs, red mullet, catfish). Between 41,000 and 59,000 tonnes of fish are caught every year. Approximately 155,000 tonnes of fish are produced through aquaculture annually. Kafr el-Sheikh is the leading governorate for fisheries (1/3 of all fish production in Egypt). The lagoon is the main source of animal protein for 600,000 people.

CONTRIBUTING ELEMENTS

- Lagoon and reed beds (nursery)
- Fish farms

BENEFICIARIES

- In 2002, 28,000 people made a living directly from fishing. In 2015, this is the activity of 55,000 families (65,000 fishermen in the Kafr El-Sheikh governorate).

PRESSURES

Overfishing; illegal fishing of fry to supply to the fish farms; increasing number and density of fish farms; reduced water surface in the lagoon - more difficult for the fisherman to access; declining water quality; declining salinity of the water, leading to a change in the species fished (fewer high-value species such as tilapia and more low-value species).

CROP AND ANIMAL AGRICULTURAL PRODUCTION (food and energy)

DESCRIPTION

There is tree-based production in the protectorate (palms and date palms), a small amount of horticulture (1% of cultivated land). Guava, legumes, beet sugar, potatoes, cereals, rice, wheat, beans, cotton, tomatoes, corn and grapes are produced. On a smaller scale, there is also pastureland and fodder crops for livestock farming (30,000 buffaloes, cattle, sheep and goats in 2005).
55 plant species are gathered for medicinal uses and 32 species are consumed by the local population (Ramsar Cop 2015). There is a great wealth of bird life in the area, which is a hibernation and migration area for waders and shorebirds. Illegal game hunting is tending to increase.

CONTRIBUTING ELEMENTS

- Wetlands adjacent to the lagoon; reedbeds;
- Agricultural land around the lagoon.

BENEFICIARIES

- Local population, especially farmers.

PRESSURES

Increasing human influence on the environment and potentially high levels of abstraction associated. Soil pollution.

EXTRACTION OF MATERIALS AND OTHER AGRORESOURCES

DESCRIPTION

The sandbar on the edge of the lagoon is a salt-producing area and reeds are harvested from the lagoon for use in hand-crafts, bird traps, traditional boats (*markab* and *faluka)*, or windbreaks. In addition, within the Burullus Protectorate, 13 plant species are used for fuel, and 4 for their wood (Ramsar Cop 2015)

CONTRIBUTING ELEMENTS

- Salt pans
- Reed beds
- Surrounding vegetation

BENEFICIARIES

- Local population, especially craftspeople and fishermen

PRESSURES

Rising sea levels and increase in soil salinity; overfishing; increased density of *hosha* fishery systems; reduced surface of water in the lagoon; falling water quality; development of illegal hunting in the Burullus Reserve and a fall in aquaculture productivity in the lagoon.

GLOBAL CLIMATE REGULATION: CARBON SEQUESTRATION

DESCRIPTION

Carbon is mainly sequestered in the sediment compartment of the lagoon, where inward carbon fluxes from plant and terrestrial sources accumulate. Eid & Shaltout (2013) estimated this carbon stock to be 3180.8 Gg. This study also estimated the annual sequestration potential of this compartment to be 4.04 Gg, and emphasized that this potential was much higher in plant-growing areas. Photosynthesis by plant biomass (especially fast-growing species such as reeds and water hyacinth) and phytoplankton also contribute to carbon storage. This service is enhanced by overexploitation of the area and the damaged state of the ecosystem

CONTRIBUTING ELEMENTS

- Sediment in the lagoon
- Soil in adjacent wetlands and cultivated land around the lagoon
- Contribution of plant biomass by photosynthesis

BENEFICIARIES

- World population

PRESSURES

The size of some reedbeds is shrinking due to human extraction, with the aim of facilitating access by boat to the fishing grounds.

LOCAL CLIMATE REGULATION

DESCRIPTION

The water surfaces mitigate temperature variation due to the thermal inertia of water, which heats up or cools down more slowly than air. The lagoon also humidifies the air through evaporation, which give the banks of the lake a cooler micro-climate than areas further inland.

CONTRIBUTING ELEMENTS

- Permanent bodies of water

BENEFICIARIES

- Local and coastal populations

PRESSURES

Increase in drought phenomena, expansion of *phragmites sp*. and reduced surface of water in the lagoon

WATER PURIFICATION

DESCRIPTION

This service mainly consists of retention and elimination of organic matter, nutrients such as nitrogen (N) and phosphorous (P) brought in through the agricultural drains (90% of water inflow and 20% of nutrient inflow) and metals (in order of concentration in the lagoon waters: Zn > Fe > Cu > Cd > Pb). The long periods during which the water remains in the wetlands, the biotic constituents (significant plant life and large micro-organism populations) and abiotic constituents (sediment) in the lagoon help purify water that flows through it. Nitrogen and phosphorous are the main pollutants in the lake, due to agricultural discharge. Eid & Shaltout's study (2010) estimated for instance that 254t of P and 5527t of N could be extracted from the lagoon each year through reed harvesting (based on a 8200 ha reedbed).

CONTRIBUTING ELEMENTS

- Plants accumulating heavy metals (especially reeds and water hyacinths)
- Micro-organisms
- Sediment from meadows and salt marshes, lagoon and agricultural drains

BENEFICIARIES

- Fish farmers and fishermen
- Farmers
- Local population (no formal wastewater treatment system for surrounding urban areas)

PRESSURES

Population growth and increasing human influence (ecosystem in overproduction).
Constant increase in inflows from aquaculture, agriculture and domestic wastewater, discharged directly into the natural environment; runoff and leaching from the catchment area.

LOW WATER REPLENISHMENT

Its position at the foot of the catchment area means that this service cannot be provided.

FLOOD REGULATION

DESCRIPTION

The lagoon is a retention area for water from the catchment area, mainly coming from the agricultural drains and, to a lesser extent, rainwater runoff and stream-flow. Excess water from agricultural drainage prevents the lagoon from fulfilling its role as a flood buffer reservoir, except for 2 winter months when the Aswan dam is closed. Before the construction of the Aswan High Dam, the lake received the Nile floods in late summer and autumn (MedWet culture).

CONTRIBUTING ELEMENTS

- Lagoon
- Areas adjacent to the lagoon.

BENEFICIARIES

- Urban coastal populations
- Fishermen, fish farmers and farmers

PRESSURES

Drainage of marshy areas for agricultural use, demographic growth in coastal urban areas, excess water in the lagoon due to drainage of agricultural irrigation

COASTAL PROTECTION

DESCRIPTION

This service is theoretically provided by the physical barrier formed by the sandbar, and the retention capacity of the lagoon. However, the subsidence of the Nile Delta and the excessive use of the lagoon for agricultural outflow minimise the service provided. Northern Egyptian lagoons nonetheless act as barriers against saline intrusion, protecting more southerly agricultural areas.

CONTRIBUTING ELEMENTS

- Dune ridge
- 3-metre high dunes to the East of the Baltim region

BENEFICIARIES

- Urban coastal populations
- Fishermen, fish farmers and farmers

PRESSURES

Drop in sediment inflow following construction of the Aswan dam (subsidence locally estimated at 40 cm per century; marine erosion of the majority of the coastline (only 10 km of accretion areas along the 70 km coastline); rising sea levels;
excess agricultural inflow and increasing urbanisation along the sandbar make the area vulnerable with respect to coastal protection.

RECREATION

DESCRIPTION

The main recreational activities in the area are sun-sea-sand tourism. Recreational hunting is allowed from mid-September to mid-November. The lagoon offers an untapped potential for cultural tourism, nature tourism and water sports.

CONTRIBUTING ELEMENTS

- Coastline and sand dunes
- Historic and religious sites
- Small hotel complex in the Baltim area

BENEFICIARIES

- Businesses and employees in seaside tourism and ecotourism (birdwatching)

PRESSURES

Intensifying aquaculture and environmental damage; Geopolitical context.
In the future, coastal erosion, rising sea levels.

ENVIRONMENTAL AMENITIES

DESCRIPTION

The environmental amenities at the site mainly depend on the aesthetic value of the coastal dunes and the continuing traditional fishing activities (use of traditional boats). The Kafr El-Sheikh Governorate has six historical sites, such as the prehistoric City of Butu, known now as Tal Elpharaeen, the former City of Xoi (now the village of Sakka) and the former place of worship of the god Amun-Re, and also some Islamic sites still to be excavated from beneath the sand dunes. This Ramsar site provides a variety of habitats for plant communities and numerous species of migratory birds. 779 plant and animal taxons (reptiles, mammals, etc.) have been identified within the protectorate, including around 60 rare species, 20 endangered species and 11 endemic species, that contribute to the amenities provided by the site.

CONTRIBUTING ELEMENTS

- Remarkable architectural sites, places of culture and Islamic worship
- Biodiversity and heritage value associated with natural habitats on site: marshes, sandy beaches, dunes, islands, etc.

BENEFICIARIES

- Local and tourist populations

PRESSURES

Environmental damage due to overexploitation and increasing human influence.

Appendix G: Fact sheet on the ecosystem services provided by Lake Yeniçağa and its peatlands, Turkey

WATER RESOURCES

DESCRIPTION

Peatlands are a water-rich environment. They are seasonally flooded with water from the lake. Former peat extraction sites are water retention areas. Very little water is abstracted from the lake and the freshwater drains for drinking water supply and agricultural irrigation.

CONTRIBUTING ELEMENTS

- Peatlands formerly dug for peat extraction
- Drainage ditches

BENEFICIARIES

- Local population, especially farmers.

PRESSURES

Natural heavy metal pollution (esp. arsenic) due to the geological nature of the site; high levels of man-made pollution: transfer of agrochemicals through runoff and leaching from surrounding fields in wet seasons; pollution/effluent from fowl farms and abattoirs; atmospheric deposition of metal pollution from the motorway running to the South of the peatland.

FISHERY AND AQUACULTURE PRODUCTS

DESCRIPTION

The lake offers high commercial potential, mainly for crayfish and carp fishing, with a national market. 21 tonnes of fish (including 6 tonnes of crayfish) are taken from the lake during the fishing season (6 months of the year).

CONTRIBUTING ELEMENTS

- Lake Yeniçağa

BENEFICIARIES

- Fisherman (primary and/or secondary livelihood)
- Local population

PRESSURES

- Episodes of drought between 2010 and 2015
- Fry trapped in peat extraction holes during dry periods.

CROP AND ANIMAL AGRICULTURAL PRODUCTION (food and energy)

DESCRIPTION

25% of the land area is used for agriculture, around the edge of the peatlands. This activity is not a main livelihood for these households. Main crops are wheat, oats, barley, potatoes, beet and lettuce. Peat meadows are used for pasture for cattle (2500 head) and sheep (1000 head) from local farms that graze freely (10% of land at Yeniçaga).

CONTRIBUTING ELEMENTS

- Peatlands and surrounding agricultural areas

BENEFICIARIES

- Farmers (primary and/or secondary livelihood)
- Local population

PRESSURES

- Episodes of drought between 2010 and 2015

EXTRACTION OF MATERIALS AND OTHER AGRORESOURCES

DESCRIPTION

The soils in the Yeniçaga peatlands comprise alternating layers of peat and clay. In the past, 100,000 m3 of peat was extracted per year for use as a horticultural fertilizer, and represented more than half of production in Turkey before 2009 (GTZ, 2010). Currently, only approximately 1.5 ha per year is used for peat extraction. Small amounts of clay is used for ceramics.

CONTRIBUTING ELEMENTS

- Peatlands still used for peat extraction

BENEFICIARIES

- Peat extraction, processing and transport businesses
- Owners of peatland plots
- Local population (indirect beneficiaries)

PRESSURES

Overgrazing, regulations limiting peat extraction

CARBON SEQUESTRATION

DESCRIPTION

The carex peatlands around Lake Yeniçaga have been a high-capacity organic carbon sequestration ecosystem over the centuries. There are peat layers to a depth of at least 6 to 12 m, with alternating layers of clay over 30% of total surface area. The plant biomass provides a second positive contribution through photosynthesis, in particular the reeds surrounding the lake (*Phragmite sp*). On the other hand, the drainage system is a source of methane emissions. Methane is specifically emitted from the 4 man-made drains running through the wetland.

CONTRIBUTING ELEMENTS

- Peatland soils and plants, surrounding forests, tree plantations on the peatland and reed beds

BENEFICIARIES

- World population

PRESSURES

- Peat extraction over an area of approximately 1.5 ha per year (to a depth of 1.5 m maximum); Overgrazing; impact of drought on water table levels, leading to carbon emissions into the atmosphere.

LOCAL CLIMATE REGULATION

DESCRIPTION

The water surfaces mitigate temperature variation due to the thermal inertia of water, which heats up or cools down more slowly than air. Peat meadows and forests exchange water with the atmosphere and humidify the air.

CONTRIBUTING ELEMENTS

- Wet peat meadows, bodies of water, woods and forests

BENEFICIARIES

- Farmers and local population

PRESSURES

Reduction in flooded environments in the event of intensifying drought events

WATER PURIFICATION

DESCRIPTION

This service consists mainly of purifying effluents (nutrients, chemical pollutants) from agricultural drains, but also from rainwater and wastewater runoff from the catchment area. Wastewater from the town of Yeniçaga sewage system is sent to treatment ponds . The "basin" location of the peatlands, their seasonal flooding and the biotic constituents (plants and micro-organisms) provide the wetland with the ability to purify water flowing through it. This natural process is based on pollution retention and elimination phenomena (suspended solids, organic matter, nutrients such as nitrogen and phosphorous, metals).

CONTRIBUTING ELEMENTS

Plants, especially *Phragmites sp* and *Typhas sp.* around the lake, peatland micro-organisms.

BENEFICIARIES

- Fishermen (fish and crayfish)
- Local population

PRESSURES

Transfer of agrochemicals through runoff and leaching from surrounding fields in wet seasons; pollution/effluent from fowl farms and abattoirs (several farms with a capacity of 280,000 to 300,000 head and 3 intensive fowl farms in the Yeniçaga area); atmospheric deposition of pollution from the motorway running to the South of the peatland.

LOW WATER REPLENISHMENT

DESCRIPTION

This service is provided naturally and artificially by the lake outlet (lake water level regulator). This mechanism regulates the level of water in the lake, supplying (or not supplying) the River Çaga via a man-made canal. In periods of drought supply to the canal is reduced. This keeps the peatlands wet.

CONTRIBUTING ELEMENTS

The peatland has the ability to retain and later return water to the environment.

BENEFICIARIES

- Local population (fishermen, farmers)
- Peat extractors

PRESSURES

Potential intensification of severe drought episodes (such as those between 2010 and 2015).

FLOOD REGULATION

DESCRIPTION

The Yeniçaga peatlands are a buffer zone when the level of the lake rises in the wet season and when the snow thaws.

CONTRIBUTING ELEMENTS

- Water retention capacity of the lake and peatlands
- Agricultural areas in the valley are also potential flood expansion areas.

BENEFICIARIES

- Local population, farmers and peat extractors

PRESSURES

Increased flooding due to climate change.

COASTAL PROTECTION

DESCRIPTION

Non-coastal site

MAINTENANCE OF AIR QUALITY

DESCRIPTION

The forests and tree plantations around Lake Yeniçaga improve air quality, capturing particulate matter (dust, ash, pollen and smoke) and absorbing gases such as ozone, carbon dioxide and various oxides of sulphur and nitrogen that are emitted in the area.

CONTRIBUTING ELEMENTS

- Peatland vegetation (peat meadows), forests and tree plantations

BENEFICIARIES

- Local population

PRESSURES

None identified

ENVIRONMENTAL AMENITIES

DESCRIPTION

The environmental amenities of the site are mainly based on the aesthetic value of the reed-clad lakeside, with willow and ash plantations and on the presence of a buried historical village (more than 2000 years old) and Islamic places of worship. The plant green belt around the lake is protected by Turkish shoreline protection regulations. The formerly exploited peatlands, peat meadows and reed beds offer a variety of habitats for plant communities and mushroom species. Moreover the peatlands offer a real wealth of bird life: 92 species observed, including common cranes, grey herons, white storks, white-tailed eagles, and wrynecks, along with 37 species of dragonflies. A bird observatory that has contributed to the educational value of the site, which is listed as an "Important Bird Area"; it is noteworthy for the presence of two rare species: the corncrake and the common crane. There are some fenced-off paddocks to protect crane nesting areas.

CONTRIBUTING ELEMENTS

- Lakes and surrounding meadows, reed bed (for bird life)

BENEFICIARIES

- Local and tourist populations

PRESSURES

Environmental damage through littering; visual and noise pollution from the road to the South

RECREATION

DESCRIPTION

The municipality has set up barbecues and picnic tables on the lakeside. A fast food restaurant operates in season. Local people hunt boar and waterfowl and practice angling. There are paved access routes plus footpaths for hiking and nature tourism (birdwatching).

CONTRIBUTING ELEMENTS

- Lake and northern part of peatlands specifically for birdwatching
- Bird observatory
- Picnic area, fast food restaurant, tarmac access roads and footpaths

BENEFICIARIES

- Local population, especially hunters and fishermen
- Restaurant managers and employees

PRESSURES

Environmental damage through littering, stray free cattle could damage infrastructure

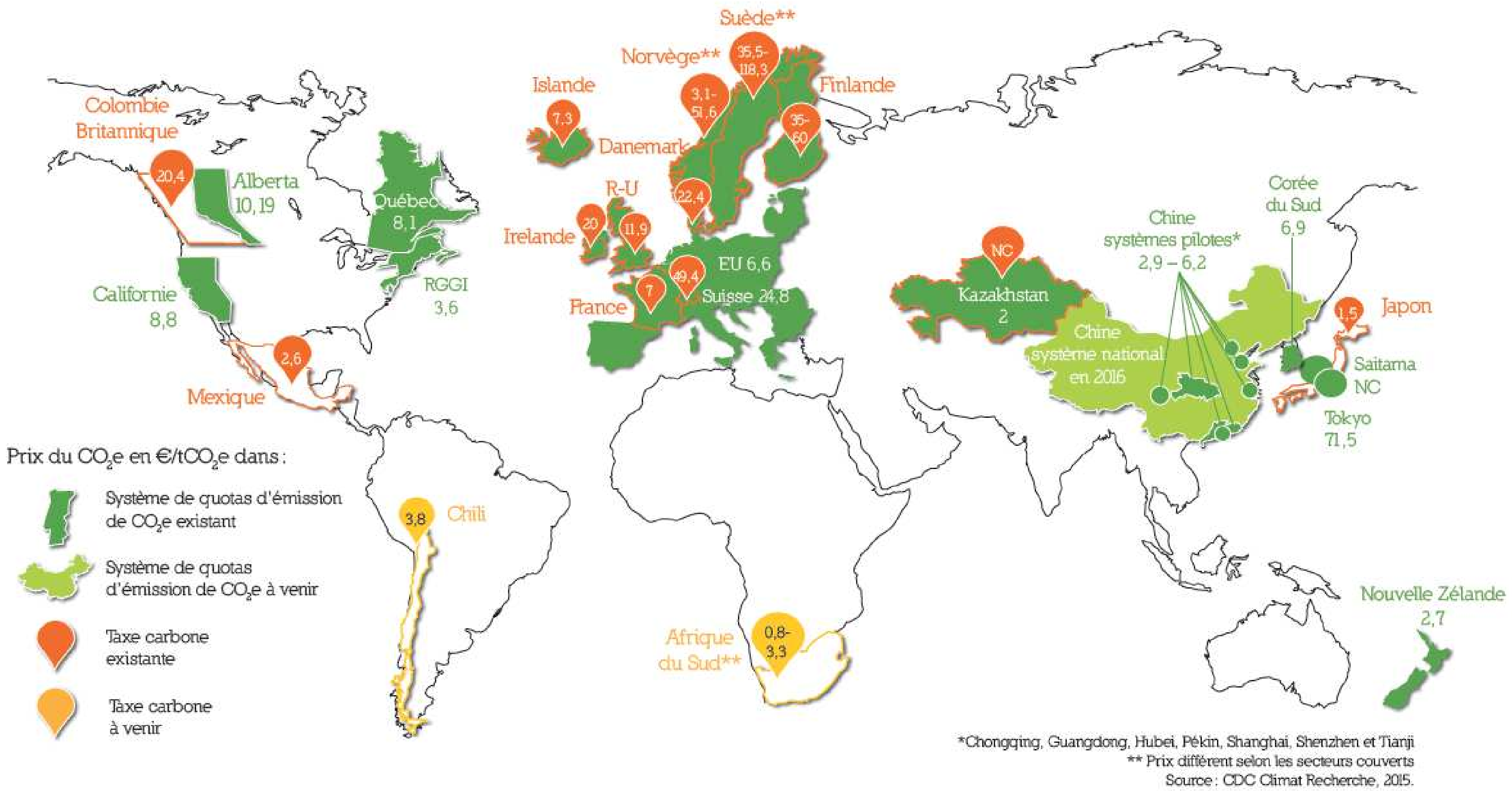
Appendix H: Economic valuations in literature of the ecosystem services studied

Site	Wetland type	What is assessed?	Technique(s) used	Value (€, $ or £ per ha per year)	Reference
Climate regulation via carbon sequestration					
North Selangor, Malaysia	Peat swamp forest	Carbon stock	Damage cost avoided	Non-sustainable management: $7080 - $8011 M per ha; Sustainable management: $8049 - $8677 M per ha	Kumari (1995)
Mississippi Alluvial Valley, USA	Floodplain	Greenhouse gas mitigation	Benefit transfer and damage cost avoided	$171 - $222 per ha per year	Jenkins *et al.* (2010)
World	Peatlands	Value of carbon storage	/	€1728 per ha per year	Brouwer and Ek (2004)
World	All wetlands	Value of carbon storage	/	€150 per ha per year	Brouwer and Ek (2004)
Le Cézallier peatlands	Peatlands	CO_2 stock	Market price	€1800 per ha (2010)	Nomadéis
Federal State of Mecklenburg-Vorpommern, Germany	Peatlands	Damage cost avoided by the restoration of 29,764 ha	Value of carbon based on a carbon price of €70 per tonne (Schäfer, 2009)	€21.7 million per year (average of €728 per ha restored)	TEEB case, Föster *et al.* (2009)
World	Posidonia seagrass	Carbon sequestration	Damage cost avoided	Min. €7.70, max. €230 per ha per year (2014)	Mangos *et al*, 2010 (2005 data), cited in Campagne *et al.* (2015)
Mediterranean Sea		Carbon sequestration	Conservative estimate of the social cost of carbon	€127 - €1722 million per year across the entire basin €135 to €1000 per km^2 per year	Melaku Canu *et al.*(2015)
Natural risk prevention					
Protection from extreme climate events					
Belize	Mangrove forests and coral reefs	Coastal protection/tourism/fish stock	Damage cost avoided	$395 - $559 million per year	Cooper *et al.* (2009)
Louisiana, USA	Marshland	Coastal Protection	Damage cost avoided	$8977 - $17,000 per acre per year	Costanza *et al.* (1989)
USA	Mangrove forests, marshland, riparian forests	Coastal Protection	Damage cost avoided	$250 - $51,000 per ha per year, with an average of $8240 per ha per year	Costanza *et al.* (2008)

Kuala Selangor, Malaysia	Mangrove forests	Presence of mangrove forests	Replacement cost	$13,842 per ha per year	Leong *et al.* (2005)
Southeast Louisiana, USA	Marshland	Continuity of wetlands and vegetation cover	Damage cost avoided	6 km of marshland continuity: $592,000 - $792,100; 6km of marshland with vegetation: $141,000 - $258,000	Barbier *et al.* (2013)
Vietnam	Mangrove forests	Presence of mangrove trees	Damage cost avoided	$220,000 - $300,000	International Federation of Red Cross and Red Crescent Societies
Guadeloupe National Park (Park Core)	Mangrove forests seagrass coral reefs	Coastal protection, maintenance of beaches and the coast	/	Mangrove forests €10,500 per ha per year seagrass €71,400 per ha per year coral reefs €600 per ha per year	Brli, (2012)
Humber Estuary, North-East England	Estuary	Coastal realignment strategy (creation of an area for new intertidal habitats)	Cost-benefit analysis comparing various embankment realignment scenarios	"Green infrastructure" scenario: 25 years: €30 - €45 50 years: €16.73 100 years: €57.83	TEEB case (2011) based on Turner *et al.* (2007)
World	*Posidonia oceanica*	Protection from coastal erosion	Damage cost avoided	€188 per ha per year (2014)	Mangos *et al.* (2010) (2001 data) cited in Campagne *et al.* (2015)
Water flow regulation					
Flood regulation					
Languedoc-Roussillon, France	Lagoons	Floodwater evacuation capacity following the rise in sea level	Replacement cost	€149,600,000 – €972,400,000	Kuhfuss *et al.* (2011)
Languedoc-Roussillon, France	Peripheral lagoon wetlands	Floodwater evacuation capacity following the rise in sea level, taking into account adaptation prospects	Benefit transfer	€10,508,967 - €13,799,181	Kuhfuss et al. (2011)
Sri Lanka west coast	Marshland	Water storage capacity during flooding	Replacement cost + benefit transfer	$5,394,556 --> $1,758 per ha;	Emerton and Kekulandala (2002)
Rhine-Meuse Delta, Netherlands	Floodplain	Restoration of floodplains and creation of new watercourses	Damage cost avoided	€3.3 billion (2000) over 100 years	Brouwer and Ek (2004)
River Elbe, Germany	River Elbe and its tributaries, polder (water retention areas)	3 flood regulation options with ecological benefits	Cost-Benefit Analysis (CBA)	3rd option: "polder regularly flooded and limited relocation of embankments" generates a net discounted value of €559 million (over 90 years)	TEEB case mainly based on Grossmann *et al.* (2010)

Marne, France	Floodplains	Flood control	Replacement cost	€182 - €594 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
La Bassée plain, France	Alluvial plains	Flood control	1) Replacement cost 2) Damage cost avoided	1) €185 - €570 per ha per year 2) €113 - €163 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
Nogentais, France	Wetlands	Flood control	Replacement cost	€203 - €617 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
La Vire lower valley	River and marshland	Flood control	Damage cost avoided	€37 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
River Charente, France	Wetlands	Flood control	Cost of actual damage	€5 - €9 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
Tarn (Agout)	Peatlands	Flood control	Replacement cost	€100 - €260 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
Middle Oise Valley		Flood control	Replacement cost	€37 - €243 per ha per year	Schéhérazade Aoubid and Hélène Gaubert (2010)
Insh Marshes, Scotland, United Kingdom	Marshland	Capital cost of building replacement flood defences	/	Several million pounds sterling (£)	FRAPNA Haute-Savoie. April 2011
Danube	Floodplains	Economic value, including their flood mitigation function	/	Total annual value: €650 million	Gren *et al.* (1995)
15 French studies	All wetlands	Flood prevention / flood control	Meta-analysis (of studies using replacement cost or damage cost avoided methods) (economic benefit of the service appears greater with the first method)	€37 - 617 per ha per year (2008)	Cited in Schéhérazade Aoubid and Hélène Gaubert (2010)
89 sites around the world	All wetlands	Flood prevention / flood control	Meta-analysis (of studies using replacement cost or damage cost avoided methods)	€438 per ha per year (2008)	Brander *et al.* (2003) cited in Schéhérazade Aoubid and Hélène Gaubert (2010)

Appendix I: Carbon market across the world in April 2015



Appendix J: Mapping operations for Burullus lake, Egypt

- Methodology

The mapping method adopted was developed as part of the GlobWetland-II project (GW-II ESA DUE project, 2010-2015) and used by the Mediterranean Wetlands Observatory (MWO) to monitor over 300 sites around the Mediterranean (MWO, 2014).

The images used were taken from the satellites Landsat-8 (L8 OLI) and Landsat-7 (L7 ETM), with a spatial resolution of 30m and 15m for the panchromatic strips. The spectral composition adopted for processing the two image types included the following channels: blue, green, red, near-infrared, mid-infrared 1, mid-infrared 2 (for L8 images), thermal infrared (for L7 images) and panchromatic.

Variation in aquatic plant life in and around the lagoon was mapped over five successive years (2011, 2012, 2013, 2014 and 2015). For these five years, all the useable (cloud-free) images were used to cover the phenological[103] and seasonal hydrological dynamics observed.

2011 (L7)	2012 (L7)	2013 (L8)	2014 (L8)	2015 (L8)
18 February	05 February	22 May	17 January	20 January
28 July	25 April	23 June	06 March	05 February
	14 July	13 August	09 May	26 April
	18 October	04 November	26 June	15 July
			29 August	16 August
				01 September
				20 November

Table 38: Dates of images used for mapping (source: Tour du Valat, 2016)

All the images were taken from the USGS (United States Geological Survey) web portal. They were orthorectified and pre-processed for atmospheric and geometric corrections.

For the purposes of this study, two map products were extracted from the images:

1. Land use map:

Supervised and object-oriented classifications (made with GEOclassifier software) were used to develop detailed land use maps across the whole study zone for 2011 and 2015, and then used to track variation between these two years. The multi-date approach (use of several images per year) incorporated seasonal variations in the plant life (phenology) and water coverage (surface flooding) in identifying and characterising the observed habitats. The mapping process features three successive steps (Figure 48):

a. thematic object segmentation based on spectral signatures, which can vary in space, in spectrum and over time;
b. automatic habitat classification using a modified CORINE Land Cover nomenclature, incorporating wetland categories based on Ramsar definitions;
c. post-classification processing to manually correct some automatic classification errors on both maps.

[103] Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonality.

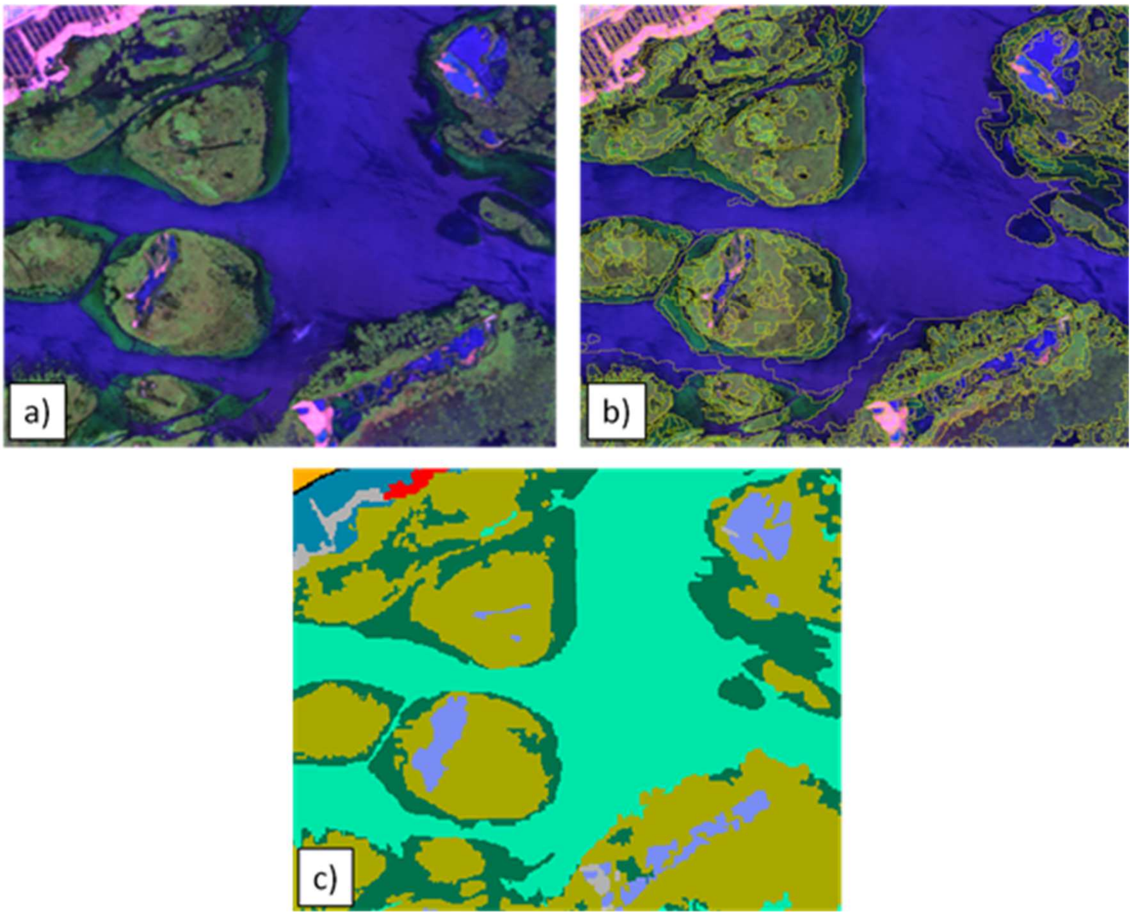


Figure 48 : Supervised and object-oriented classification of Landsat images. a) pre-processed images (input data); b) image segmentation based on spectral signatures of each pixel (including spatial, spectral and temporal variables); c) final land use map obtained after automatic classification and manual error correction (source: Tour du Valat, 2016)

2. Aquatic plant life map:

Aquatic vegetation was mapped using Landsat images for all 5 periods with the ENVI 4.7 software. These maps were used to characterise the main aquatic plant communities in the lagoon by type (helophytes and submerged vegetation) and density. In order to generate the maps, the Normalized Difference Vegetation Index (NDVI) was calculated from the Landsat images and added to the 7 tracks already available. Results were generated using the approach described below (Figure 49):

- Supervised and object-orientated image classification (multi-date analysis), with demarcation of lagoon plant life;
- Two main plant formations were identified:
    - helophytes with fairly dense leaf and rhizome networks, which enable them to be distinguished from other plants, in particular in winter when the dead stems remain;
    - submerged aquatic plants (probably water hyacinth), which is mainly found around the small islands in the middle of the lake, with high NDVI values in summer, but close to zero in the winter.
- Variations in NDVI in high chlorophyll activity periods (spring and summer) were used to define various density levels for each formation. These levels are defined according to the mean NDVI value for each segment, calculated over the spring-summer period and expressed as a %. (The index is normalized with a range from -1 to 1, where 0 is the plant presence threshold; this normalized range means that percentages can be calculated). Three density categories were adopted: i) low density (<20%); ii) medium density (20% - 30%) and iii) high density (>30%).

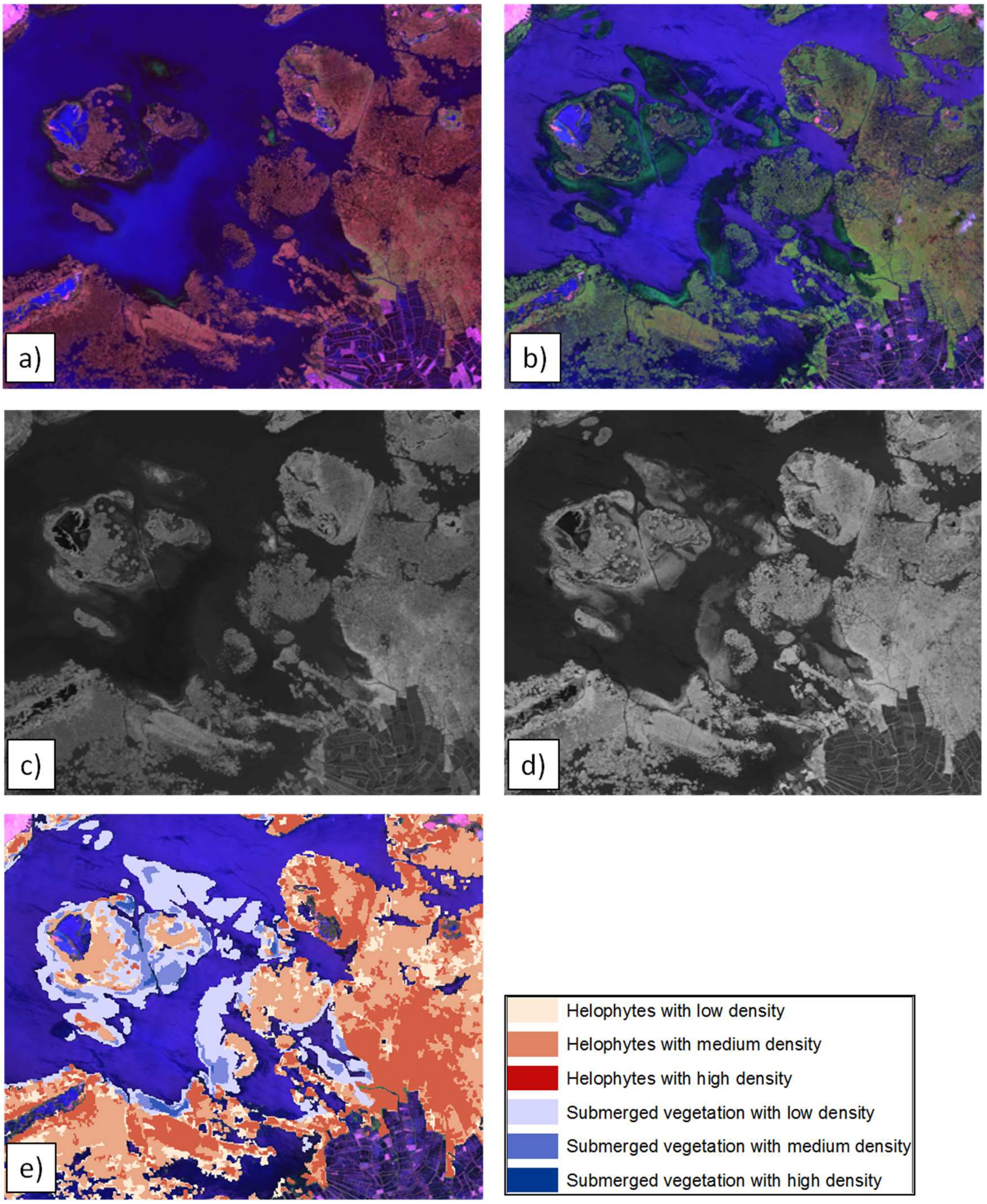


Figure 49: Map of aquatic plant life showing density levels. a) Landsat-8 multi-spectral image from 05 Feb 2015; b) Landsat-8 multi-spectral image from 15 Jul 2015; c) NDVI calculated from Landsat-8 image of 05 Feb 2015; d) NDVI calculated from Landsat-8 image of 15 Jul 2015 e) aquatic plant life map (helophytes and submerged vegetation) with density categories (source: Tour du Valat, 2016)

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