ADAPTA BLUES

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C1.5: Methodology for the design of Climate Change adaptation strategies in estuarine areas based on estuarine ecosystems restoration and conservation

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure 1. Proposed methodology for the prioritization of adaptation measures..... 9

1 INTRODUCTION

Given the impacts that estuarine regions may suffer because of climate change, it is important and necessary to develop an adaptation process to maintain or reduce the levels of risk, or to increase the resilience of these important ecosystems in the face of climate-induced changes or the frequency and intensity of extreme events.

Adaptation measures refer to options and actions that can be implemented to enhance adaptation to climate change, either to reduce risk to an acceptable level or to exploit an opportunity that may emerge (Climate Adapt, 2017). For the purposes of this report, adaptation refers to adjustments in natural or human systems in response to expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities (IPCC 2014).

Adaptation options in estuarine regions can vary widely and as will be seen, can be classified according to different criteria. However, in any case, to choose the best option, it is necessary to develop a process for selecting adaptation measures. This process must consider the set of available options, a set of criteria that allow for their assessment, which must be as complete and related as possible, and finally, the opinion of the society.

This document precisely develops a methodological proposal that aims to meet this objective by considering the three factors described above.

2 GENERAL APPROACH

Adaptation arises as a need to adjust a natural or socio-economic system to the projected climate and its effects. The ultimate goal of adaptation is thus to make systems more resilient to climate action or to take advantage of the new opportunities it offers.

Adaptation planning in estuarine systems must be done on the basis of a prior climate change risk analysis, but with adaptation framed within the context of existing ecosystem management policies, strategies, planning and decision-making processes. In contrast to the mere elaboration of a risk analysis, adaptation requires the intervention and implementation of concrete measures and therefore needs to be contextualised within existing frameworks.

Adaptation involves the programming and implementation of a set of adaptation options aimed at reducing the risk or increasing the resilience of the coastal system. In this context, however, there is no single classification for the different adaptation options available in estuarine areas.

Firstly, we can distinguish between:

- anticipatory adaptation, which takes place before the impacts of climate change are observed;
- autonomous or spontaneous adaptation, which is not a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and market or welfare changes in human systems,
- and finally, planned adaptation, which is the result of a policy decision, based on the realisation that conditions have changed or are about to change and consequently action is required to return to, maintain or achieve a desired state.

Natural systems have the potential to adapt through multiple autonomous processes (e.g. changes in phenology, migration, compositional changes, phenotypic acclimatisation or genetic changes), and humans can intervene to promote particular adjustments, such as through the reduction of non-climatic stresses or through managed migration. Successful adaptation will depend on the ability to allow and facilitate natural systems to adjust to a changing climate while maintaining the ecosystem services on which life depends (Noble et al., 2014).

According to the latest classification in AR5 (IPCC 5th Assessment Report), adaptation options can be organized into three broad categories:

- structural or physical options;
- social options;
- and institutional options.

Each of these options can be further subdivided into more specific sub-categories. In general, we could say that structural or physical options have in common that they are concrete and discrete options, well defined in space and time and implemented locally. Although some of the options under the heading of social options could also respond to this criterion, in general, their main objective is to reduce social vulnerability. Finally, institutional options respond to legal, financial and economic aspects.

In previous IPCC reports (AR4, 2007) and other literature, coastal adaptation options are also organised into four main groups:

- protection;
- accommodation;
- retreat;
- and advancement.

Protection options are defined as those that ultimately aim to protect at-risk areas, whether they are part of the socio-economic or natural system, by trying to prevent impacts from flooding, erosion, saline intrusion, etc., by reducing hazards (hazard) and/or especially exposure. A special case of these, which is usually considered separately, are advancement options where the shoreline is artificially advanced to counteract loss of land through erosion or saline intrusion or to minimise the effects of flooding.

Accommodation options are those which, while maintaining potentially at-risk elements in affected areas, prioritise reducing their vulnerability by modifying land use, introducing specific regulations for infrastructure and housing, or adopting measures to increase the preparedness of exposed elements to potential impacts.

Finally, retreat options are based on the planned abandonment of areas likely to be affected by the impacts of climate change or extreme coastal hazards. Within each of these options, there are different alternatives that can be applied individually or in combination and whose implementation will depend on the technological capabilities, legal and financial frameworks and coastal management policies in place at any given time.

Obviously, any of the options considered within this classification can be included within the categories included in the previous classification proposed by AR5.

Regardless of the mode of classification, adaptation options should be selected to meet a specific objective in reducing any of the risk-reducing factors. It is therefore important to understand their typologies, the benefits in terms of risk reduction and the factors that condition their effectiveness. Other relevant social, environmental, economic or mitigation co-benefits must be added to these to determine the most appropriate solution.

All this information and knowledge is the basis for identifying and selecting the optimal adaptation measures considering criteria of effectiveness, long-term adaptability, robustness, comprehensiveness, efficiency, equity, dimension, and environmental value, as well as the perception and needs of society.

3 METHODOLOGY

This section describes the methodology proposed for the selection and prioritisation of adaptation measures in estuarine areas. The methodology comprises four stages:

1. A prioritisation of adaptation strategies with involved stakeholders
2. A selection of potential adaptation measures among all the available options,
3. A prioritisation of the potential measures by use of an analytical hierarchical method (comprising 10 steps),
4. A participation process to assess the selected adaptation measures.

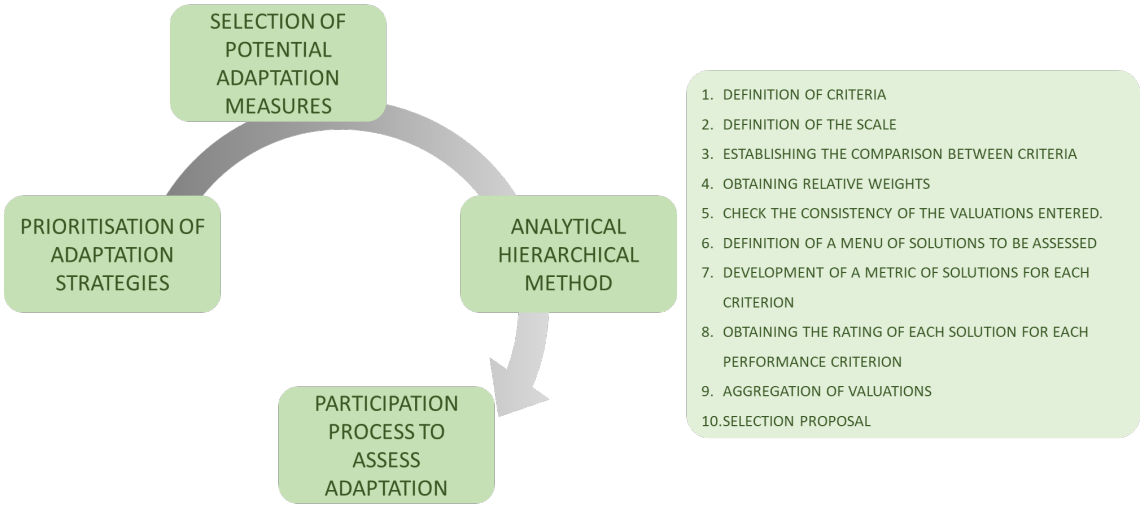

Figure 1. Proposed methodology for the prioritization of adaptation measures

It is important to note that any adaptation process in estuarine systems must be done on the basis of a prior climate change risk analysis.

3.1 Prioritisation of adaptation strategies

As explained in Section 2, there are multiple typologies of adaptation strategies for climate change in estuarine areas, and or each of them, multiple options in the form of adaptation measures can be applied. However, it is necessary to determine which of these strategies may be the most appropriate and suitable.

The first stage of this proposed methodology seeks to achieve the objective of deciding which adaptation strategy or strategies are preferred. To this end, it is proposed to use workshops in which the participation of the agents involved and affected is considered fundamental. For the elaboration of these workshops, the starting point will be the identification of the agents carried out in previous stages of this project. These workshops will be carried out specifically for each of the areas of study on which this project focuses.

These workshops, which will be approached from an eminently collaborative perspective, will have the following outline:

- A brief presentation of the project, its general objectives, and the particular objectives of the session.
- A presentation of the main threats identified in the estuary, as well as the level of risk obtained during the analysis carried out in the previous actions.
- A description of the range of adaptation strategies available, with examples of their application in other potentially similar areas.
- A participatory and communication process leading to the prioritization of the above strategies.

The objective of this stage is to end up with a prioritization of the strategies according to the inputs provided by the actors involved.

3.2 Selection of potential adaptation measures

The second stage to be taken is to identify and shortly describe a set of adaptation measures that can be implemented in the study area. These potential adaptation measures will be based on the prioritization of strategies obtained in the previous stage.

For developing this, two steps are necessary:

- a catalogue of adaptation measures that sets out the set of options for each of the strategies.
- an evaluation of the measures in the catalogue to identify those that can be applied in each specific case, depending on the location of the study area and its level of risk for the identified risks.

This second step can be carried out with the help of a panel of experts who, based on the previous information provided by a risk analysis and their own expert knowledge, are able to evaluate and prioritize different adaptation strategies and measures.

In the case of coastal areas and estuaries, an example of a panel group, including the specialist profiles, is presented on Table 1.

SPECIALIST	PROFILE
Maritime climate	Experience in the development and analysis of marine dynamics and climate change scenarios.
Hydrology	Experience in the field of hydrometeorology, maximum floods, water availability and flood modelling.
Coastal impact assessment	Experience in modelling, analysis and assessment of impacts of extreme events in the coastal zone.
Hurricanes	Experience in modelling, analysis and evaluation of the effects caused by hurricanes in the coastal zone.
Coastal engineering	Experience in the study of coastal behaviour and evolution, including the management and evaluation of natural and anthropogenic risks.
Exposure and vulnerability	Experience in the development and analysis of socioeconomic studies on population, built elements and infrastructure.
Economy	Experience in the study and analysis of the effects caused by climate impacts on the socioeconomic environment and the productive network.
Ecosystems	Experience in the characterization of ecosystems and study of the consequences of extreme climate events.
Risk and climate change adaptation	Experience in the elaboration of risk analyses due to climate change, as well as in the development of adaptation measures.
Urban and land use planning	Experience in urban area management and land-use planning, especially in coastal areas.

Table 1. Profiles of the specialists that compose the expert panel in charge of assessing the adaptation estrategies and measures.

The expert panel will be the responsible for evaluating each of the possible strategies and the associated measures. This evaluation seeks to determine the suitability, performance, and adequacy of each of the measures as risk reduction elements, considering the specificities and particularities of the case study.

This assessment could be made quantitatively, on a scale ranging from 1 to 5, where 1 means the lowest level and 5 the highest possible. To make this assessment, the expert panel relies on all the information gathered in previous stages, namely the risk analysis developed in the case studies.

The result of this process is a priority classification obtained for the different strategies and the associated measures, defined by a ranking.

3.3 Analytical hierarchical method

When approaching to the problems derived from the application of the direct multi-criteria method, which is based on applying criteria and assessments directly, we are faced with the need to objectify the decision criteria and metrics, as well as to provide both with internal consistency.

The Analytic Hierarchical Method (AHM) (Saaty,1980) is a methodological approach that addresses both problems through a pairwise comparison of criteria and alternatives using a rated scale

Based on this method, the methodological proposal for its application for the selection of climate change adaptation measures is based on the development of 10 steps:

1. To define independent assessment criteria that cover the different facets to be handled.
2. To adopt a rated scale for comparisons according to AHM proposal (Saaty,1980)
3. To construct a comparison matrix by pairs of the criteria, to characterise the relative importance of the criteria.
4. To calculate the relative weights of the criteria.
5. To verify the consistency of the valuations entered.
6. To define a menu of solutions to be evaluated.
7. To carry out a pairwise comparison of the intervention proposals for each criterion.
8. To obtain the valuation of each solution for each criterion of action.
9. To aggregate all the evaluations according to the weights established in step 4.
10. To define the order of preferences and validate the proposal.

The following is a detailed description of each of the above steps that comprise the methodological proposal.

3.3.1 Definition of criteria

The first step to develop is to define the set of criteria under which the potential adaptation measures will be assessed.

The following (Table 2) is a broad collection of possible (but not limited) criteria to serve as a guiding example.

NUM.	CRITERION	DESCRIPTION
1	Effectiveness	A solution is more effective when it achieves greater intensity in the desired results.
2	Long-term adaptability	A solution is adaptable in the long term when it shows the capacity to evolve in the future.
3	Robustness	A solution is more robust when it shows the capacity to assume variability in environmental conditions.
4	Comprehensiveness	The more comprehensive a solution is, the more it can be integrated into larger-scale solutions.
5	Efficiency	A solution is more efficient when it makes the best use of the resources employed
6	Equity	A solution is the more equitable the more it is able to specifically address the needs of disadvantaged groups, minorities, lower income levels, women….
7	Dimension	The dimension is given by the extent of the service provided.
8	Environmental value	A solution has greater environmental value the better environmental conditions it creates for the survival of ecosystems.

Table 2. Criteria to analyze the potential adaptation measures.

3.3.2 Definition of the scale

The second step is to define the valuating scale to assess the potential measures according to the previously defined criteria. In this proposal, this scale must be quantitative. Implications regarding the use of odd or even scales (and the existence or not of midpoint) should not affect, based on the good practice of producing scale labels.

Following AHM, the following scale (Table 3) could serve as a good working example.

SCALE	DEFINITION	EXPLANATION
1	Equally preferred	The two criteria contribute equally to the objective A=B.
3	Moderately preferred	Experience and judgement somewhat favour one criterion over the other A>B
5	Strongly Preferred	Experience and judgement strongly favour one criterion over the other. The second criterion would be valid for resolving ties A>>B
7	Strongly preferred	One criterion is strongly favoured over another. Its dominance can be demonstrated in practice. The

		second criterion could be used to settle ties. A>>>>B and nuanced judgements
9	Extremely preferred	The evidence most strongly favours one criterion over another A

Table 3. Saaty preference scale

3.3.3 Establishing the comparison between criteria

This step involves constructing a comparison matrix by pairs of criteria, crossing the criteria by rows and columns, where we characterise the relative importance of the criteria according to Saaty's scale (from 1/9 to 9). (Saaty, 1980)

In this matrix, the elements of the diagonal have a value of 1 because they are of equal importance, and consistency is maintained between each term and its reciprocal. This maintains a number of independent comparisons equal to $n = {(n-1)}/{2}$, where n is the number of criteria.

Based on this double-entry table, weights are given to the comparison of each criterion under the following conditions:

- Diagonal elements are filled with 1.
- The symmetrical terms receive reciprocal ratings: if cell (i, j) is rated with a value v_k, the cell (j, i) receives a value of $1/v_k$.
- Each cell receives its valuation according to the scale, calling A the row criterion and B the column criterion according with table (3).

In a simplified example, matrix like the following (Table 4) could be obtained. Note that the sum by columns is obtained as it is required for further steps.

Criteria	Benefit from Protection	Recreational service	Environmental	Navigation
Benefit from Protection.	1	5	3	7
Recreational service	1/5	1	1/5	5
Environmental	1/3	5	1	7
Navigation	1/7	1/5	1/7	1
Sum	1.676	11.200	4.343	20

Table 4. Results of the pairwise assessments

3.3.4 Obtaining relative weights

From the previous step, a normalisation process for each column is perform based on the sum of the column itself. This allows to obtain the final weights consistent with these binary assessments. Following this procedure, the assessment weights in accordance with the relevance attributed to the criteria are obtained.

An example is shown in Table 5.

CRITERIA	Benefit from protection	Recreational service	Environmental	Navigation	AVERAGE
Benefit from Protection.	0.60	0.45	0.691	0.35	**0.52**
Recreational service	0.12	0.089	0.046	0.25	**0.13**
Environmental	0.20	0.45	0.230	0.35	**0.31**
Navigation	0.085	0.018	0.033	0.05	**0.05**
Sum	1.0	1.00	1.00	1.00	**1.00**

Table 5. Normalized weigths

3.3.5 Check the consistency of the valuations entered

To assess the consistency of the decisions made in the previous steps, the maximum eigenvalue of the matrix (K) is calculated, and a consistency index can be obtained.

$$CI = \frac{(K - n)}{(n - 1)}$$

This index can be used as an indicator of the degree of "alignment of judgements".

Next, the consistency index of a matrix of the same structure that has been filled with random numbers, denoted by RI, can be obtained. The average value of this coefficient is provided in the literature, where the average result of a large number of random examples has been obtained. By dividing both values, the significance of the differences can be calculated, and according to Saaty's criterion, a maximum value of 0.10 to this ratio can be obtained, which must be met to guarantee the internal consistency of the results.

3.3.6 Definition of a menu of solutions to be assessed

In the first step of the methodology proposal, a catalogue of solutions has been drawn up as potential adaptation measures. These alternatives will compose the choice space of the problem in our area of study.

Following the previous examples, Table 6 comprises a set of potential adaptation measures to be applied in an estuarine area. This short set of options should be understood only as an example.

Passable dock
Submerged dyke
Dune regraded
Abandonment

Table 6. Potential adaptation measures

3.3.7 Development of a metric of solutions for each criterion

In this step, and for each of the criterion defined, a new matrix is built, using a new pairwise comparison among adaptation measures, and applying the same scale previously defined. It is important to note that this new matrix is built on the basis of the previously compiled set of indicators.

As a continuous example, and for the protection service criterion, Table 7 defines the raw rating following the procedure. A similar matrix must be obtained of each of the criteria.

Protection	Passable dyke	Submerged dyke	Dune regraded	Abandonment
Passable dock	1	5	3	7
Submerged dyke	1/5	1	1/3	9
Dune regraded	1/3	3	1	7
Abandonment	1/7	1/9	1/7	1
Sum	1.67	9.11	4.476	24

Table 7. Pairwise evaluation of the proposals according to criterion #1 "protection"

3.3.8 Obtaining the rating of each solution for each performance criterion

Repeating the process followed for the criteria, all the scores obtained from the ratings given in the previous step are now normalised (by columns), and the average value is obtained (by rows).

Following with the presented example, the calculation of the matrix associated for the "protection" criterion is presented in Table 8. This process will be repeated for each criterion, obtaining a similar matrix for all of the criteria.

Protection	Passable dyke	Submerged dyke	Dune regraded	Abandonment	Average
Passable dock	0.596	0.55	0.67	0.291	**0.53**
Submerged dyke	0.119	0. 11	0.075	0.375	**0.17**
Dune regraded	0.199	0.33	0.223	0.291	**0.26**
Abandonment	0.085	0.01	0.032	0.042	**0.04**
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table 8. Normalised evaluation of the proposals according to criterion #1 "protection"

3.3.9 Aggregation of valuations

In this step, the aggregation of all the previous valuations and the respective weights defined is done. By multiplying the rating obtained for the potential adaptation measures analysed according to each criterion, by the rating weight set for the criterion, a synthetic rating for the measures is obtained.

Table 9 resumes the valuation of the example potential measures for a set of different criteria.

Recreational	CR1	CR2	CR3	CR4	Value
Weights	*0.52*	*0.13*	*0.31*	*0.05*	
Passable dock	0.53	0.17	0.26	0.04	**0.40**
Submerged dyke	0.35	0.32	0.30	0.03	**0.30**
Dune raised	0.15	0.52	0.28	0.05	**0.27**
Abandoned	0.65	0.20	0.11	0.04	**0.04**
Sum	**1**	**1**	**1**	**1**	

Table 9. Pairwise evaluation of the proposals according to criterion 2

3.3.10 Selection proposal

In this last step of this point of the methodology, the results obtained are validated and a ranking of proposals is obtained. Likewise, proposals that do not reach a minimum value are eliminated. For this purpose, one comment can be done. Considering the validity of the solutions as candidates, as we can easily check, the maximum score that an ideal alternative could reach would be 1. Therefore, the ratings of the options can be seen as a percentage of achievement of the objectives with respect to a perfect ideal solution. This process will generally allow us to discard irrelevant solutions that unnecessarily complicate the process.

Following the example used, and considering the values in Table 9, the preferred alternatives would be ordered as “Passable dock”, “Submerged dyke”, “Dune raised” and “Abandoned”. It is justified to discard measure “Abandoned” which barely reaches 4% of the maximum possible.

3.4 Addressing public participation

The process of public participation in climate change adaptation decision-making must capture the general perspective of society on the one hand, and, on the other hand, the vision of the affected stakeholders.

These contributions must be integrated at two different levels: a first economic level where the relative importance of the decision-making processes is defined; and a second, more technical level where the contribution of each proposal to the described objectives must be assessed.

Considering this double level, the integration of the public perspective in the decision-making process will be applied, keeping in mind that two prioritisations of measures will be obtained:

- Version #1 will include the technical contributions and will be subject to the participation processes.
- Version #2 will include the public contributions of this process.

To incorporate this participation in Version #2, a new criterion will be defined and included in the previous step of the methodology. This new criterion accounts to incorporate the social support of the solution, which obviously forces to redefine the weights in step 2.

For the valuation of the new criterion, a discussion in the citizen participation workshops could be held, modifying, if necessary, the weights given to citizen support proposed in the previous phase. In these workshops, the evaluations made to the participants will be identified with a view to their endorsement and new evaluations will be collected.

Once the proposals and their evaluation have been determined, the measures proposed in each phase will be defined.

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