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A Methodological Proposal for the Climate Change Risk Assessment of Coastal Habitats Based on the Evaluation of Ecosystem Services: Lessons Learnt from the INTERREG Project ECO-SMART

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Abstract: Climate change is seriously impacting coastal biodiversity and the benefits it provides to humans. This issue is particularly relevant in the case of the European Union's Natura 2000 network of areas for nature protection, where the sensitivity of local ecosystems calls for intervention to increase resistance and resilience to climate-related risks. Given the complex ways in which climate can influence conservation hotspot areas, there is a need to develop effective strategic approaches and general operational models to identify priorities for management and inform adaptation and mitigation measures. Here, a novel methodological proposal to perform climate risk assessment in Natura 2000 sites is presented that implements the systematic approach of ISO 14090 in combination with the theoretical framework of ecosystem services assessment and local stakeholder participation to identify climate-related issues for local protected habitats and improve the knowledge base needed to plan sustainable conservation and restoration measures. The methodology was applied to five Natura 2000 sites located along the Adriatic coast of Italy and Slovenia. Results show that each of the assessed sites, despite being along the coast of the same sea, is affected by different climate-related issues, impacting different habitats and corresponding ecosystem services. This novel methodology enables a simple and rapid screening for the prioritization of conservation actions and of the possible further investigations needed to support decision making, and was found to be robust and of general applicability. These findings highlight the importance of designing site-specific adaptation measures, tailored to address the peculiar response to climate change of each site in terms of biodiversity and ecosystem services.

Keywords: ecosystem services; climate change adaptation; Natura 2000; nature conservation; sustainability; coastal management

1. Introduction

The United Nations' Intergovernmental Panel on Climate Change (IPCC) recently stated that human civilization has already influenced climate irreversibly on timescales much longer than human lives. Human-driven climate changes are much larger than those due to naturally occurring drivers, and they are affecting not only average descriptors of weather and climate, such as mean annual global surface temperature, but also extreme events across the whole Earth [1]. Consequently, it is predicted that the frequency and intensity of climate and weather extremes will become larger. While climate change affects all ecosystems, on land and water, through the multiple changes already occurring, coastal ecosystems are especially vulnerable. Here, relative sea level rise contributes to the increase in the frequency and severity of coastal flooding and erosion in low-lying coastal areas, impacting both biodiversity and human settlements, which are usually concentrated along the coasts [1,2].

In 1992, the European Union (EU) established Natura 2000, a coherent network of areas for nature protection, where its most valuable and threatened habitats and species, as listed in the EU's Directive 92/43/EEC 'Habitats' and 2009/147/EC 'Birds', are safeguarded. Natura 2000 is the largest coordinated network of protected areas existing within the EU and the world, stretching over 27 countries, and it has a core role also within the recent EU Biodiversity Strategy for 2030 [3] that aims, among other things, for an improved and wider network of protected areas and an EU nature restoration plan, transformative change in environmental governance, and the implementation of a global biodiversity agenda.

The Natura 2000 network of protected terrestrial and marine areas hosts habitats and species whose conservation and restoration are not merely important for biodiversity. In these ecosystems, human activities are not excluded, if sustainable, and in fact the ecosystem services (ESS for short: the benefits that nature provides humans with [2]) provided by Natura 2000 and contributing to local economies are multiple and extremely valuable, as shown by the EU's recent fitness check of the Habitats and Birds Directive [4]. Such socio-ecological interrelations link ecosystem properties to specific benefits for society or some of its individual components, and enhance social welfare based on human co-existence with biodiversity. Understanding the socio-economic value of the ecosystem services provided by the Natura 2000 network is fundamental to properly recognizing the societal importance of nature conservation and promote biodiversity restoration to generate multiple socio-economic benefits, including those deriving from carbon emission reduction and from building resilience to climate change [2–4]. On the other hand, climate change represents a major threat to biodiversity and so to the Natura 2000 network, together with changes in land and sea use, direct exploitation of organisms, pollution, and invasive alien species [5].

The risks posed by climate-related impacts can be expressed as a result of the interaction of climate-related hazards with the vulnerability of socio-ecological systems, which includes system exposure and ability to adapt [6]. Guidelines for the systematic assessment of the risks related to the potential impacts of climate change have been published by the International Organization for Standardization [7]; however, to date, structured and up-to-date approaches for identifying adaptation measures are lacking, and including ecosystem services and interaction with stakeholders might contribute to generating capacity and improving the knowledge base. For protected areas, in particular, there are limited general methodologies that examine resilience to climate impacts while considering interactions between biodiversity and ecosystem services, thus looking at nature conservation in the face of climate change from a sustainability perspective. For example, a guidance paper based on mountain ecosystems provides information on how to holistically integrate ecosystems and their services into a climate change-vulnerability and impact assessment [8]. It emphasizes the evaluation of current and future adaptive capacities and vulnerability plans, while understanding the related social-ecological background with the relevant stakeholders. More recently, a report on a lagoon system was published that describes a similar stakeholder-informed development of an ecosystem services-based action plan [9].

Consequently, in the case of coastal ecosystems, general climate change adaptation methodologies have been sparsely reported, e.g., [9,10], although the ecosystems services they provide are numerous [11], and are severely endangered by climate through processes that include relative sea level rise, flooding, and erosion [1,2]. In general, ecosystem-based climate change adaptation methodologies for coastal ecosystems accounting for the interactions between ecosystem quality, resilience and services are lacking. Several approaches demonstrate the general vulnerability of coastal ecosystem services, e.g., in Australia [12], USA [13], the French overseas mangrove territories [14], and the coasts of Italy [15]. Risk assessments for coastal habitats in connection to climatic threats should be based on a general methodology and be easily transferrable across the many and hugely diverse sites of the network, on the one hand, and yet, on the other, site-specific assessments tailored to the peculiarities of the individual Natura 2000 sites appear fundamental to fully achieving the network potential to support the provision of multiple environmental, social and economic benefits.

The cross-border cooperation project ECO-SMART—'Market of ecosystem services for an advanced Natura 2000 area protection policy' [16]—funded by the EU Interregional Cooperation Programme 'Interreg V-A Italia-Slovenija 2014–2020', aims to help filling this seeming lack of general methodologies and their application regarding climate change adaptation of Natura 2000 coastal sites by adopting a holistic, ecosystem-based perspective to achieve sustainability and mobilize funding and stakeholder capacity. The sites included in this project had not been comprehensively analyzed before, so only sparse information on hazards, habitats and ecosystem services was available, and knowledge of local adaptation capacity was absent or rather limited. Therefore, this paper specifically aims (1) to develop a systematic ecosystem-based risk assessment methodology to support climate change adaptation in coastal areas representing nature protection sites, inspired by the recent guidelines from the International Organization for Standardization (ISO), which includes site-specific assessments of ecosystem services, climate change vulnerability of habitats and services, and stakeholder involvement (which could assist with generating adaptation capacity in the future), (2) to apply this methodological approach to five Natura 2000 coastal wetland systems in Italy and Slovenia, to consequently verify its applicability and validate its theoretical framework, and (3) to open the discussion for a more general use of this ecosystem-based approach in European Natura 2000 sites extending beyond coastal ecosystems.

2. Materials and Methods

2.1. Methodological Proposal

Here, a methodological proposal for assessing the risk posed by climate change to coastal sites is developed based on the concept and structure of the ISO 14091 standard on adaptation to climate change [7]. This document is part of the ISO 14090 family [17] of standards that address climate change adaption. It provides requirements and guidelines to perform a climate change risk assessment by organizations and to support them in developing suitable climate change adaptation plans. The standard is structured as an introduction to the concept of climate change risk assessment, followed by the preparation, the implementation and the documentation and communication of the climate change risk assessment [7].

According to ISO 14091, climate change risk assessment, also referred to as vulnerability, can be addressed as the result of the evaluation of hazards, exposure, sensitivity, and the adaption capacity of the system under assessment. Hazard is defined as the potential source of harm that can affect the system; for example, the sea level rise, which can result in coastal flooding influencing the activities of local businesses working along the seaside. Exposure is defined as the presence of people, livelihoods, species, habitats or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be affected by the climate change hazards. Sensitivity is defined as the degree to which the system is affected, either adversely or beneficially, by climate change. As such, sensitivity can be seen as a function of applicable hazards and the exposure of the system under study that results in quantification of potential climate change risks and related impacts. Therefore, adaptive capacity is defined as the ability of the system to adjust to potential damages and/or take advantage of emerging opportunities and, thus, to respond to climate change consequences. The vulnerability of the system is finally represented as the propensity or predisposition of the system to be adversely affected by climate change and it is determined as a function of applicable climate-related risks combined with the adaptive capacity of the system.

In more general terms, the climate change risk assessment presented by ISO 14091 is coherent with the risk assessment approach described in the IPPC's 5th Assessment Report [18,19]. The novelty of the study presented here is that the framework presented by ISO 14091 was implemented, adapted, further developed, and finally applied for the vulnerability assessment of coastal Natura 2000 sites. The adaptation was based on the main objective of ECO-SMART project, which aims to support the protection of Natura 2000 sites from climate change effects through the combination of local stakeholder involvement and payment for ecosystem services (PES) schemes. The methodology followed in this research is structured into four steps:

(1) Assessment of the Natura 2000 sites in terms of habitats, and related provision of ecosystem services, that could be exposed to climate change effects. In this screening step, all identified habitats and related ecosystem services are included regardless of their actual exposure to climate change effects;
(2) Identification of hazards, defined here as the climate change driven processes which can affect the habitats of the Natura 2000 site being assessed, and consequently the services they provide;
(3) Assessment of the sensitivity, determined as the significance (to borrow the terminology of the EU's Habitats Directive), or relevance, of the effects of the climate change related hazards on the habitats of the Natura 2000 site being assessed. Local sensitivity can be determined with several technical methodologies, e.g., quantitative ones such as ecological modelling or qualitative ones, as done in this paper, such as the use of the expertise and local ecological knowledge [20,21] of stakeholders;
(4) Assessment of the potential climate change risk, or vulnerability, for the Natura 2000 site under investigation, which is finally determined based on the previous steps by considering how many habitats and ecosystem services are at risk. This risk differs from the actual climate change risk in that the adaptive capacity of stakeholders is not accounted for.

The details of each step as implemented in ECO-SMART are described in the following sections. Figure 1 presents the conceptual framework of the analysis that links the main risk components, pointing out that the risk results from the interaction of exposure and hazard, mediated by sensitivity.

2.1.1. Quantification of Exposure

The selected reference system for the identification of ecosystem services occurring in the study areas is the Common International Classification of Ecosystem Services (CICES), the classification system developed by the European Environment Agency (EEA). The currently most recent CICES classification (version 5.1) [22] is hierarchically organized in five levels, from broader to more detailed ones: Section, Division, Group, Class and Class Type. In the case of 'Section', each ecosystem service can be ascribed to one of these categories:

(a) Provisioning services: the nutritional, material and energetic contributions of the ecosystem to human needs and economic activities;
(b) Regulation and maintenance: the way in which living organisms or abiotic agents can influence the environmental variables that affect human quality of life and safety;
(c) Cultural services: every non-material and normally non-consumptive output of the ecosystem that influences the psychophysical state of people.

The remaining hierarchically lower levels for ecosystem service classification contain more specifically detailed definitions of the services [22].

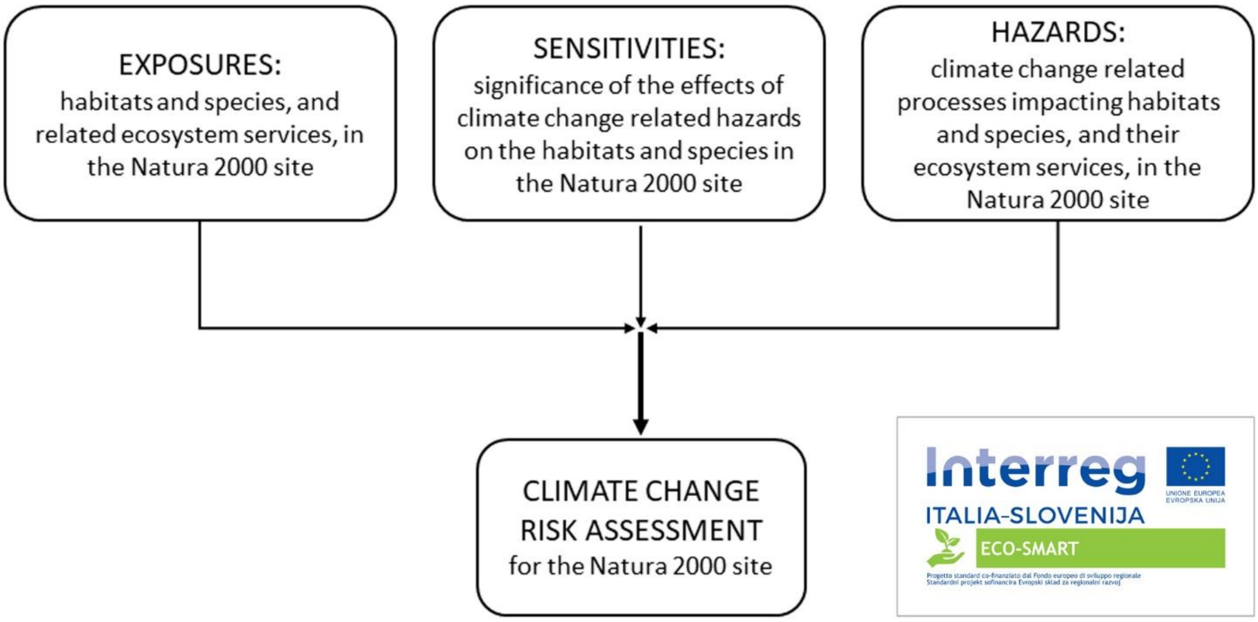

Figure 1. Conceptual framework of climate risk assessment for a given Natura 2000 site according to the ECO-SMART methodology, adapted from ISO 14091 [7,17].

A check list in an electronic datasheet format, shown in Table 1 and containing the 90 possible ecosystem service typologies according to the CICES classification, was drafted and, for each Natura 2000 site investigated in ECO-SMART, a project partner considered to be an expert for the site, with the additional help of local experts and stakeholders (such as those represented by a local participatory strategic planning process taking place in the Veneto region and named 'Wetland contract of the Caorle Lagoon system'), provided information concerning the presence and relevance of each of these ecosystem service typologies in the site, a brief description of each ecosystem service as it actually takes place in the site, and the relevant stakeholders for each service.

Habitats were classified by adopting the Natura 2000 code system (the four-digit code given in the Natura 2000 standard data form) as found in the Annex I of the EU's Habitats directive 92/43/EEC. Information on habitat presence was taken from the official standard Data Forms of each Natura 2000 site.

The aim of this data collection step was to obtain a general mapping of habitats and ecosystem services occurring in the pilot Natura 2000 sites, as well as to detect relevant ecosystem services, where relevance is determined from the management perspective according to the point of view of local stakeholders (e.g., to develop PES schemes, as per ECO-SMART goal). For instance, in the example reported in Table 1 for the pilot Natura 2000 sites located in the Veneto Region (listed below), the ecosystem service of control of chemical water quality by natural habitats is present and was identified by local experts as relevant in the area, both from a biophysical point of view and in relation to the public and private stakeholders found there.

2.1.2. Identification of Hazards

Once the identification of habitats and ecosystem services was completed (Section 2.1.1), in this screening step the hazards that can *potentially* influence the Natura 2000 sites through climate-change-driven processes, affecting the habitats and species of the Natura 2000 sites and consequently the services they provide, were identified. The most important climate-driven hazards affecting coastal transitional and wetland ecosystems along the Northern Adriatic coast were selected according the recent climate change projection scenarios of IPCC [1]: global average temperature rise, increase in average sea level, increase of intensity of extreme weather events, increase of frequency of extreme weather events, increase of intensity of heat waves, increase of frequency of heat waves, increase of duration of each heat wave, ocean acidification, changing hypoxia and anoxia of soils and water, increase of wildfires, saltwater intrusion, subsidence, changing sea currents, changing in rivers water regime, variation in the frequency of precipitations, variation in rainfall abundance, increase in the high tide level.

Table 1. Structure of the datasheet used to collect information for exposure quantification, with an example. The presence of the ecosystem service at the site (column 3) is an assessment of the presence of a given ecosystem service within the Natura 2000 site; the description of the service and connected habitat(s) (column 4) is a brief description of the specific service found in the Natura 2000 site being assessed and the identification of the habitats that provide it (the described habitats were subsequently matched to the Natura 2000 habitat codes); the relevance of the service for the area (column 5) is a qualitative, literature-based and/or expert-based assessment of the importance of the ecosystem service to the stakeholders who benefit from it, which are identified in column 6.

CICES V 5.1 Classification		**Additional Information for Contextual Understanding of CICES Classification within the Natura 2000 Site**			
CICES coding according to: Section; Division; Group; Class; Class type	Simple description of the CICES code	Presence of the ecosystem service at the Natura 200 site (yes/no/no information)	Description of service and connected habitat(s)	Is this ecosystem service important/relevant for the area? (yes/no)	Who are the stakeholders for this ecosystem service?
Code 2.2.5.1: Regulation and maintenance (biotic); Regulation of physical, chemical, biological conditions; Water conditions; Regulation of the chemical condition of freshwaters by living processes; by type of living system	Controlling the chemical quality of freshwater	Yes	Water quality treatment by wetlands, lagoon channels, buffer strips	Yes (e.g., in Vallevecchia this service is exploited to clean water)	Farms, land reclamation consortia, local municipalities, Veneto Agricoltura-regional agency for innovation in the primary sector, environmentalist NGOs

2.1.3. Assessment of Sensitivity

In this screening step, the relevance to stakeholders of the effects of the climate-change-related hazards on the habitats of the assessed Natura 2000 sites were determined. The local sensitivities were qualitatively determined by eliciting the opinion of site-specific experts and the local ecological stakeholder of stakeholders [20,21] to inform the completion of Table 2. This checklist was used to qualitatively connect the habitats found in each investigated Natura 2000 site, and the related ecosystem services (as per exposure quantification, Section 2.1.1), to the specific hazards which can influence them. Therefore, the matrix indicates if there are links of services, through habitats, with hazards and the sign of such effect (negative and also, potentially, positive, although the latter type of effect was not considered here due to lack of data and a precautionary approach).

2.1.4. Climate Change Risk Assessment

The final step of the proposed procedure is the *climate change risk assessment* for the Natura 2000 site under investigation, i.e., a cumulative assessment of risk done by considering how many habitats and ecosystems services are at risk due to climate change based on the previous three steps. Based on data obtained through the abovementioned data collection (checklist exposure quantification in Section 2.1.1, sensitivity matrix datasheet in Section 2.1.3) it was possible to build, for each of the investigated Natura 2000 sites, an Impact Chain (Figure 2), which is a network representation of the impact of climate change hazards on habitats and, as a consequence, on ecosystem services, i.e., a potential climate change risk assessment.

This assessment can be performed in different ways, each generating a different output indicator:

Habitat Vulnerability Analysis

This analysis aims to identify the habitats that are most vulnerable to climate change in the area under study. Habitat vulnerability was quantified by the sum of the number of hazards affecting the selected habitat.

$$Habitat_i\ vulnerability = \sum_{1}^{j} Hazards\ influencing\ Habitat_i$$

Table 2. The table used to collect information for the sensitivity assessment, with an example. Rows represent habitat types found in the investigated Natura 2000 site (in the example habitat 2130*—grey dunes), columns represent climate related hazards. Cell values show the presence (+1 positive effect, −1 negative effect) or absence (0) of an effect of the hazard on the corresponding habitat. The final column lists the ecosystem services provided by the habitat (examples are provided).

		Climate Related Hazards		**Ecosystem Services**
		Saltwater Intrusion	**Increase in the Intensity of Extreme Weather Events**	
Natura 2000 Habitats	2130*—Fixed coastal dunes with herbaceous vegetation (“grey dunes”)	0	−1	Control of erosion rates; seed dispersal; maintaining nursery populations and habitats (including gene pool protection)
	Habitat i^{th}	...	...	ESS j^{th}

Ecosystem Service Vulnerability Analysis

This analysis aims to identify the ecosystem services provided by the Natura 2000 habitats of the investigated site that are most vulnerable to climate change. ESS vulnerability was quantified through the sum of the hazards affecting the selected service, considering that an ecosystem service can be provided by more than one habitat (for example, nursery services can be provided by dune habitats as well as by wetlands) and, therefore, summing over different hazard–habitat–service pathways.

$$ESS_k\ vulnerability = \sum_{1}^{j} Hazards\ influencing\ ESS_k$$

Analysis of Relevance of Hazards

The hazards with the most widespread impacts in the area under study are identified through the following array.

$$Hazard_j\ relevance = \begin{bmatrix} \sum_{1}^{i} Habitat\ influenced\ by\ Hazard_j \\ \sum_{1}^{k} ESS\ influenced\ by\ Hazard_k \end{bmatrix}$$

The combination of these three assessments provides an overview of climate change risk assessment for the given Natura 2000 site.

Figure 2. The general structure of a climate change impact chain.

2.2. Comparative External Expert Evaluation

In the framework of the ECO-SMART project, selected external experts were invited to provide an evaluation of the robustness of the proposed methodology based on the output data of the methodology as implemented in the pilot sites, and furthermore were asked to answer the following questions according to SWOT analysis:

1. What are the strengths and added values of the methodology that go beyond the existing climate change adaptation approaches?
2. What are the limits, weaknesses, opportunities of this methodology?
3. How effective is the methodology regarding these specific aspects: ESS selection, ESS relevance to the Natura 2000 sites, and ESS vulnerability to climate change?

A total of seven experts participated in the evaluation affiliated with the following organizations: the Italian Ministry of the Ecological Transition; Italian and Slovenian members of the EUSAIR Pillar 3—Environmental quality and EUSALP Action Group 6-Resources; the Institute for Water of the Republic of Slovenia; the UN Environment Programme/Mediterranean Action Plan Priority Actions Programme Regional Activity Centre.

2.3. Natura 2000 Sites for the Pilot Methodological Application

The proposed methodology for climate change risk assessment was applied in five Natura 2000 wetland sites located along the Adriatic Sea coast of Italy and Slovenia: sites IT3250033 "Laguna di Caorle-Foce del Tagliamento", IT3250040 "Foce del Tagliamento" and IT3250041 "Valle Vecchia-Zumelle-Valli di Bibione" in the Veneto region of Italy; site IT3330007 "Cavana di Monfalcone" in the Friuli Venezia Giulia region of Italy; and site SI3000252 "Škocjanski zatok Nature Reserve" in Slovenia. These Natura 2000 sites are characterized by different covered surface, habitats, and ecosystem service typologies, and display varying degrees of management initiatives, stakeholder engagement and scientific knowledge of the local socio-ecological system. Taken together, the five sites cover a broad set of coastal habitats, ecosystem services and represent an even broader set of stakeholders.

3. Results

3.1. Škocjanski zatok Nature Reserve (SI3000252)

Established in 1998, Škocjanski zatok Nature Reserve comprises approximately 122 hectares, and in 2004 it was declared a Special Protected Area (SPA) upon the Decree on Natura 2000 sites [23,24] and upon the same Decree in 2012 it was upgraded to Special Area of Conservation (SAC) [25]. From 1999, the reserve is managed by the NGO DOPPS-Birdlife Slovenia [26]. The site contains five Natura 2000 habitat types (see Figure 3): Mediterranean and thermo-Atlantic halophilous scrubs *Sarcocornietea fruticosi* (code 1420); Mudflats and sandflats not covered by seawater at low tide (code 1140); *Salicornia* and other annuals colonizing mud and sand (code 1310); Mediterranean salt meadows *Juncetalia maritimi* (code 1410); Coastal lagoons (code 1150*).

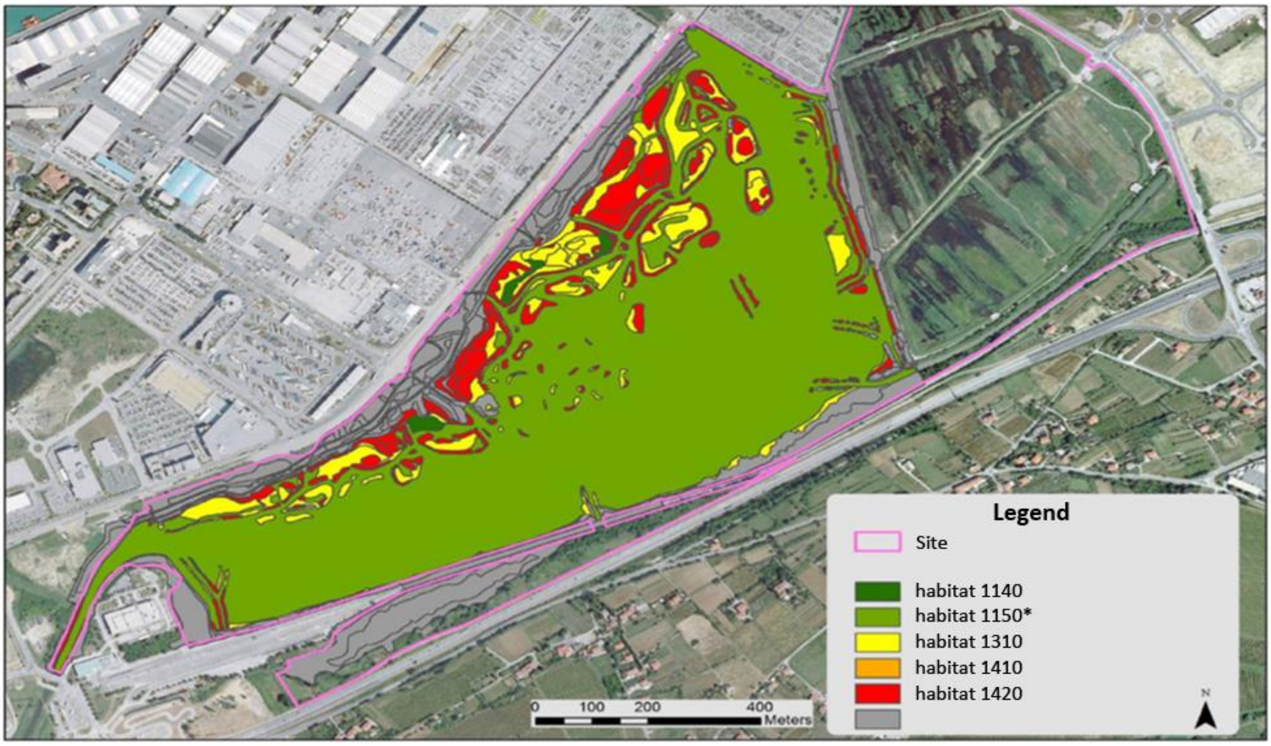

Figure 3. Aerial view for the Slovenian Natura 2000 site of Škocjanski zatok Nature Reserve (SI3000252) showing the habitats identified according to color coding. The symbol * indicates priority habitat types according to the EU's Habitats Directive.

To the habitats of the site, 31 identified CICES Ecosystem Services are linked that are classified 45% as regulatory and maintenance, while only 10% provisioning, and another 45% cultural. Among cultural services *interactions with nature* play a prominent role for the various stakeholders of the wider community, like citizens, civil society and organizations, governance public bodies, small and large businesses, educational and science sectors.

A total of 17 potential hazards were considered to be of importance in terms of impact to this wetland area. These potential hazards for the Natura 2000 site Škocjanski zatok Nature Reserve have been assessed using literature data including those collected and analyzed by the Slovenian environmental agency-ARSO [27]. Climate change projection has been done at national (Slovenian) and regional level, so the resolution of the climate change connected potential hazards at the local scale or even at the scale of habitats was impossible. Additionally, because of this, potential hazards refer to all Natura 2000 habitats of the Škocjanski zatok Nature Reserve.

Through the impact chain analysis, the hazards affecting the whole area of the Škocjanski zatok Nature Reserve, as they affect both the individual habitats and the site-specific ESS, can be identified (Figure 4). The hazards of greatest significance are depicted as pink boxes on the left side and were: average temperature rise (of water, soil and air); increased intensity of heat waves; increased frequency of heat waves; increased duration of each heat wave; increase in the frequency of extreme weather events; increased intensity of extreme weather events; changes in the river water regime; variations in the frequency of precipitation; variation in rainfall abundance; sea level rise.

The vulnerability analyses considered the Natura 2000 habitat types localized in the brackish part of the reserve only (Natura 2000 habitats are not present in the freshwater parts), which is considered more vulnerable than the freshwater part of the reserve. Previous research [28] assessed that sea level rise was a major hazard to these Natura 2000 habitats. Depending on different scenarios of climate changes and in particular projection of sea level rise in the 21st century, the mentioned Natura 2000 habitats could shift to each other and decrease their surfaces in total. Although these habitats represent a relatively small part of the reserve, only about 13% of the total area, they are very important as nesting and feeding grounds for birds.

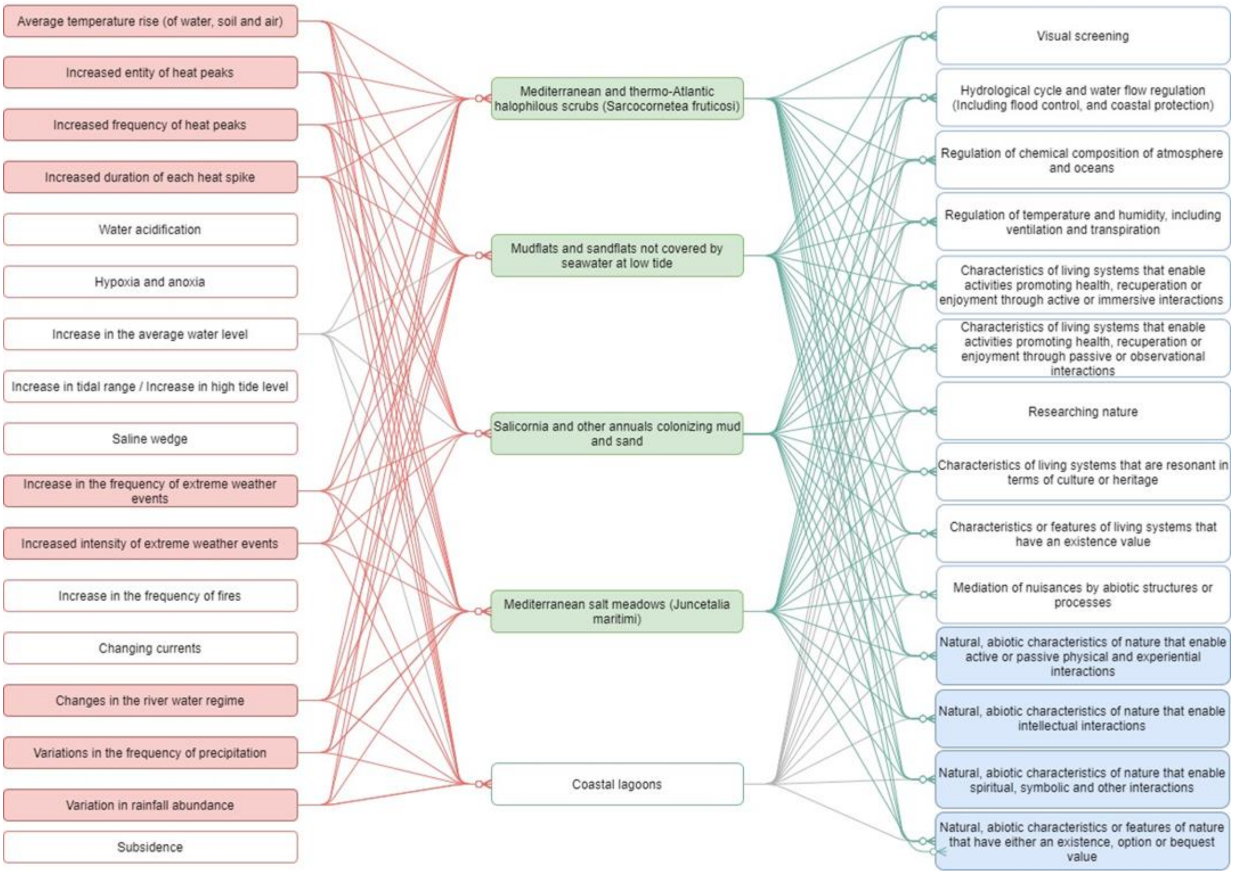

Figure 4. Impact chain analysis for the Slovenian Natura 2000 site of Škocjanski zatok Nature Reserve (SI3000252). This site-specific coastal climate change risk assessment represents the impact network of climate change hazards (left, pink) on the site's habitats (middle, green) and site-specific ecosystem services (right, blue). Hazards, habitats, and ecosystem services of most relevance according to the coastal climate change risk assessment are indicated by color-filled boxes, while less relevant ones are left blank.

The hazards influenced the cultural ESS, *interactions with nature*, the most (right blue boxes in the impact chain of Figure 4), and more specifically these were: natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions; natural, abiotic characteristics of nature that enable intellectual interactions; natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions; natural, abiotic characteristics or features of nature that have either an existence, option or bequest value.

3.2. Laguna di Caorle–Foce del Tagliamento (IT3250033), Foce del Tagliamento (IT3250040), Valle Vecchia–Zumelle-Valli di Bibione (IT3250041)

The Caorle Lagoon system comprises wetlands in the area shared among the municipalities of Caorle, San Michele al Tagliamento and Concordia Sagittaria, included in the Natura 2000 network and protected by local legislation ("Piano Territoriale Regionale di Coordinamento"). Proposed as Site of Community Importance (SCI) in 1995, the site "Laguna di Caorle–Foce del Tagliamento" comprises 4386 hectares and it was declared a Special Area of Conservation (SAC) upon the DM 27/07/2018. Instead, the site "Valle

Vecchia–Zumelle–Valli di Bibione" was designated as a Special Protection Area (SPA) in 2003, covering 2089 hectares.

The sites contain these Natura 2000 habitat types (see Figure 5): mudflats and sandflats not covered by seawater at low tide (code 1140); coastal lagoons (code 1150*); annual vegetation of drift lines (code 1210); *Salicornia* and other annuals colonizing mud and sand (code 1310); Spartina swards (*Spartinion maritimae*) (code 1320), Mediterranean salt meadows (*Juncetalia maritimi*) (code 1410), Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosi*) (code 1420); Mediterranean salt steppes (Limonietalia) (code 1510*), embryonic shifting dunes (code 2110); shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) (code 2120); fixed coastal dunes with herbaceous vegetation (grey dunes) (code 2130*); humid dune slacks (code 2190); Malcolmietalia dune grasslands (code 2230), coastal dunes with *Juniperus* spp. (code 2250*); wooded dunes with *Pinus pinea* and/or *Pinus pinaster* (code 2270*); Molinia meadows on calcareous, peaty or clayey-siltladen soils (*Molinion caeruleae*) (code 6410); Mediterranean tall humid herb grasslands of the Molinio-Holoschoenion (code 6420); calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (code 7210*); *Salix alba* and *Populus alba* galleries (code 92A0), and *Quercus ilex* and *Quercus rotundifolia* forests (code 9340).

Figure 5. Aerial view for the Italian Natura 2000 sites Laguna di Caorle–Foce del Tagliamento (IT3250033), Foce del Tagliamento (IT3250040), Valle Vecchia–Zumelle–Valli di Bibione (IT3250041) showing the habitats identified according to color coding. The symbol * indicates priority habitat types according to the EU's Habitats Directive.

The identification process carried out with a key contribution of local stakeholders identified a total number of 32 ecosystem services (36% of the total ecosystem services proposed by CICES), 26 of them particularly relevant for the area. Among the latter, seven were classified as Provisioning (biotic), 10 belonged to the category Regulating and Maintenance (biotic), seven were Cultural (biotic) and only two were Provisioning (abiotic). The local stakeholders served by these ecosystem services were mainly landowners, a local reclamation consortium, fish farmers and hunters, various nature-related and environmentalist NGOs, Veneto Agricoltura (a local agency for innovation in the primary sector, an instrumental body of the Veneto Region), the Veneto Region, municipal administrations, and the whole citizenry.

3.3. Foce del Tagliamento (IT3250040)

The most relevant hazards connected with climate change, indicated in the pink boxes of the Impact Chain figure (Figure 6), were: subsidence, increase in average sea level, increase of intensity and frequency of extreme weather events, changing in the river flow regime, the variation in the frequency of precipitations and in rainfall abundance.

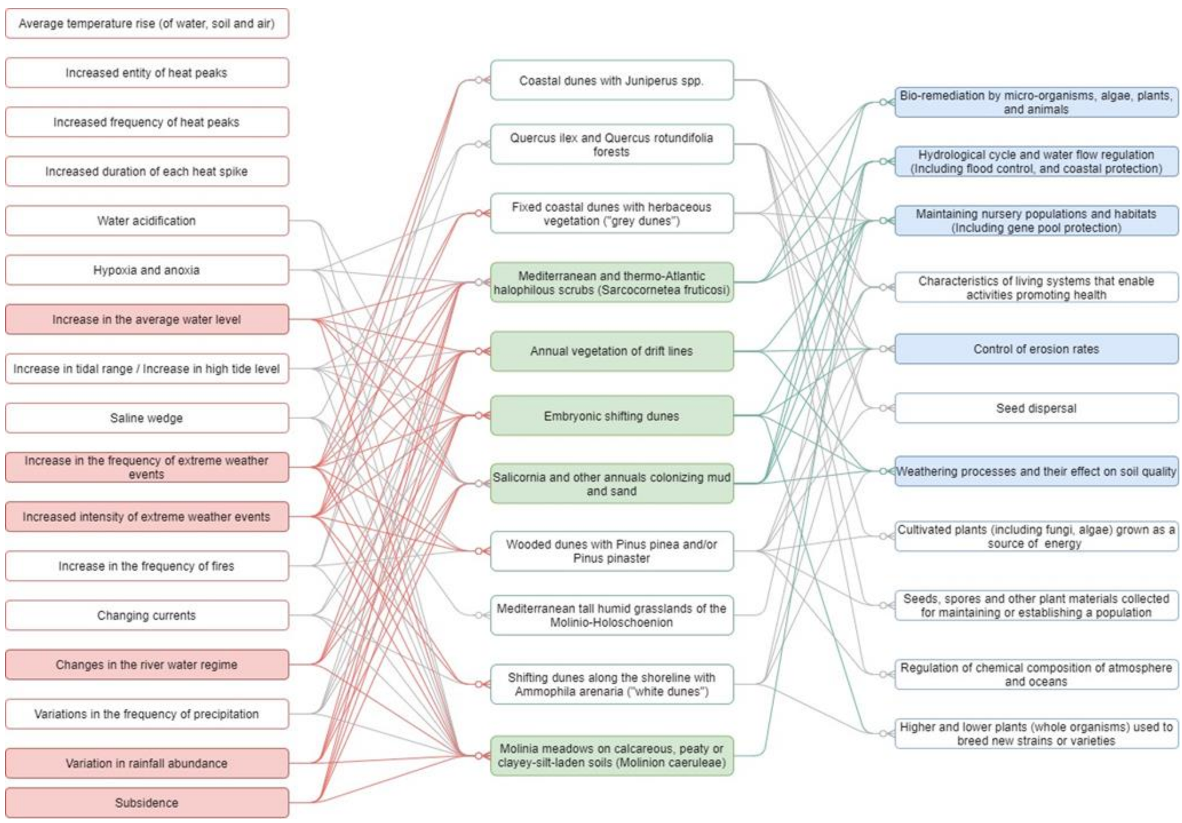

Figure 6. Impact chain analysis for the Italian Natura 2000 site Foce del Tagliamento (IT3250040). This site-specific coastal climate change risk assessment represents the impact network of climate change hazards (left, pink) on the site's habitats (middle, green) and site-specific ecosystem services (right, blue). Hazards, habitats, and ESS of most relevance according to the coastal climate change risk assessment are indicated by color-filled boxes, while less relevant ones are left blank.

The habitat vulnerability analysis detected the following most threatened habitat types, which are indicated in the green boxes in Figure 6: Molinia meadows on calcareous, peaty or clayey-siltladen soils (*Molinion caeruleae*) (code 6410), annual vegetation of drift lines (code 1210), embryonic shifting dunes (code 2110), Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosi*) (code 1420), *Salicornia* and other annuals colonizing mud and sand (code 1310).

The ecosystem services mainly affected by the hazards, highlighted in the blue box in the impact chain (Figure 6), were: bioremediation by microorganisms, algae, plants, and animals; hydrogeological cycle and water flow regulation (including flood control and coastal protection); maintaining nursery population and habitats (including gene pool protection); control of erosion rates; weathering processes and their effect on soil quality.

3.4. Laguna di Caorle–Foce del Tagliamento (IT3250033)

The most relevant hazards in this Rete Natura 2000 site were: increase in the average water level, increase in high tide level, saline wedge, changes in the river water regime, variation in rainfall abundance, subsidence. They are indicated in the pink boxes in Figure 7.

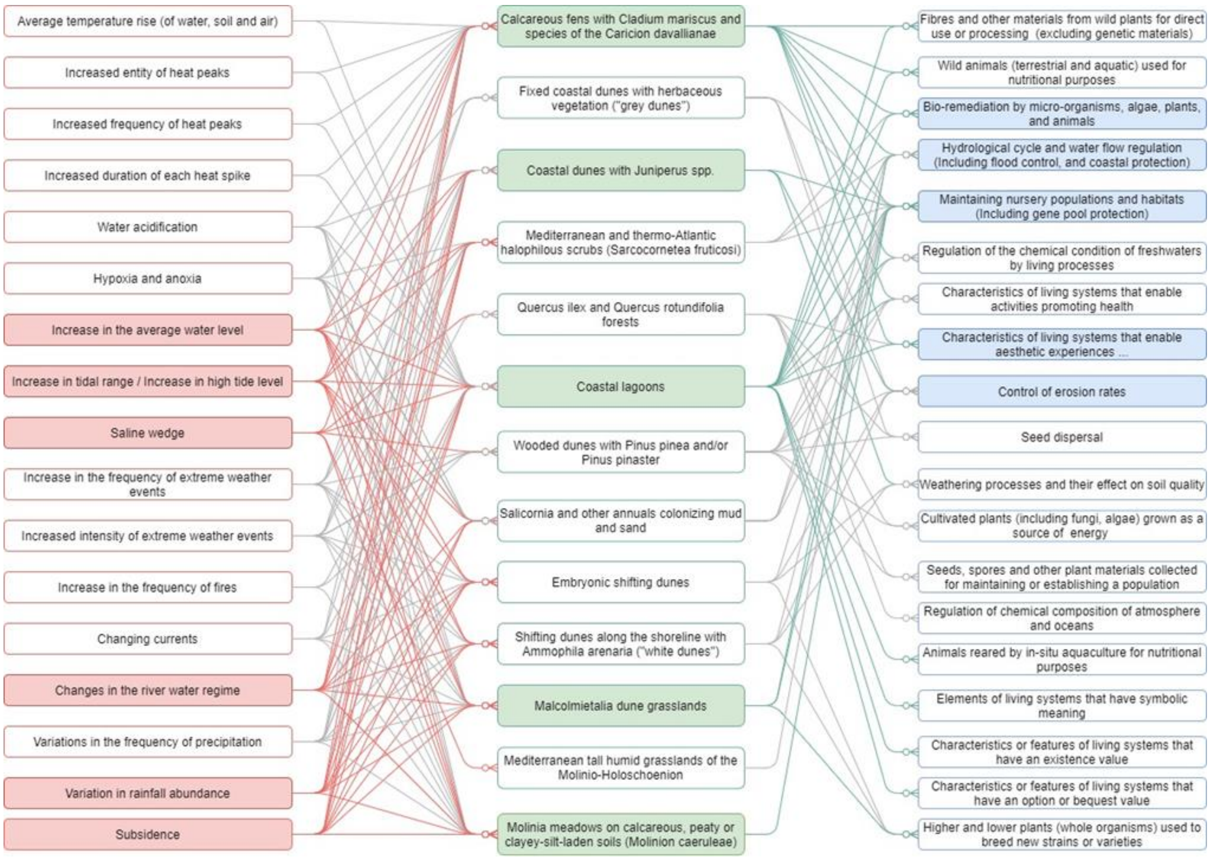

Figure 7. Impact chain analysis for the Italian Natura 2000 site of Laguna di Caorle–Foce del Tagliamento (IT3250033). See previous figures for the use of colors.

The habitat most threatened, indicated in green in Figure 7, were: coastal lagoons (code 1150*), calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (code 7210*), Molinia meadows on calcareous, peaty, or clayey-siltladen soils (*Molinion caeruleae*) (code 6410), Malcolmietalia dune grasslands (code 2230), coastal dunes with *Juniperus* spp. (code 2250*).

The ecosystem services most affected by the hazards (blue box in Figure 7) were: bioremediation by microorganisms, algae, plants, and animals; hydrogeological cycle and water flow regulation (including flood control and coastal protection); maintaining nursery population and habitats (including gene pool protection); characteristics of living systems that enable aesthetic experiences; control of erosion rates.

3.5. Valle Vecchia–Zumelle–Valli di Bibione (IT3250041)

The most significant hazards for this site were: subsidence, increase in high tide level, changes in the river water regime, increase in the average water level, variation in the rainfall abundance and frequency (pink boxes in Figure 8).

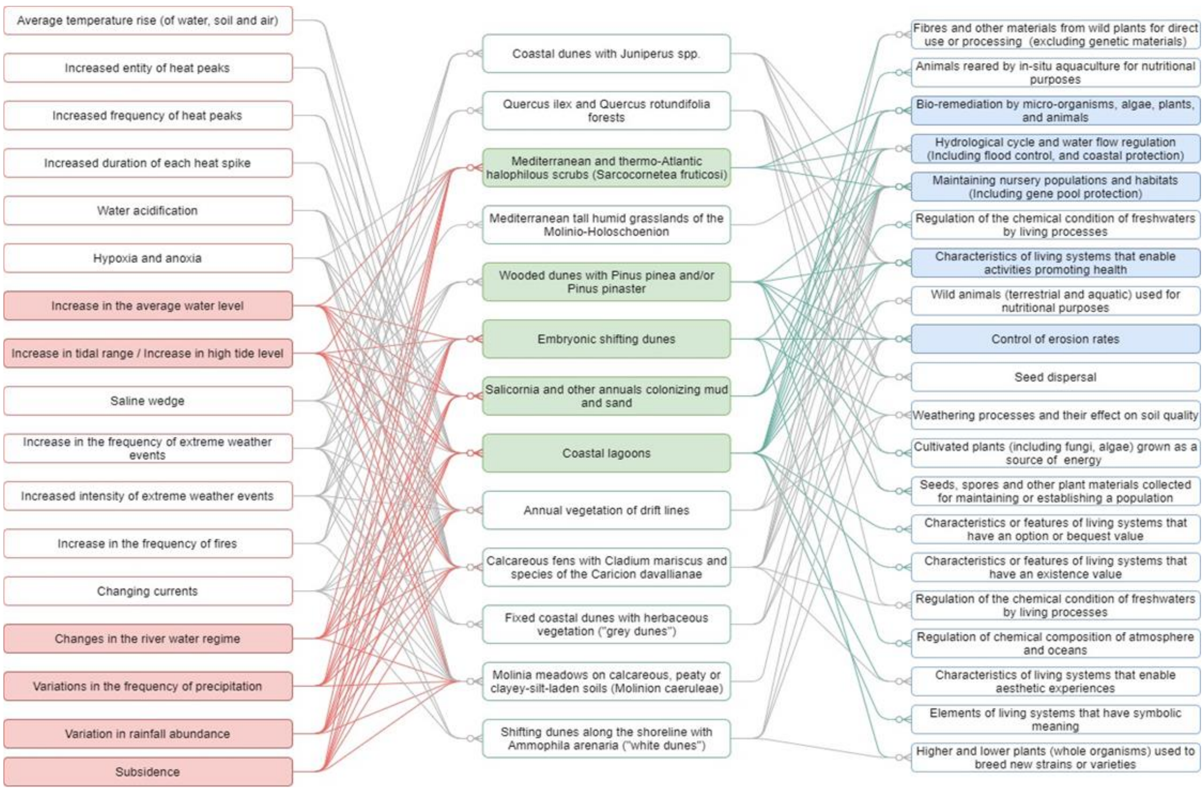

Figure 8. Impact chain analysis for the Italian Natura 2000 site of Vallevecchia–Zumelle–Valli di Bibione (IT3250041). See previous figures for the use of colors.

These hazards have greater influence on the following types of habitat: coastal lagoons (code 1150*), embryonic shifting dunes (code 2110), Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosi*) (code 1420), Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (code 6410), *Salicornia* and other annuals colonizing mud and sand (code 1310), wooded dunes with *Pinus pinea* and/or *Pinus pinaster* (code 2270*).

The ecosystem services most affected by the hazards (blue box in Figure 8) were bioremediation by microorganisms, algae, plants, and animals; hydrogeological cycle and water flow regulation (including flood control and coastal protection); maintaining nursery population and habitats (including gene pool protection); characteristics of living systems that enable aesthetic experiences; control of erosion rates.

3.6. Cavana of Monfalcone (IT3330007)

The Cavana of Monfalcone (IT3330007), declared as a Special Area of Conservation (SAC) in 2013, is a transitional area located between the lower Isonzo plain and the Adriatic Sea (Figure 9). The site covers 133.42 hectares. A large part (84.8%) includes the municipality of Monfalcone, a small part the municipality of Staranzano (3.3%) and a significant part is sea (11.9%). Part of the site is affected by the land reclamation works of the last century that transformed the transition areas into extensive monoculture cultivations. The natural value of the site is determined by the presence of resurgence areas close to the sea that have resisted land reclamation and intense industrialization found near the site. In the SAC, 56.9% of the surface is characterized by habitats that are not of Community interest, while in the remaining fraction 10 habitats included in Annex I of the Habitats Directive were identified, of which two are considered a priority: calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (code 7210*), alluvial forests of *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) (code 91E0*).

Figure 9. Aerial view for the Italian Natura 2000 site Cavana of Monfalcone (IT3330007) showing the habitats identified according to color coding. The symbol * indicates priority habitat types according to the EU's Habitats Directive.

The extent of the site is such that the whole area should be considered a core area, and economic activities are located outside the side. Nevertheless, the anthropogenic pressure on habitats and species is significant (due to the proximity to an industrial area, port and shipbuilding areas, agricultural and tourism areas).

Of the 90 ESS listed by the CICES, 22 were identified in the site. The most represented are classified as regulation and maintenance (59%), 23% are cultural ESS, while 18% are provisioning services. Additionally, a total of 17 potential hazards were considered. A panel of external experts from research centers and academia was established in order to assess the ESS vulnerability to climate change. Figure 10 illustrates the impact chain of the Cavana of Monfalcone. On the left side, the hazards with greatest significance are highlighted in the pink boxes: average temperature rise; increased magnitude of heat peaks; increased frequency of heat peaks; increase in the average water level; increase in high tide level; saline wedge.

The most affected habitats (highlighted in the green boxes in Figure 10) are those with an excellent conservation status and are listed in importance order: Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* (code 3260); the calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (code 7210*);

the Molinia meadows on calcareous, peaty, or clayey-silt-laden soils (*Molinion caeruleae*) (code 6410); the alcaline fens (code 7230); hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (code 6430).

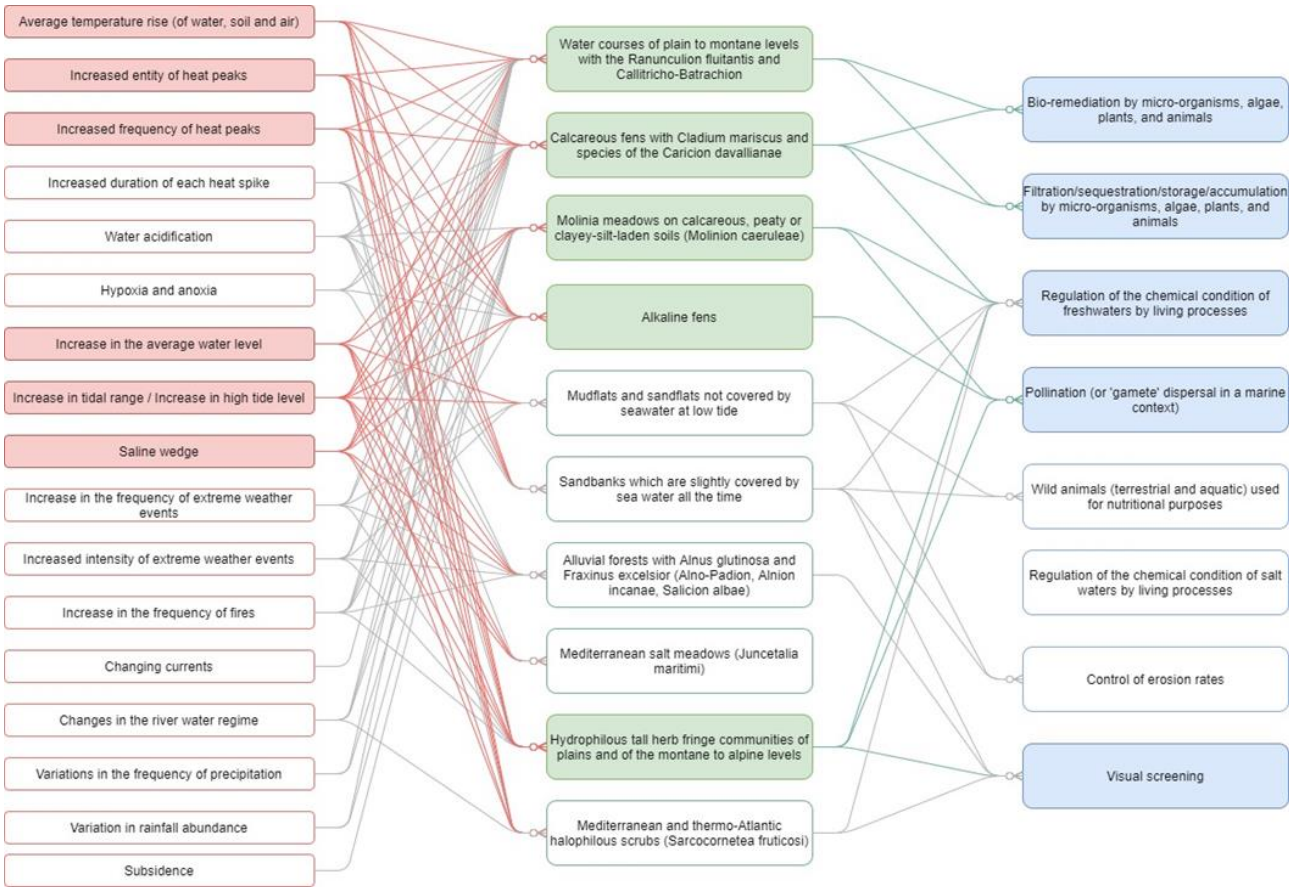

Figure 10. Impact chain analysis for the Italian Natura 2000 site Cavana of Monfalcone (IT3330007). See previous figures for the use of colors.

The ESS (highlighted in the blue boxes) linked to the previous habitats and most exposed to the selected hazards are: regulation of the chemical condition of freshwaters by living processes; pollination (or 'gamete' dispersal in a marine context); filtration/sequestration/storage/accumulation by microorganisms, algae, plants, and animals; bioremediation by microorganisms, algae, plants, and animals; visual screening.

3.7. Comparative Results of the External Expert Evaluation

While only one of the external experts mentioned that the overall methodology was experienced as "very robust", the other six indicated the methodology as "robust". Some general remarks describing the methodology, as well as some critical points are given in Table 3.

More specifically, the ESS selection criteria of the methodology are characterized by a lower level of comparison among the pilot cases, and therefore the selection effectiveness has a medium to high added value. Additionally, with respect to ESS relevance at the Natura 2000 site, the methodology is characterized by comparable elements even if the contents differ among the pilot sites, and in general this was found to be quite effective, with medium to high added value. However, it was remarked that in order to ensure transferability, the methodology should provide a more structured approach, and since the pilot areas are characterized by the same (coastal) ecosystems, transferability to other ecosystems cannot be assessed. Finally, regarding EES vulnerability to climate change, the methodology shows comparable elements and common content among the pilot sites, with vulnerability to climate change covered effectively and having medium to high added value, and can be easily transferred to other contexts/sites. One general statement captures the overall evaluation of the seven external experts: 'the feasibility of the selected measure should be well analyzed, and the pilot sites have shown that this can be done'.

Table 3. Remarks from the external expert evaluation of the vulnerability methodology.

General Description of the Methodology
Well structured, and the workflow has a very clear logic.
Consistent, and the steps are logically linked.
Transparent and integrated assessment and allows for the identification and planning of future actions for the better management of Natura 2000 sites.
Allows identification of the strengths of the area on which to evaluate the management strategy and a better identification of the conservation objectives for the site.
Critical Remarks Regarding the Methodology
The method requires a lot of preparatory work such as the identification of the habitats and ESS that are most sensitive to climate change.
The adoption of the CICES taxonomy could be a weak point, because while it is sufficiently comprehensive in terms of provisioning ESS, for operational purposes, the definitions of regulatory and cultural ESS are not adequate.

4. Discussion

This is the first time that the ISO approach has been combined with the human-centered theoretical framework of ecosystem services to support the systematic identification of the habitats and services impacted by climate change in ecologically valuable coastal sites. This socio-ecological perspective and its proven functionality can contribute to bring perspective to public authorities and site managers to promote the involvement of stakeholders in nature conservation. Participation is fundamental to mobilizing resources towards sustainability; while ethical reasons are crucial justifications for nature conservation, seeing coastal ecosystems as green infrastructures which can provide society with valuable services can contribute to increase societal consensus regarding conservation and restoration, as well as to promote additional investments in biodiversity protection [2–4].

Climate change risk assessment according to the ISO approach is addressed as the result of the evaluations of (1) hazards, (2) exposures, (3) sensitivities and (4) the adaptation capacity of the assessed system. Exposures here are partly considered as habitats and partly as ESS. Sensitivities are defined as the degrees to which the system is affected, either adversely or beneficially, by climate change. As such, sensitivities can be seen as a function of the applicable hazards and the exposure of the studied system that results in the quantification of potential climate change risks and related impacts. In our approach, this hazard–exposure connection is represented by the most relevant hazards and ESS in the impact chains (indicated by color-filled boxes). Thus, according to our approach, the potential *climate change risk*, or *vulnerability*, for the Natura 2000 site under investigation, is assessed through consecutive steps by considering how many habitats, species and ESS are at risk. This risk estimate further differs from the actual (ISO-driven) climate change risk assessment in that the adaptive capacity of the stakeholders is not accounted for. The adaptive capacity is defined as the ability of the system to adjust to potential damages and/or take advantage of emerging opportunities and, thus, to respond to climate change consequences. The (true) vulnerability of the system is the propensity or predisposition of the system to be adversely affected by climate change, and can be determined as a function of applicable climate-related risks combined with the adaptive capacity of the system. Our vulnerability methodology does assess the predisposition of the system, but only as an admittedly simple impact chain of hazards, habitat, and ESS, thus representing a precautionary, worst-case scenario. One limitation of our work is that of equal weights, which can potentially introduce biases: in the case that good-quality data are available, a weighting of hazards could be implemented or, as a simplified alternative, weights could be defined based on the habitat surface that is threatened by the hazards, although such surface-based weighting approach also contains assumptions which can potentially bias results (for certain habitats, for example, service provision is not necessarily proportional to surface but depends on other features such as spatial structure, e.g., linear length is—possibly—a better indicator of the service of coastal protection against storms by dunes). Other—possibly synergistic—aspects could be considered as well, and an accurate adaptation strategy certainly should implement multi-criteria weighting. Although the quantification of adaptive capacity is out of the scope of this paper, it is a task planned in the ECO-SMART project, namely in the activities leading to the definition of sustainable and applicable PES schemes [16]. Such PES schemes represent examples of anthropogenic responses to adjust to potential damages, by creating more powerful and sustainable opportunities of conservation. For example, the combination of the IMPRECO project results [23], a protected area management model that include stakeholders in the decisional process, and ECO-SMART results [16] has resulted in planning a model of co-creation of climate change adaptation plans for the Škocjanski zatok Nature Reserve site, with PES simulations and feasibility studies of identified measures that include stakeholders and in particular key actors during the whole process. We believe that our proposed methodology enables relatively simple and fast screening to identify locally relevant conservation issues in terms of hazards, habitats, and ecosystem services, providing an improved framework for decision making.

The results of a climate change risk assessment might of course change when socio-ecological feedbacks are considered, e.g., in terms of adaptation capacity. The potential importance of considering societal aspects is already clear when looking at the present analysis of the Slovenian site Škocjanski zatok Nature Reserve: while previous literature mentions sea level rise as the most important hazard, other hazards seem relevant too according to our analysis accounting for human-nature relationships in term of ecosystem services, highlighting that they deserve further investigation from a conservation point of view. Such methodology has the additional advantage of being fit to consider potential synergistic effects of hazards.

Again regarding the proposed methodology, although the Natura 2000 network and the Habitats and Birds directives also deal with species protection, in this paper the focus was on habitats which were a more obvious and simpler first choice according to the infrastructure-oriented focus of the ECO-SMART project. It should be noted, however, that the illustrated methodology can also be applied to species, which also remain central for biodiversity conservation as well as for ecosystem service provision.

The detailed comparative analysis by the external experts regarding ESS selection, relevance, and vulnerability effectiveness, highlight that inter-site comparison with the current method is feasible, but mainly that this method seems generally applicable to any coastal site, or for that matter our opinion is that this approach has the merit of being quickly applicable everywhere, whether in a natural or urban system, even in data-poor areas, which are unfortunately a common situation across nature conservation sites. Since Natura 2000 sites often have some habitats in common, it might be possible to adopt this methodology to carry out habitat-specific sensitivity assessments across multiple sites. Additionally, are hazards associated with specific habitats? And does the ECO-SMART vulnerability method allow identification of management priorities for both general coastal and site-specific environments? We believe that the vulnerability assessment methodology presented may be a useful tool for answering some of these questions in the future.

Although a quantitative analysis to investigate adaptation capacity is beyond the scope of this paper, the presented methodology can surely be a contribution in that direction, as knowledge of the provision of ecosystem services and stakeholder involvement is a precondition to generate adaptation capacity. Indeed, a limitation of the proposed approach is that it assumes that no adaptation capacity is in place within the local socio-economic system [7]. Such an absence, often present in practice in conservation sites, should be considered a worst-case scenario, making the methodology precautionary, and the proposed approach most likely positively contributes to adaptive capacity by offering site managers and local authorities an assessment tool. Other methodological limitations reside in the assumption made by assigning equal weights to each hazard. This choice was forced by lack of quantitative data, a common issue in nature management and Natura 2000 areas. While a quantitative analysis to generate adaptation capacity was beyond the scope of this work, it should be noted that the proposed methodology has the advantage that it can be easily run multiple times and even periodically to accommodate novel data, allowing the re-assessment of a site, and such re-assessments can easily go quantitative or semi-quantitative (e.g., through a Multicriteria Analysis—MCA [29]), for instance by assigning different weights to different hazards, if more information becomes available, making it possible to perform a better risk assessment. On the other hand, introducing weighted hazards could change the results: in the absence of quantitative data the reliability of predictions could be explored through an uncertainty analysis, which is however beyond the scope of this paper.

5. Conclusions

This paper presents a climate change risk assessment method that combines the socio-ecological theoretical framework of ecosystem services assessment with local stakeholder participation, to systematically identify climate related issues for local protected habitats. The methodology was applied to selected Natura 2000 sites along the Adriatic coast, an area at high risk of ecosystem service loss due to climate change [15]. Results show that each of the assessed sites, despite being along the coast of the same sea, is affected by different climate-related issues impacting different habitats and corresponding ecosystem services. The methodology was evaluated as robust and generally applicable, as it addresses the peculiar response to climate change of each nature conservation site in terms of habitats and ecosystem services, and can thus become a useful tool for public authorities, site managers and other stakeholders to contribute to plan site-specific measures of adaptation, conservation and restoration.

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