DELIVERABLE 4.2

ASSESSMENT FRAMEWORK TO DETERMINE ECOLOGICAL FEASIBILITY OF MULTI-USE PLATFORMS

Work Package 4

Environmental gain of multi-use of marine space and infrastructure

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Author(s)	Thomas Kerkhove and Steven Degraer (RBINS) Marcel Rozemeijer, Robbert Jak and Marnix Poelman (WUR), Annelies Declercq and Nancy Nevejan (UGent), Manuel Lago and Ariel Araujo (Ecologic), Alex Ziemba, Rieke Santjer and Elias de Korte (Deltares), Eva Strothotte (FuE), Ivana Lukic (Submariner), Ioanna Drigkopoulou (Wings)
Editor	Ghada El Serafy
Approved by	Ghada El Serafy
Project Officer	Giuseppe La Ciura
Abstract	This report aims to develop an environmental assessment framework to determine the ecological feasibility of multi-use

	platforms. The framework is based on the practice of environmental impact assessment (EIA) and applies an integrated cumulative effects assessment (iCEA) in the scoping and identification of the key possible impacts. The framework furthermore enables to assess the added environmental value ('benefits') of marine multi-use.
Keywords	Environmental impact assessment, cumulative effects assessment, linkage framework, pressures, multi-use

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2. ACRONYMES

CCT	Coordination Committee Team
CEA	Cumulative Effects Assessment
CSET	Core Services Exploitation Team
CT	Consortium Coordination Team
EC	European Commission
EIA	Environmental Impact Assessment
EU	European Union
ES	Ecosystem Services
GES	Good Environmental Status
IAS	Invasive Alien Species
ICES	International Council for the Exploration of the Sea
IMTA	Integrated Multi-Trophic Aquaculture
IPR	Intellectual Property Right
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
ODEMM	Options for Delivering Ecosystem-Based Marine Management
OWF	Offshore Wind Farm
PA	Partner Assembly
PM	Project Management
SAB	Stakeholder Advisory Board
WP	Work Package
WUR	Wageningen University & Research
UAF	UNITED Assessment Framework

3. EXECUTIVE SUMMARY

This deliverable has developed an environmental assessment framework to assess the possible environmental impacts (both positive and negative) of the multi-use pilots. The assessment framework is based on the general UNITED Assessment Framework developed in WP8 (which in itself is derived from an EIA perspective) and applies an integrated cumulative effects assessment (iCEA) for the first two stages of the framework. The rationale behind iCEA is that each activity (aquaculture, tourism, etc.) is divided into specific actions, to which pressures (based on the MSFD) can be assigned. Each action-pressure link can have an effect on specific ecosystem components (seabirds, fish, benthos), and the action-pressure-ecosystem component linkages are called 'impact chains', which all together form a linkage framework. Each impact chain can be qualitatively assessed by expert knowledge, and also quantitatively assessed in the case of sufficient data. This provides a ranking of the impact chains, which makes it possible to identify the key possible impacts or 'hot spots'. A further selection of which hot spots to assess in detail can be made by an ecosystem services approach. Important to note is that the hot spots represent both positive and negative impact chains, and in a multi-use setting, combining actions can mitigate or have positive impacts compared to the single-use activities. The deliverable includes an Annex 'Manual for the implementation of environmental assessments in the UNITED pilots: establishing uniformised integrated Cumulative Effects Assessment' which is a hands-on guidance on how to apply the environmental assessment in the UNITED pilots. This manual is furthermore intended to be generic too, i.e. it can be applied for other multi-use cases.

4. INTRODUCTION

4.1. D4.2 situated within the UNITED project – link with other work packages

4.1.1. The UNITED project

The Horizon 2020 project UNITED aims to provide evidence for the viability of ocean multi-use through the development of five demonstration pilots in the marine environment across European regional seas. Furthermore, the project aspires to draw lessons from these pilots to boost the current and future application of ocean multi-use. As such, the project addresses current challenges and opportunities for the deployment of multi-use across five key pillars:

1. Technological;
2. Economic;
3. Environmental;
4. Societal;
5. Legal/Policy/Governance.

The environmental pillar of the UNITED project (WP4) addresses current knowledge gaps on how to measure and assess the cumulative environmental impacts of ocean multi-use, both at the local as well as the broader ecosystem level. This pillar responds to the need for a harmonized assessment framework, as well as harmonized methods to assess both the positive and negative environmental impacts of multi-use in the marine space. Deliverable 4.1 'Current environmental assessment and status of Pilots', which has already been finalised, collected the environmental assessment practices and requirements, and the available environmental information on the five UNITED pilots. The current deliverable aims to develop the environmental assessment framework for ocean multi-use, which will be applied to the five UNITED multi-use pilots in Task 4.3 'Application of assessment framework within pilots'.

4.1.2. Link with other work packages

WP2 – Technology

Within WP2 'Technology', the technological requirements of the different UNITED pilots are addressed. Information relating to the technological improvements of multi-use are collected for pilots' implementation to help overcome technological issues or optimise pilot activities. Specific attention in this work package is given to the (environmental) monitoring activities in the context of each of the pilots to ensure that the collected (sensor) data is archived, processed and disseminated in the best possible way and available to any of the project partners.

WP3 – Economics

WP3 of UNITED addresses the 'Economics of Multi-use Platforms'. This WP supports the economic assessment of multi-use combinations by providing and applying a multi-method economic assessment framework. This includes an assessment of the costs and benefits of multi-use as compared to single-use alternatives. The outcomes of the economic assessment framework will steer future decisions regarding multi-use of the different pilots. The work in WP4 is crucial for the understanding of the environmental impacts of multi-use and the identification of relevant indicators to measure changes in associated ecosystem services that affect human well-being.

WP5 – Social / WP9 – Communication

Stakeholder consultation is a key element throughout the environmental assessment framework. In a dedicated UNITED workshop organised by WP5 'Societal Interactions and Engagement' and WP9 'Dissemination, Exploitation and Training Activities', the framework will be evaluated and refined through consultation and discussion with key stakeholders.

WP7 – The Pilots

The five UNITED pilots of WP7 'Implementation of Multi-Use Concepts Within Pilots' will test and implement the environmental assessment framework developed in the current deliverable. This is the core task of Task 4.3 'Application of assessment framework within pilots'. Feedback from the pilots has been taken into account in developing the framework.

WP8 – Assessment and validation

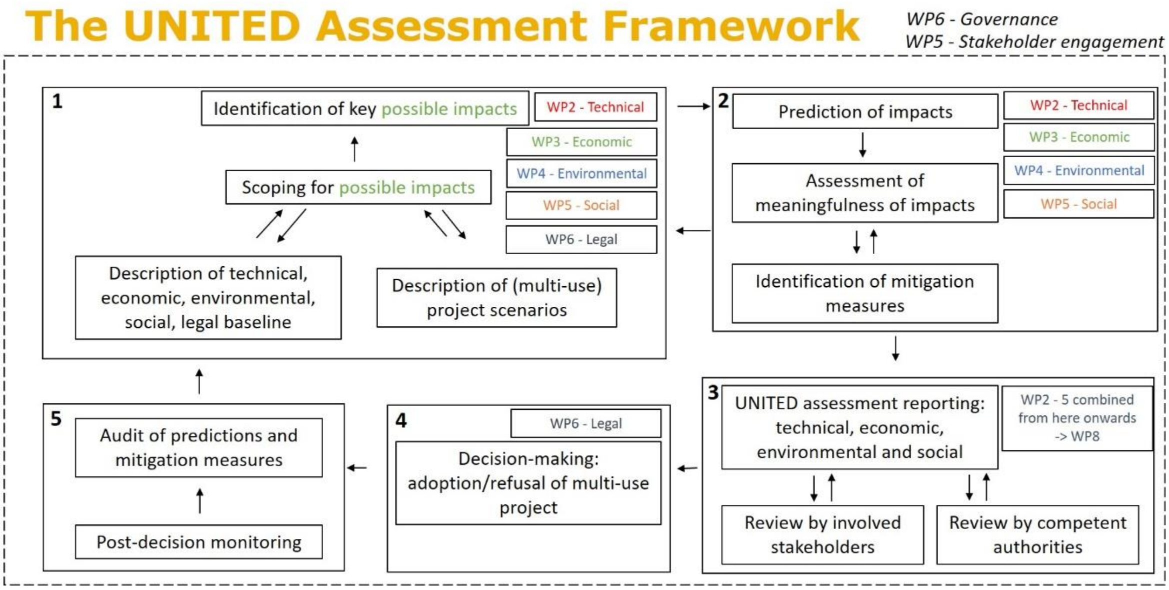
The environmental assessment framework developed in the current deliverable is the application, from an environmental perspective, of the UNITED Assessment Framework as being developed in WP8, the 'Assessment and validation' WP. The UNITED Assessment Framework is a generic framework to assess the impacts of ocean multi-use, and can be applied to all five UNITED pillars. The environmental application of the overall framework developed in WP8 is probably its most explicit application: in the current deliverable the direct translation of each step from the generic to the environmental framework is undertaken. Therefore, a general overview of the UNITED Assessment Framework is first presented in the following section.

4.2. The UNITED Assessment Framework

The UNITED Assessment Framework (UAF) aims to assess the impacts of multi-use projects in the marine space against alternative scenarios, including no-use and single use. As such, the UNITED Assessment Framework will quantify the added value of multi-use projects in comparison with alternative uses. To do this, the (possible) impacts of multi-use projects will be assessed, after which the outcomes will be compared with the outcomes of the assessments of alternative scenarios.

The assessment of the impacts of the different scenarios are approached around the five pillars of the UNITED project: technical, economic, regulatory, environmental and societal. Each of these pillars applies different tools and assessment criteria in the scoping for possible impacts and assessment of these impacts allowing flexibility for each pillar. However, the key steps that are followed are the same for all pillars and these steps form the backbone of the UNITED Assessment Framework.

Schematically, the UNITED Assessment Framework looks as follows:



The first step (Early Stages, Box 1) for each pillar starts with a description of the baseline situation and of the proposed multi-use project; be it from a technical, economic, regulatory, environmental or societal perspective. Based on these descriptions, a scoping for possible impacts is conducted, followed by the identification of key possible impacts. These are those possible impacts that are considered priority issues for further processing during the Prediction Stages. In the Prediction Stages (Box 2), the impacts related to the key possible impacts, are predicted and the meaningfulness of these impacts is assessed. Comparison between the alternative scenarios enables to inform on the added value of multi-use. If relevant, also mitigation measures are identified to deal with undesirable impacts of the preferred scenario.

For each pillar, different tools are applied, such as life-cycle analysis, cost-benefit analysis and cumulative (environmental) effects assessment, to identify and predict the impacts.

The next step consists of reporting the outcomes of the different analyses and reviewing these by the competent authorities (Reporting Stages, Box 3). Based on this, the optimal scenario is chosen (Decision Stage, Box 4). When adopted, a monitoring scheme is implemented to audit the predictions and mitigation measures proposed during the assessment (Monitoring Stages, Box 5). Governance and stakeholder engagement (may) encompass all steps of the UNITED Assessment Framework.

The UNITED Assessment Framework finds its roots in the concept of Environmental Impact Assessment (EIA) (Glasson&Therivel, 2019), while the application of the first two stages of the framework is mainly derived from the concept of integrated Cumulative Effects Assessment (iCEA). Both concepts are discussed in the next section.

4.3. Environmental assessment tools: EIA and iCEA

Traditionally, environmental impacts originating from activities and projects are assessed through Environmental Impact Assessments (EIAs). In the European Union, this is regulated through the (updated) EIA Directive (2011/92/EU), and describes for which activities and projects an EIA should be conducted, and what ecosystem components (= receptors) should be assessed. Next to ecosystem components, also socio-economic receptors are included, such as cultural heritage and interaction with other activities, but the main focus remains on ecosystem components. In essence, EIA is focused on activities, and the impact these have on ecosystem components. For example, an offshore wind farm (OWF) is a typical project for which an EIA is required. For each action of the project (e.g. installation of the turbine foundations), the impact will be assessed for each receptor (e.g. marine mammals, cultural heritage), and this for each phase of the project (installation, operation and decommissioning) and for a selection of alternatives for the project.

For the application of the first two stages of the assessment framework (Early Stages and Prediction Stages, see Fig. 1), an integrated Cumulative Effects Assessment (iCEA) approach is brought forward. An iCEA focusses on ecosystem components (possibly) experiencing the impact of different activities, and is defined as a systematic procedure to identify and evaluate (the meaningfulness of) impacts from multiple activities to inform management measures (Judd *et al.* 2015). The focus on several activities impacting ecosystem components makes this a suitable tool to approach the environmental assessment of multi-use projects, which are by definition comprised by more than one activity. One of the strengths of iCEA is that the meaningfulness of the impact of minor activities accumulating on ecosystem components - and the wider ecosystem – can be better appreciated (Willsteed *et al.* 2017). In the context of marine multi-use, an iCEA can be applied to assess the (cumulative) impacts on ecosystem components caused by the different activities of the multi-use project. The focal point of an iCEA are the ecosystem components possibly impacted by different activities. An example of this is the effect of multiple activities such as fishing, renewable energy, aquaculture and shipping on marine mammals (Piet et al 2017).

In an iCEA procedure, the analysis of the pathways (or "impact chains") from causes (= activities), to the resulting pressures, and the impacts these have on ecosystem components is an essential and integral part of the procedure (Judd *et al.* 2015). The description of this analysis forms the main part of the current deliverable, and its implementation in the pilots is the core of Task 4.3. The main principles of the iCEA procedure are the following:

- Activities exert pressures, which have an effect on ecosystem components. These pathways, or impact chains, form the basis of the analysis.
- The effect of a single pressure on an ecosystem component can result in an impact (= change of state), expressed as a proportional change in abundance (which can be species density, habitat cover, etc.). This change in abundance can be negative or positive and can take values ranging from -1 to +1.

- The cumulative impacts then reflect the overall footprint of the human activities on the ecosystem. This is the sum of all the impacts per ecosystem component and then aggregated into an ecosystem assessment as the average across the ecosystem components (assuming equal importance of the ecosystem components). Depending on the parametrisation, cumulative impacts can be >1 or <-1 for any specific ecosystem component, selection of ecosystem components or for the ecosystem as a whole.

For the envisaged iCEA approach, the description of the pressures and the ecosystem components is based on the EU Marine Strategy Framework Directive (MSFD).

4.4. Situating the assessment within European legislation

4.4.1. The Marine Strategy Framework Directive

The European Union's Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) was adopted on June 17, 2008, and strives for a more effective protection of the marine environment across Europe[1]. It presents a framework to aim for Good Environmental Status (GES) of the marine environment across 11 descriptors, whereby ecosystem components are linked with anthropogenic pressures and impacts on the marine environment. This enables a better understanding of the driving pressures impacting marine ecosystem components, including protected habitats and species. Within the UNITED project, the environmental assessment of the multi-use pilots will be based on key elements of the MSFD. The implementation of the UNITED Assessment Framework in an iCEA approach explicitly links pressures with impacts on ecosystem components, as envisaged in the MSFD.

Annex III, Table 2a of the MSFD Directive (amended in 2017[2]) presents a list of anthropogenic pressures, and an overview of human uses and activities on the marine environment. The anthropogenic pressures are categorised into biological, physical, and substances, litter and energy pressures (see Table 1) and this list will directly serve as the basis for the implementation of the environmental assessment. However, as pressures in the UNITED assessment are defined as to include both positive and negative effects, the MSFD classification is adapted to reflect this (see manual in the Annex for the adapted pressures list). The activity list of the MSFD (Annex III, Table 2b) can inform, but will not directly be applicable to the assessment, as the described activities are defined too broadly (see further).

Table 1- List of pressures derived from the Marine Strategy Framework Directive

List of pressures	
Biological	Introduction or spread of non-indigenous species
	Introduction of microbial pathogens
	Introduction of genetically modified species and translocation of native species
	Loss or change of biological communities due to the aquaculture of animal or plant species
	Disturbance of species due to human presence
	Extraction or injury to species by human activities (including fishing)
Physical	Physical disturbance to seabed
	Physical loss of seabed substrate or morphology
	Changes to hydrological conditions

[1] https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1495097018132&uri=CELEX:32017L0845

Substances, litter and energy	Input of nutrients Input of organic matter Input of other substances (synthetic, non-synthetic, radionuclides) Input of litter Input of anthropogenic sound Input of energy (electromagnetic fields, light, heat) Input of water (affecting salinity levels)

4.4.2. EU Birds and Habitats Directives

The European Birds[3] (2009/147/EC) and Habitats[4] (92/43/EEC) Directives form the centerpiece of the European biodiversity policy and aim to conserve the European bird populations, and other fauna and flora and natural habitats, respectively. Both Directives require the member states to establish protected areas for the conservation of birds of interest (listed in Annex I of the Birds Directive) and habitats and (non-bird) species of interest (listed in Annexes I and II, respectively, of the Habitats Directive). Combined, these protected areas form the Natura 2000 network of the European protected areas.

5. APPLICATION OF THE UNITED ASSESSMENT FRAMEWORK

The approach to conduct the environmental assessment of the UNITED pilots consists of two major parts. In the first part, covering the first two stages (Early and Prediction stages) of the UNITED Assessment Framework, an integrated Cumulative Effects Assessment (iCEA), which has been introduced above, is applied. In the second part, the Reporting, Decision and Monitoring stages are discussed.

The applicability of this approach is not limited to the UNITED pilots only: we argue that this will be a useful approach to assess environmental impacts of marine multi-use in general, covering local as well as larger regional scales. The application in the pilots, while it may deliver new insights and guidance on environmental impacts of multi-use, is to be regarded as a proof of concept. The goal is thus not to obtain an extended environmental assessment for each individual pilot, but rather to demonstrate that the proposed approach is successful across a range of different multi-use cases in different marine environments.

In the chapters below, the environmental application of the UNITED Assessment Framework is described in more detail. For the early and the prediction stages, this is described integrating the application of an iCEA.

5.1. Early stages

5.1.1. Description of environmental baseline

The environmental baseline sets the reference condition to which changes are measured. Several reference conditions are possible, including based on pristine areas, historical data, baseline set in the past or at present conditions. Also modelling and expert judgement are used to determine reference conditions, whether or not used in combination with the former methods (Borja *et al.* 2012). Part of the information for setting the environmental baseline can be found in Deliverable 4.1 'Current environmental assessment and status of Pilots'.

In view of determining 'added value' of marine multi-use, a baseline set in the past is favoured, possibly supported by expert judgement. In the UNITED Assessment Framework concept paper (Kerkhove et al *in prep* in WP8), both the historical situation/pristine conditions and baseline/business-as-usual scenario can be regarded as a baseline set in the past. For the current application, the baseline/business-as-usual scenario from the UAF is chosen as the environmental baseline. This baseline scenario is set at the situation before EIA and Marine Spatial Planning (MSP) became implemented, and thus before projects claiming space at sea (and that are obliged to conduct an EIA) became apparent. A pragmatic reason to define the baseline as such is that the environmental

[3] https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
[4] https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

benefits of marine multi-use (with respect to single-use) can be better appreciated than choosing a baseline based on historical or undisturbed conditions. Additionally, its advantage over choosing a baseline from the present condition, which means that for each assessed project a different baseline is selected, is that it prevents continuously changing reference points (Gatti et al 2015).

We however acknowledge that the chosen baseline situation is a somewhat arbitrary point, and may vary between regions (and thus pilots). However, this is also likely the case if historical or present conditions would be considered.

5.1.2. Description of multi-use project

The description of the multi-use project gives a general overview of the pilot, including the aim of the pilot, the goals and, specific for a research project as UNITED, the research objectives. This information can also be found scattered around in other deliverables (e.g. D4.1 and D7.2) so a summary overview will be presented. Additionally, the economic (sub-)sectors of the pilot are given, which generally consists of the single-use activities (see D3.2). Because the activities classification from D3.2 is too broad to be applicable in our approach, activities are divided into actions, which we define here as 'clearly defined processes or movements to which pressures can be unambiguously assigned to' (see also Glossary). Some actions are sector-specific (e.g. harvesting of bivalves for aquaculture or pile driving of wind turbine foundations), others can be associated with several sectors (e.g. shipping or introduction of artificial hard structures). The rationale in dividing activities into actions is that synergies between actions (and thus activities) are easier identified. If several activities have similar or the same actions, an optimisation can be undertaken (such as merging the actions), which will strengthen the multi-use approach.

As such, the environmental assessment needs a detailed overview of all the actions the pilot will take. Due to the nature of marine projects, and the different spatial and temporal scales on which pressures operate, actions are divided between the three different phases of a project: installation, operation and decommissioning. The overview of actions for each phase forms the central part of the multi-use project description. It includes all the actions that are expected to have an impact on ecosystem components that the pilot will take during its entire life cycle, so covering the three different phases.

5.1.3. Scoping for possible environmental impacts

The scoping of the possible environmental impacts will be done through the iCEA approach. Its application will deliver a longlist of "impact chains" in the form of actions → pressures → ecosystem components. For example, the action 'culturing (bivalve) species' causes the pressure 'changes in input of nutrients', which has an impact on the ecosystem component 'primary producers'. For each pilot, the actions and ecosystem components are provided by the pilot leads, while Wageningen University & Research (WUR) will construct the impact chains based on the provided information. The impact chains are not only the ones that are expected to be measured/estimated, or for which data is available, but include all possible environmental impacts that may occur within a pilot. As such, all possible environmental impacts are taken into account in a coherent and comprehensive way, including the possible impacts which can, with the current data and knowledge, not be reliably assessed or predicted.

5.1.4. Identification of key possible environmental impacts

From the longlist of possible impacts, a shortlist of key possible impacts, or "hot spots", will be selected to investigate in more depth in the pilots. On the one hand, the key possible impacts are selected by applying one or more selection criteria. On the other hand, selection will be based on stakeholder consultation as hot spots for one stakeholder group are not necessarily the same for another stakeholder group. This level of important subjectivity cannot be tackled by using selection criteria only, although selection criteria play an important informing role. Examples of selection criteria for the Identification of key possible environmental impacts are protected species under the IUCN Red List or the EU Habitats and Birds Directives, or Ecosystem Services that are of special importance for the pilot. These selection criteria will be further elaborated on in chapter 6.4.

5.2. Prediction stages

During the prediction stages, the key possible impacts identified in the previous steps are predicted and the meaningfulness of these impacts is assessed. Comparison between the alternative scenarios enables to inform on the added environmental value of multi-use.

5.2.1. Prediction of impacts

In this step, the focus lies on the prediction of key environmental aspects identified and selected during the early stages. During the iCEA approach, an analysis has already been made based on the available information and involving expert opinion, and during this step, the key possible impacts are assessed in further detail. Several tools or approaches are available for this, such as the use of prediction models, the collection and analysis of additional data, expert consultation, etc. Which tool or approach to use will be pilot and impact-specific, and depends on the nature of the impact, the availability of existing data, the possibility of the pilot to collect additional data, etc.

5.2.2. Assessment of meaningfulness of impacts

When the impacts are thoroughly predicted, an assessment of their presumed meaningfulness (= impact size x importance) is undertaken, and their level of confidence. Impacts characterised by a high impact size and importance, and a high level of confidence, can be considered relevant or meaningful, while low impact size and a low confidence level makes impacts less meaningful. A significant decrease in water turbidity may be well below what is observed between tidal cycles and thus not considered as a meaningful impact.

This step wants to discern between meaningful impacts, and thus relevant to take further into account, and impacts that may be not so informative.

5.2.3. Identification of mitigation measures

If relevant, mitigation measures are identified to deal with undesirable impacts or to optimise the developed solutions. When several mitigations measures are possible, an assessment of different mitigation options may be undertaken to select the most optimal measure(s).

5.3. Reporting stages

This step summarises the outcomes of all the assessments across pillars (environmental, social, economic, etc.). In this stage, all the information is integrated to present a complete and holistic view on the different scenarios, which is a core task of WP8. It may indeed be the case that a multi-use scenario scores less than the separate single-use scenarios from an environmental perspective, but scores higher on social and economic indicators. Additionally, this step presents the lessons learned, identifies knowledge gaps and presents advice for policy makers.

The reporting stages are thus not pillar-specific, and are only given below for the sake of completeness.

5.3.1. Assessment reporting

The outcomes of the different analyses (environmental, economic, etc.) are reported and analysed in a holistic way. This includes a comparative assessment between the different scenarios.

5.3.2. Review by stakeholders

Stakeholders are engaged throughout most of the steps of the UAF, and also in the reporting stages, stakeholders will be encouraged to deliver input and comments on the analysis of the outcomes. Although a balance between pillars should be kept, stakeholder input is ideally suited to safeguard this balance.

5.3.3. Review by competent authorities

The competent authorities are invited to review the analysis of the outcomes, as they will make the final decision on the go or no-go of a (multi-use) project. They can give a first indication if all conditions for licensing are met or if some elements of the analysis should be adapted.

5.4. Decision stage

In this stage, the decision-making is undertaken. Based on the reviewed assessment report integrating all pillars, the competent authorities will make a decision on the (multi-use) project. Increasingly, licensing advocates or even requires the facilitation of multi-use activities, so the outcome of the assessment will aid in deciding which combination of activities has the most added value.

5.5. Monitoring stages

During the monitoring stages, a set of specific variables are monitored which are selected based on the outcomes of the different assessments. Especially for the environmental pillar, monitoring is a key step to follow-up on the environmental consequences of the licensed project, to confirm or adapt mitigation measures and to inform and guide future environmental assessments.

5.5.1. Post-decision monitoring

During the different stages of the approved project, a monitoring scheme is implemented to monitor selected variables, and this for each pillar. The variables may be the same as the key possible impacts assessed in step 2.

5.5.2. Audit of prediction and mitigation measures

Based on the monitoring outcomes, the prediction of the impacts and the proposed mitigation measures can be evaluated. This evaluation is done through expert opinion and stakeholder engagement and may lead to an adaptation of the mitigation measures and eventually improve future assessments.

6. IMPLEMENTATION GUIDANCE

The environmental assessment framework as described above presents a full and comprehensive approach to assess the environmental impacts of (multi-use) projects. As it is not the goal for the UNITED pilots to perform a full-fledged environmental assessment, but rather a demonstration that the approach is applicable and straightforward, some relevant steps to be implemented in the pilots are highlighted below. Two key steps in the environmental assessment are 'Scoping for possible environmental impacts' and 'Identification of key possible environmental impacts'. This is approached by applying the integrated Cumulative Effects Assessment. To guide the implementation of the iCEA in the pilots, a guidance document has been constructed, 'Manual for establishing uniformised integrated Cumulative Effects Assessments for different marine multi-use cases across Europe'. Here, we set out the rationale behind the manual and present the essentials. For a detailed and hands-on approach on how to implement the iCEA approach, we refer to this manual in the Annex.

6.1. Relevant scenarios

The UAF identifies several scenarios that can be compared to assess the environmental impact and the added value of multi-use projects. In general, we advise to compare at least the following three scenarios (adopted from the UAF developed in WP8):

- Baseline scenario: In this scenario, the situation before any of the projects of the pilots is taken into account. The activities that took place in this situation might not be present anymore in the current situation, for example fishing and aggregate extraction. Although it is a possibility that some of the projects of the pilots were already installed before UNITED started, the baseline scenario looks at the situation before these projects were present. The baseline scenario might be similar for each pilot, although the baseline characteristics differ according to socio-economic and ecosystem variables.
- Single-use scenario: This scenario comprises the different single-use activities of the pilots, happening at the same time in the same environment, but spatially separated and independent from each other. Synergies of combining activities or space are not apparent in this scenario and cumulative environmental effects (both positive and negative) are not considered to be of major importance. It is important to note that in the comparison of the scenarios, it is crucial that the environmental impact of the single-use scenario is assessed as the sum of the impact of all activities. The rationale behind this is that we do not want to compare the (environmental) impacts of a single activity (e.g. a seaweed farm) with that of a multi-use project (e.g. a seaweed farm within an offshore wind farm (OWF)), but rather the multi-use

project with a scenario where both activities (seaweed farm and OWF) are separated – spatially as well as logistically.
For the already existing projects, like OWF, EIAs have mostly been conducted from which information can be extracted. The other single-use projects not always have this information available, because this is not mandatory or simply because these are only now being implemented in the pilots. Information can however be gathered from D4.1 or from current or past projects in a similar location.

- Multi-use scenario: This scenario is defined as the multi-use combinations that are implemented in the UNITED pilots. For future multi-use projects, it might also be interesting to include scenarios with several types or combinations of multi-use to search for the optimal configuration of activities.

Which scenarios that will be applied in the assessment for each pilot will be decided in close cooperation with the other WPs and stakeholder workshops. It is not meaningful to have different scenarios tested in for example the economic (WP3) and the environmental (WP4) assessments. In a later stage, in the framework of WP8, all the assessment information on a WP and pilot level will be collected and analysed together.

6.2. First step in the iCEA: Linkage Framework

After setting the baseline and the description of the scenarios, the next step in the environmental assessment is the scoping for the possible environmental impacts. For this, a linkage framework approach is used to construct the action-pressure-ecosystem component links (or 'impact chains'). The linkage framework, as implemented in the iCEA, describes and visualises in a systematic way how actions generate pressures, which have impacts on ecosystem components (see Fig 2). In a further step, these ecosystem components can be linked to Ecosystem Services (ES). The direct translation of impacts of pressures on Ecosystem Services is almost impossible without a step through ecosystem components. Although the link can be made with ES at the later stage, the impact of pressures on ecosystem components forms the core of the environmental assessment framework and thus also the core of the implementation in the pilots. Additionally, the linkage framework will act as the basis for the economic assessment of the pilots in WP3-Task 3.3, where the explicit link with ES will be made.

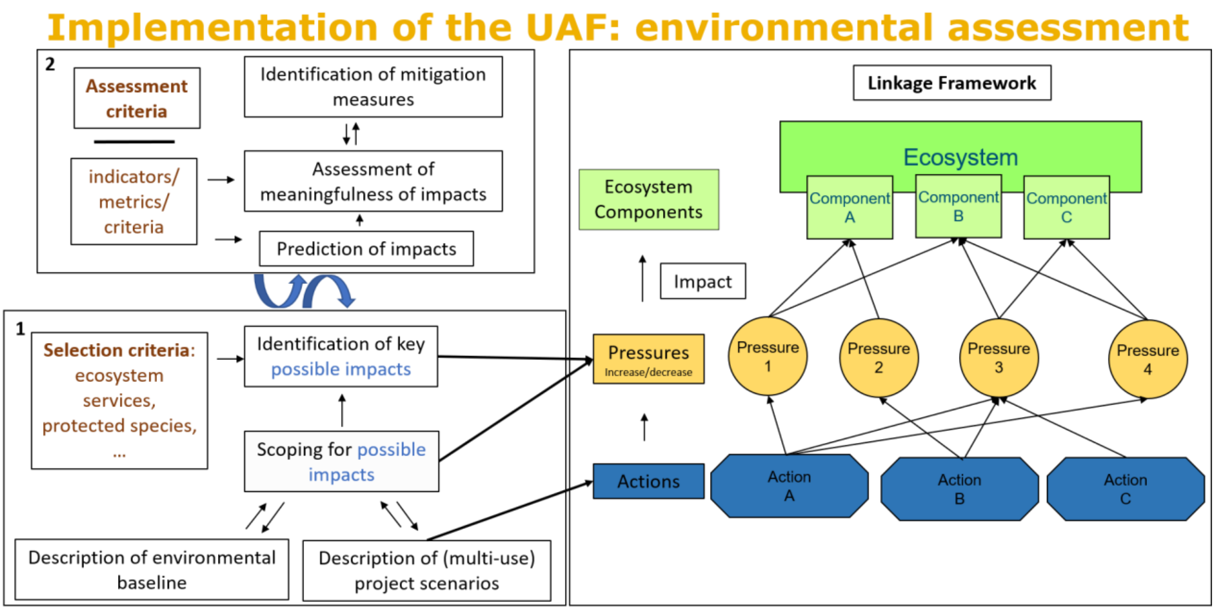


Figure 2: The linkage framework implemented in the UNITED Assessment Framework

Below, we will briefly describe the different steps to apply the linkage framework, tailored to the implementation in the pilots. For more details, we refer to the guidance manual in the Annex. The description below and the guidance manual will serve as the guiding documentation for Task 4.3, which is the implementation of the environmental assessment framework to assess the environmental impacts of the pilots.

6.2.1. Listing the actions

The first step in the linkage framework is the identification of the different actions in the pilots. Actions can be linked to activities and sectors of the Blue Economy, for which a description is given in Deliverable 3.2 'Assessment framework to determine economic feasibility of multi-use platforms.' In the three scenarios envisaged (see above), different sectors can be recognised, performing certain (single-use) activities. Pooling of these activities form the multi-use scenario. Each of the activities can be subdivided into specific actions, which are the smallest relevant units to which pressures can be assigned to. For example, the activity of mussel farms (within the sub-sector aquaculture) includes the actions 'installation of aquaculture structures', '*in-situ* bivalve aquaculture' and 'harvest' for example. An indicative list of actions for each activity will be provided, but depending on the specific nature of the projects, actions can be omitted or additional actions can be added during the pilot exercises (Task 4.3)

6.2.2. Listing the pressures

Each of the identified actions can exert pressures. The list of possible pressures originates from the EU Marine Strategy Framework Directive (MSFD), with additional pressures from the ODEMM (Options for Delivering Ecosystem-Based Marine Management) approach (White et al 2013) and others (see manual in the Annex for the pressures list). During dedicated workshops involving experts and stakeholders on the pilot level, this list might be extended with pressures that were not included initially. Ultimately, a list of pressures will be produced covering all possible pressures, a list which is supported by both experts and stakeholders. The list will be rooted in European law, and extended with experience form the pilots, experts and stakeholders.

6.2.3. Listing the ecosystem components

Generally speaking, ecosystem components are ecologically coherent elements of an ecosystem on which actions have an impact through pressures. Although the more general term 'receptors' is often used in a social or economic setting, for the purpose of the environmental assessment framework, we translate 'receptor' to the more specific 'ecosystem component'. The pressures are thus impacting ecosystem components. Ecosystem components can be functional groups of species, habitats, or single species. Groups of species are classified in a hierarchical way. For example, the pelagic components can be divided into zooplankton and nekton, and zooplankton can be further divided into groups of species with similar characteristics (functional groups). For ease of use however, the hierarchical classification will be assumed but not explicitly taken into account. Next to species groups, also habitats and single species can be selected in the linkage framework. A list of the selected (marine) ecosystem components to be taken into account is provided in Table 2. Which habitats or species to select is based on assessment criteria (see below) and supported by stakeholder consultation. These assessment criteria can be based on, for example, EU Habitats and Birds Directive species, Red List species, etc.

Table 2. List of Ecosystem Components

Ecosystem Components	
Species groups	Primary producers
	Zooplankton
	Benthos
	Cephalopods
	Fish
	Reptiles
	Birds
	Bats
	Sea mammals

Habitats	Pelagic habitat Sublittoral rock and other hard substrata Sublittoral coarse sediment Sublittoral mixed sediments Sublittoral mud Sublittoral sand
Specific species	Species that are endangered, protected, iconic, etc.

6.2.4. The Linkage Framework in practice

The identified pressures are not necessarily on a one-on-one basis attributed to actions. A single pressure is generally not unique to a single action, nor is a single action restricted to only one pressure. Identifying all the impact chains generates a linkage framework connecting different actions with different pressures. For example, pressures associated with the installation of aquaculture structures are the physical disturbance of the seabed, hydrological changes and disturbance by human presence, while the latter pressure is also associated with the action 'maintenance and harvest'.

6.3. Second step in the iCEA: Risk Assessment

The established linkage framework identifies the whole range of action:pressure:ecosystem component impact chains for each pilot. To guide the selection of the key possible impacts, the importance of each impact chain is determined by estimating their "Impact Risk". The Impact Risk is estimated through the following six criteria:

- Spatial extent: The spatial overlap of the action:pressure combination with the ecosystem component;
- Dispersal: Effect of the pressure on the area of spatial overlap;
- Frequency: The temporal overlap of the action:pressure combination with the ecosystem component;
- Persistence: The duration of the pressure after cessation of the action;
- Severity: The sensitivity of the ecosystem component to the pressure;
- Resilience: The duration before the ecosystem component returns to pre-impact conditions. Also called recovery time.

Each of the criteria is scored according to Table 3 in the manual (Annex). By assigning a numerical score to each criterion, the linkages can be weighted.

Some of the criteria are dependent of the action, while others are independent (e.g. severity). For example, the pressure 'Physical loss of seabed substrate or morphology' on the ecosystem component 'benthos' will always be chronic, irrespective of the action causing the pressure, while the spatial extent will be strongly action-dependent.

6.4. Selection criteria

Selection criteria are used to select the key possible impacts or 'hot spots' from the longlist of the action:pressure:ecosystem component impact chains. In other words, they allow to prioritise the key possible impacts. In the context of the (environmental) assessment of multi-use projects, both positive and negative impacts are taken into account. For UNITED, selection criteria are based on Ecosystem Services and on protected species and habitats, following national, European (Birds and Habitats Directives, see higher) and international (OSPAR, IUCN Red List) policies. While the protected species/habitats can be selected already in the linkage framework, ecosystem services are selected for each pilot, possibly using the concept of beneficiaries. The ecosystem services regarded as most important for each pilot will then be coupled with the associated pressure:ecosystem component chains from the linkage framework. As such, the pressure:ecosystem component chains, which ultimately determine the impacts, will form the core element in the selection procedure (Fig 3). It is also from these linkages that the key possible impacts will be selected. The different selection criteria are briefly discussed in the following paragraphs.

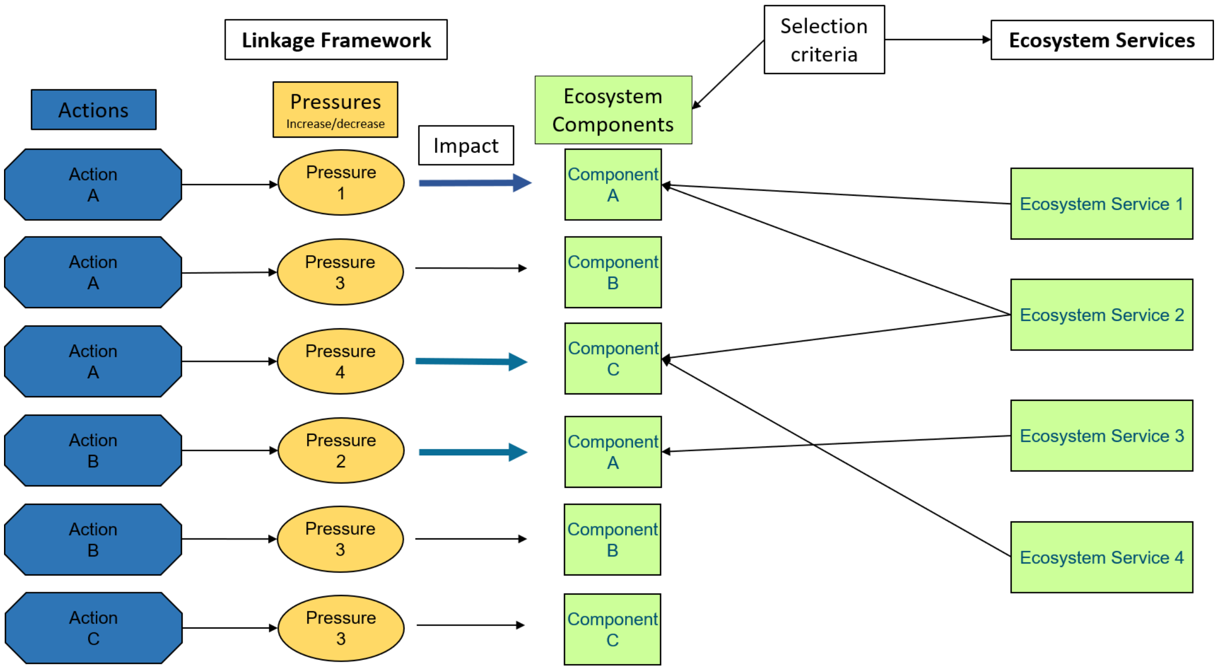


Figure 1. Coupling of the linkage framework and ecosystem services through the impact chains.

6.4.1. Ecosystem Services

Ecosystem Services (ES) are defined as the final outputs from ecosystems that are directly consumed, used (actively or passively) or enjoyed by people (adapted from Haines-Young & Potschin, 2018, Culhane *et al.* 2019), and include both biotic as well as abiotic components.

Ecosystem services are becoming increasingly important in connecting ecological considerations with social and economic aspects. The coupling of ecosystem services with impacts on ecosystem components is not easily quantified, but one way, as also proposed by ICES (International Council for the Exploration of the Sea) (WKTRANSPARENT report 2020), is to connect the state of the ecosystem with its capacity to supply services. The implicit link between both goes through ecosystem functioning, but its quantification is outside the scope of this deliverable. A qualification can be made however through e.g. consulting scientific literature and obtaining expert opinion within the consortium and collected through the planned workshops. As a starting point, the following characteristics of ES in the UNITED project are proposed:

- The inclusion of both biotic and abiotic services
- The distinction of four types of ES:
    - Provisioning services (e.g. food resources, raw material)
    - Regulating services (e.g. water quality, biological control)
    - Cultural services (e.g. cognitive benefit, leisure, non-consumptive/iconic species)
    - Supporting services (or ecological functions) (e.g. nutrient cycling, nursery, biodiversity)
- For the purpose of Task 4.2 and 4.3, we will focus on the environmental impacts of the pilots, primarily concerning regulating services and ecological functions, while provisioning and cultural services are primarily tackled by the economic (WP3) and social (WP5) pillar respectively. Cultural services may however be informed by protected species and habitat lists. We thus acknowledge that boundaries between pillars are flexible and a certain overlap between them exists and is deemed necessary.

Implementation guidance proposal for the ES-informed key possible impact selection:

Following a beneficiary centric approach (DeWitt *et al.* 2020), each pilot identifies the final ecosystem goods and services associated with their pilot. From the list of possible impacts, the key possible impacts are identified for which the highest impact on the identified ES is expected, based on literature, expert judgement, in-field experience and stakeholder engagement.

6.4.2. EU Birds and Habitats Directives

See chapter 4.4.2

6.4.3. International Union for the Conservation of Nature's Red List

The Red List of the IUCN is a global assessment of a selection of species and populations and categorises species into five classes of status: 1) Least Concern, 2) Near Threatened, 3) Vulnerable, 4) Endangered and 5) Critically Endangered. For the sake of completeness, the following statuses are also recognized: Extinct in the wild, Extinct and Data Deficient. These last categories are however not relevant in the context of the UNITED project and its pilots.

6.4.4. National Legislation

Next to the European legislation (Birds and Habitats Directives, see above), EU Member States may also implement stricter protection of certain species. If this is the case, pilots might consider these species, as they are of special interest to the pilot's respective country.

6.5. Added environmental value of multi-use

Multiple impacts of multiple pressures from multiple activities are called cumulative impacts. The combination of these impacts is not necessarily additive. There are several directions of cumulative impacts apparent. If the combination of impacts is merely the sum of the individual impacts, then these impacts are additive. If the combination of pressures causes a greater impact than what can be expected by the sum of the individual impacts, then the impacts are synergistic impacts, while the other way around are antagonistic impacts. This is apparent when one pressure partially or fully counteracts the impact of another pressure. Antagonistic impacts can be actively sought in marine activities, for example by the application of integrated multi-trophic aquaculture (IMTA), in which the waste (feed, excrements) of one species (e.g. fish, shrimp) is utilised by another species (e.g. bivalves, seaweed). In the marine environment however, the predominant impacts are synergistic, although in individual cases also additive or antagonistic impacts may occur (Crain, Kroeker and Halpern 2008). This uncertainty in the prediction of the direction of cumulative impacts stresses the need of a case-by-case study for marine multi-use projects, as is applied for each pilot of the UNITED project.

Next to the cumulative impacts of certain pressures, we could also approach the environmental impact of multi-use from a more holistic view. The environmental impacts of a combination of single-use projects can likewise be additive, synergistic or antagonistic. Synergistic impacts do not necessarily indicate a worse environmental impact, as impacts can also be (perceived as) positive, such as increased habitat heterogeneity, increased carbon storage or increased fish production. The assessment of the direction of impacts (positive – neutral – negative) requires however an appropriate stakeholder consultation. Not every impact will be appreciated in the same way for each stakeholder. Ultimately, it will be the decision makers who decide on the acceptability of multi-use projects, informed by scientific knowledge summarised in environmental impact statements, and complemented with an appropriate stakeholder consultation.

Through the iCEA approach, cumulative impacts on ecosystem components can be identified and traced back to the relevant pressures. As such, the linkage framework applied in the iCEA approach is a 'method/tool' to identify actions (generating pressures) that may exert cumulative impacts on ecosystem components, may it be positive or negative.

By breaking down the pilot activities into the different actions, similar or identical actions across activities can be easily identified. For example, the activities 'OWF' and 'bivalve aquaculture', have the same actions 'shipping' and 'introduction of hard substrates'. Increasing synergies between both activities, i.e. in a multi-use setting, which is one of the goals of UNITED, enables to decrease the negative environmental impacts (shipping) and increases the positive and negative environmental impacts linked to the introduction of hard substrates. To achieve this potential however, considering multi-use from the start is advisable. It is much easier to plan for the ecologically most optimal way to introduce hard substrates, considering all activities in the multi-use setting, than to adapt afterwards.

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8. GLOSSARY

Term	Definition
Activity	A defined project or business within a sector, with the aim of the production of goods and services, in general regarded as single-use.
Action	A clearly defined process or movement to which pressures can be unambiguously assigned to, derived from an activity.
Cumulative effect	the incremental impact of the action when added to the other past, present and reasonably foreseeable actions
Cumulative Effects Assessment (CEA)	A systematic procedure for identifying and evaluating the meaningfulness of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures. The analysis of the causes (source of pressures and effects), pathways and consequences of these effects on receptors is an essential and integral part of the process.
Ecosystem Component	Ecologically coherent elements of an ecosystem, that group together more disparate taxonomic groups into the minimum number of elements, based on the view that the lower the number of elements, the easier it is to gain a coherent and integrated assessment across the ecosystem.
Effect	A change caused by a pressure that is a departure from a baseline condition. An effect can be positive or negative.
Exposure	The contact of ecosystem components with chemical, physical, or biologic pressures over space and time.
Impact chain	Pathway linking activity-pressure-ecosystem component that causes the specific impact.
Impact	A meaningful effect that reflects a change whose direction, magnitude and/or duration is sufficient to have consequences in comparison with the baseline condition. Like an effect, an impact can be positive or negative.
Linkage Framework	The combination of all the possible linkages through which the activity may have an effect on the receptor. Each linkage is called an impact chain.
Magnitude	The (measurable) level or concentration of the pressure which is quantitatively and casually linked to the direct or indirect effects on the receptor.
Meaningful	Relevant in a broader setting, with consequences for the future; often used with effects or impacts
Persistence	Length of time that a pressure is able to remain in the environment after being introduced into it.
Phase	A temporal dimension of the activity indicating a specific process of the activity; e.g. installation, operation, decommissioning
Pressure	The mechanism through which an activity has an effect on any part of the ecosystem. Pressures can be physical, chemical or biological.
Receptor	Physical (beaches, sandbanks, mudflats), ecological (ecosystem components, e.g. fish, birds, mammals, plants), economic (tourism, business) or social/cultural (public enjoyment of open space) entities which are susceptible to the pressures under investigation.

Recovery	The return of an ecosystem component towards its baseline state as the pressure is relaxed.
Resilience	The ability of an ecosystem component to return to its baseline state after being disturbed.
Risk	A function of exposure and effect which is more appropriate when an assessment of on-going (current) pressure is needed.
Risk Assessment	A methodology to determine the nature and extent of risk by analysing potential pressures and evaluating existing conditions of vulnerability that together could potentially harm exposed ecosystem components.
Scale	The spatial, temporal, quantitative or analytic dimension to measure and study objects and processes. Accordingly, scale is dependent on the extent (magnitude of dimension) and grain/resolution (precision in measurement).
Sector	A business that exploits the same or related product or service provided by the marine environment.
Sensitivity	The level of impact on a receptor caused by a pressure, mostly used in comparison to other pressures.
Spatial extent	The extent and distribution of the pressure from an action with the aim to determine its overlap (in time and space) with a particular ecosystem component (for which its spatial extent is also identified).

9. ANNEX

Manual for the implementation of environmental assessments in the UNITED pilots: establishing uniformised integrated Cumulative Effects Assessment

M.J.C. Rozemeijer[1], R.G. Jak[1], T.R.H. Kerkhove[2], M. Poelman[1]

[1]: Wageningen Marine Research

[2]: Royal Belgian Institute of Natural Sciences

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1 INTRODUCTION

The EU Horizon 2020 project UNITED addresses the topic "BG-05-2019 Multi-use of the marine space, offshore and near-shore: pilot demonstrators". We are combining several activities such as renewable energy and aquaculture, in the same marine space, including in multi-use platforms, that will serve to divide and reduce the costs of offshore operations and the demand on the space needed for different activities. UNITED will provide solutions to improve operation, planning, and management of multiple marine offshore activities. Among others, it will propose business models to reduce costs and generate benefits to both the aquaculture and renewable energy sector. Multi-use means both sharing use of space of the activities such that they generate simultaneously impacts on the environment.

One of the main aspects to be examined in the project is how to assess the cumulative environmental impacts[5] that occur due to the combination of multiple activities. Thus, by using the pilot demonstration approach, the project is aiming to assess the environmental impacts of multi-use and at the same time demonstrate the environmental added value of multi-use. To do this, the UNITED Assessment Framework (Figure 2) provides the structure. The potential impact of the sectorial activities will be assessed both separately and combined to determine the potential impacts (Box 1 in Figure 2). Next to that, the availability of existing environmental data will be assessed. Based on the severity of estimates and data availability, key possible impacts will be selected for step 2 (Box 2 in Figure 2, more precise determination of impacts) and also for monitoring (retrieving more data) to improve environmental impact assessments.

To identify and assess the environmental impacts, we introduce a uniform approach to perform *integrated Cumulative Effects Assessments* (iCEAs), applicable across the five different UNITED pilots, but also for multi-use in general, in the marine environment of different European seas. Specifically, we use a Risk-Based approach and its translation to ecosystem components: the concept of Vulnerability.

For each pilot, we want to demonstrate the differences in iCEAs for the single-use scenarios (the two activities per pilot sufficiently separated in space to not have an overlap of impacts in space and time) and in a multi-use scenario.

Reading guide for this manual: chapter 2 elaborates further on the approach and the principles of the iCEA. Chapter 3 gives a quick guide to perform an iCEA. Chapter 4 deals with estimating data availability and thereby the confidence in the estimates generated. Chapter 6 deepens knowledge on essential elements. A glossary is provided in chapter 7.

[5] See Chapter 7 for a glossary for terms like impact, effect, activity, pilot, vulnerability etc.

1.1 HYPOTHESIS

Our hypothesis is that the positive cumulative impacts of multi-use outweigh its negative cumulative impacts in comparison to simultaneous single-use (Figure 4 The thematic pillars that pave the way for the research work in UNITED (WP8 concept paper Kerkhove et al, 2021).).

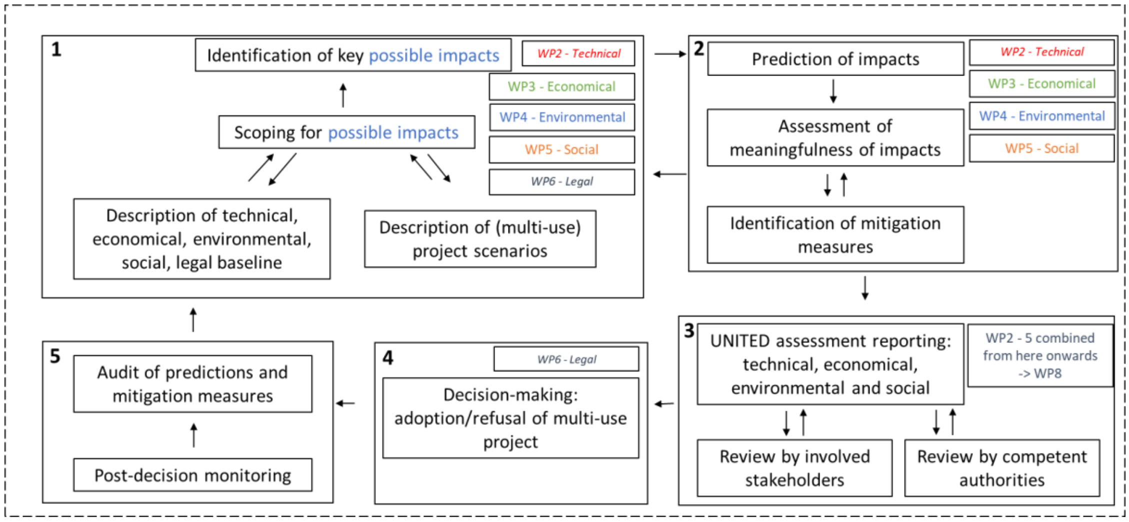


Figure 2 The UNITED Assessment Framework. The current guide to assess the environmental impacts by performing an iCEA is placed in Box 1: scoping for possible impacts in order to define key possible impacts.

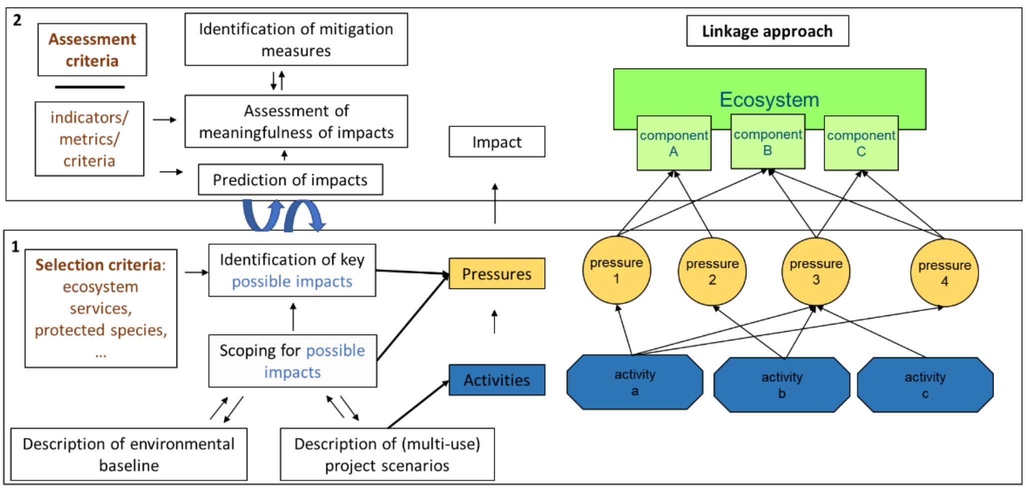


Figure 3 Positioning the iCEA approach in relation to Box 1 and 2 of Figure 2 of the UNITED Assessment Framework

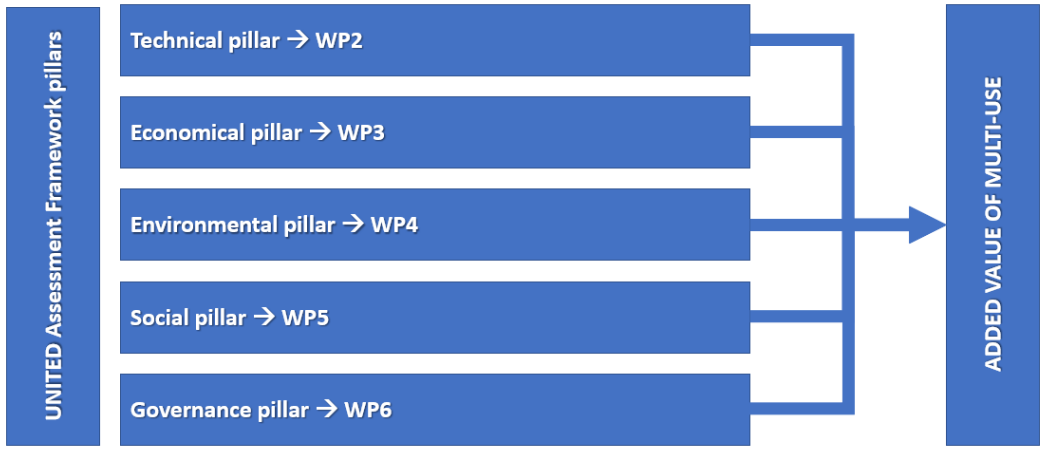


Figure 4 The thematic pillars that pave the way for the research work in UNITED (WP8 concept paper Kerkhove et al, 2021).

1.2 INTRODUCING ICEA

An iCEA is defined as a systematic procedure for identifying and evaluating the significance of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures. The analysis of the causes (source of pressures and effects), pathways and consequences of these effects on receptors (= ecosystem components) is an essential and integral part of the process (Judd et al., 2015, Piet et al. 2017a). Main principles are:

- The effect of a pressure on an ecosystem component results in an impact (= change in state) expressed as a proportional change in abundance. The quantitative term abundance is valid for the usual components like species and also for abstract terms like biodiversity and habitat. As an impact can be positive or negative, the proportional change ranges form -1 over 0 (no impact) to +1.
- The cumulative impacts then reflect the overall footprint of the human activities on the ecosystem. This is the sum of all the impacts per ecosystem component and then aggregated into an ecosystem assessment as the average across the components (thus assuming equal importance). Cumulative impacts can be synergestic, additive or antagonistic. Depending on the parametrisation, cumulative impacts can thus be > 1 or < -1 for any specific ecosystem component, selection of ecosystem components or for the ecosystem as a whole.

2 STEPWISE APPROACH FOR AN ICEA

The iCEA is embedded in a stepwise approach structured in four different phases (Table 2). Phase 1: Conception, where the purpose and scope are defined. Phase 2: Execution (presence) is the identification of potential effects of human activities, resulting actions and their pressures on the ecosystem. This results in a so-called "linkage framework" consisting of all the relevant impact chains, i.e. a chain linking action-pressure-ecosystem component. Phase 3: Execution (importance) is where the relative importance of each impact chain is established using a risk-based approach that calculates "Impact Risk" (= Vulnerability), i.e. the contribution of that impact chain to the overall impact risk a specific ecosystem component is experiencing. Impact Risk is the key concept around which this iCEA evolves. The quality of the underlying information and hence our level of confidence is assessed. Phase 4: Evaluation, this is where the meaningfulness of the results, including the level of confidence, is considered. E.g. data availability is assessed. This is both to inform further work to improve the knowledge base as well as provide guidance on the application of the iCEA as identified in the conception phase (Piet et al. 2017a). For the purpose of this study all four phases are performed in Box 1 of Figure 2 in a qualitative manner. In the next step (Box 2 of Figure 2), the selected criteria are quantified.

Table 2: iCEA framework adopted from Piet et al. (2017a), based on Judd et al. (2015). Modified into an iterative process where the outcome of the 4th phase should feed back into the process at any of the previous phases.

iCEA phase		**General description**	**Specifics**
1	Conception	Purpose and Scope.	How will the iCEA be applied • Identify spatial and temporal scale
2	Execution (presence)	Identification of potential effect of activities, their resulting actions and their pressures on the ecosystem.	Develop linkage framework based on an appropriate typology of • (Sub-)actions, • Pressures, and • Ecosystem components and the possible linkages between them
3	Execution (importance)	Estimation of the "Impact Risk" or "Vulnerability" per impact chain. This may be based on expert judgement or quantitative information.	• Is the available information appropriate for the agreed spatial and temporal scale? • Likelihood of exposure • Magnitude of the pressure(s) • Sensitivity of the ecosystem component(s) • Occurrence and/or relevance of additive/synergistic/antagonistic processes • Assessment quality of the data • Assumptions, uncertainty and thus level of confidence
4	Evaluation	Consider results in the broader context and informing the next iteration cycle.	• Significance of results • Main stressors/threats/causal factors/pressures • Possible mitigation measures • Application of results in the institutional context • Knowledge gaps

In the next sections, principles of each step will be described. In chapter 3 the actual execution of the process will be described in a Quick Guide approach.

2.1 CONCEPTION

The aim is to substantiate an existing conceptual iCEA framework for the five different specific situations of the UNITED pilots. The substantiated iCEA framework will map all ecological impacts in and around the pilot sites, caused by the multi-use activities and their actions, and where necessary also other substantial effect-causing activities. The reason that also external activities can be taken into account is that the focus of iCEA is on ecosystem components, and the UNITED pilots cannot be approached separate from the environment, including other human activities, where they are operating in. The iCEA framework is designed in such a way that cumulative effects of other sources and activities can also be incorporated at a later stage. To this extend, it is important to describe the spatial and temporal scale of all relevant (sub-)activities, their actions and relevant ecosystem components. Incorporating Ecosystem services (ESs) will be done at a later stage (outside the scope of this manual), by using both the results of the current approach and a beneficiary centric approach. The approach to define relevant ecosystem components (ECs) is starting from Action -> Pressure -> ECs -> Impact whereas ESs start from relevant ESs which are connected with associated ecosystem components.

2.2 EXECUTION (PRESENCE)

Linkage framework: a linkage framework describes how human activities can impact the ecosystem through actions and pressures: a receptor-led and fully integrated framework. It involves the coupling of different actions to multiple occurrences of multiple pressures (from single and/or different sources) on multiple receptors (=ecosystem components). Each action can generate many different pressures which directly impact one or more ecosystem components. The impacts on ecosystem components have derived impacts on ecosystem structures, functions and services that are depending on those ECs. For example, the action of "Mechanical harvesting" of seaweed causes the pressure "visual disturbance to fauna". "Visual disturbance to fauna" has an impact on Birds and the changes in Birds can have an effect on the ecosystem structure "Biodiversity". The same pressures from different sectors are cumulative, e.g. the "visual disturbance to fauna" caused by Mechanical harvesting and by "Transport of maintenance crew". See the example for seaweed cultivation in Figure 7.

2.3 EXECUTION (IMPORTANCE)

In determining the importance, the estimation of the "Impact Risk" per impact chain is done. This may be based on expert judgement or quantitative information. In a deconstructed exposure-effect approach, the exposure is determined by the spatio-temporal overlap between the anthropogenic pressure and the ecosystem component and the severity of the effect is determined by the magnitude of the pressure and the sensitivity of the ecosystem component (Figure 7).

The risk is translated into Vulnerability. Vulnerability is defined as the potential for loss as a function of exposure (= probability of a hazard), sensitivity (= susceptibility to this hazard), and adaptive capacity (= ability to cope with the hazard and its consequences) (Weishuhn et al., 2018, Piet et al., 2021b in prep).

For each impact chain identified in the linkage framework it is necessary to determine:

- Exposure represented by the spatio-temporal overlap.
- Magnitude (or intensity) of the pressure for which an appropriate pressure-specific metric will be identified.
- Sensitivity of the ecosystem component expressed in terms of the relationship between the chosen pressure metric and an effect on the ecosystem component.
- This results in the risk of the pressure and the vulnerability of the ecosystem component subject to a particular pressure (the importance).

2.4 EVALUATION

In the evaluation phase, the results are considered in a broader context and to inform the next iteration cycle (e.g. area management). First the confidence of the risk estimate is established by evaluating data availability (resolution in time and space). We want to emphasise here that this assessment is on quantity, and not on quality (the assessment on quality is currently under development).

The next step is to derive the main stressors, threats, causal factors and pressures. Also, the confidence of the importance estimates is taken into consideration.

In our case the ranking of these aspects and their confidence will assist in prioritising and selecting key impact chains (action -> pressure -> ecosystems component linkages). The confidence estimate can be used to prioritise monitoring.

The other aspects of evaluation (possible mitigation measures; application of results in the institutional context; knowledge gaps) will be tackled in further steps of the UNITED Assessment Framework.

3 QUICK GUIDE

See chapter 7 for the glossary and definition of terms.

The marine environment is heavily exploited by different industrial sectors with their activities in the same regions (e.g. offshore wind farms (OWFs), shipping, aggregate extraction etc.). Different forms of actions (done by activities within or across sectors, Figure 5B) can exhibit pressures on ecosystem components. These pressures can be the same exhibiting an alike effect or impact[6] on the ecosystem components (ECs). E.g. underwater sound by ship engines and OWF monopiles exhibit the same combinable (=cumulative) effects on the ECs. Introduction of synthetic compounds by ships or monopiles or sewers exhibit the same cumulative effect on the ECs, etc. Our approach enables cumulating of alike pressures across sectors (Knight et al., 2013, 2015, Robinson et al., 2014, Piet et al., 2017). The approach enables stakeholders to evaluate and review each interaction.

The starting point is a Linkage framework (Figure 5B, Figure 6), which is used to describe the interactions between human activities through actions with the (local) ecological characteristics of the ecosystem. In our case we have the multi-use pilots, each with at least two combined activities. Due to the visualisation of the interactions, the linkage frameworks can serve in communication purposes. Note that when each linkage is viewed independently, cumulation of impacts over activities is not possible. We use the Cumulative Linkage frame method which is offered by the ODEMM (Options for Delivering Ecosystem-Based Marine Management) approach, specifically designed to evaluate management measures in the context of the EU Marine Strategy Framework Directive (MSFD) (White et al., 2013, Knight et al., 2013, 2015, Robinson et al., 2014, Tamis et al., 2015, Piet et al., 2017).

Next, the iCEA consists of three steps

1. Linkage framework: a linkage framework describes how human activities can impact the ecosystem through pressures: a receptor-led and fully integrated framework. It involves the coupling of different sectoral (sub-) activities and actions to multiple occurrences of multiple pressures (from single and/or different sources) on multiple receptors (=ECs).
2. Risk estimate of the pressures on ECs: estimating both the potential effect (damage or benefit) on the ECs and the exposure (change), resulting in an estimate of the vulnerability of the ECs (indicated by a quantitative estimate of change).
3. Evaluate data availability: estimating the confidence in the data that underly the generation of the iCEA and thereby also in the risk estimate (e.g. in order to prioritise research needs).

[6] Effect: change (+ or -); impact: meaningful change.

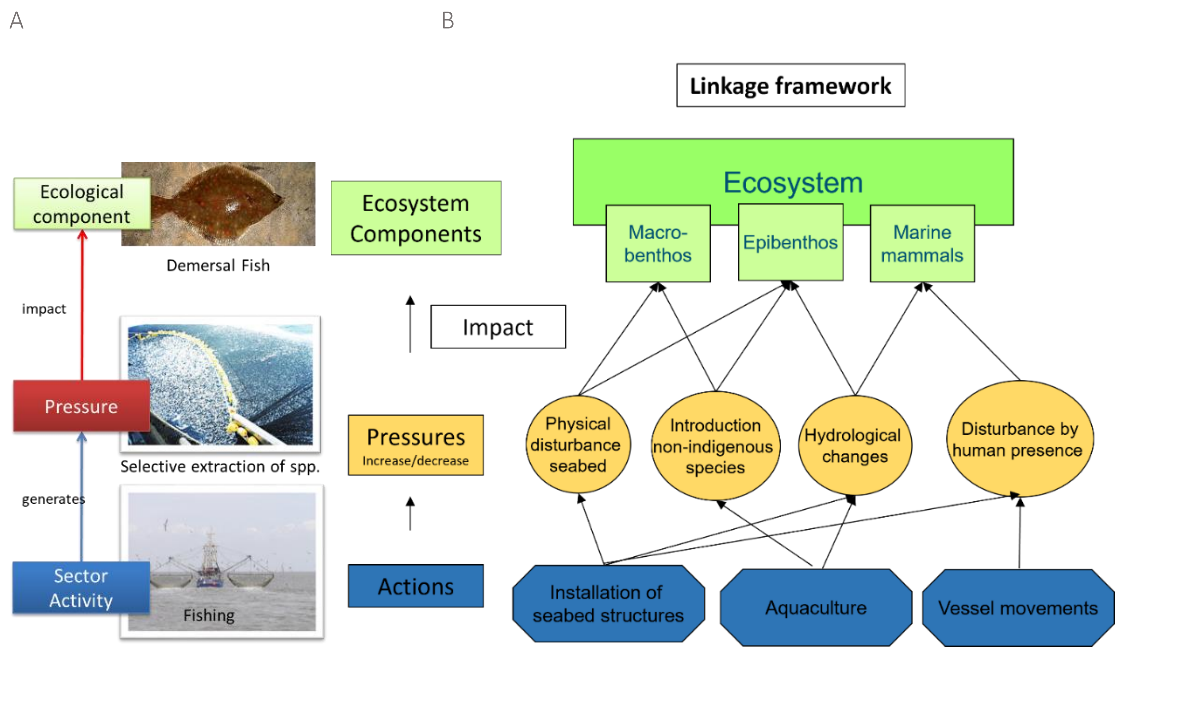


Figure 5 Example of how to construct a linkage framework from different activity -> action -> pressures -> ecosystem component relationships.

A: Example of an EA chain for one pressure (selective removal of species) of fisheries on an ecosystem component (plaice).

B: Example of a more elaborated linkage framework with different actions exhibiting several pressures interacting with several ecosystem components

3.1 HOW TO ESTABLISH A LINKAGE FRAMEWORK

A. First, have all data on the activity readily available: nature of the activity, surface occupied, installation period, timeframe of operation, etc.

B. Establish all **actions** of an activity of a pilot and generate a complete list using the oversight provide in the Excel-file:
   - Go to the H2020-BG05-UNITED environment in Teams. (Do not forget to switch to the Sticht-ing Deltares account)
   - Go to Folder 04 – Environment -> Task 4.3 -> EIA -> 'Your Pilot'
   - Here the ready-to-fill-in files can be found. Open the 'Actions' file
   - Applicable definitions of the glossary are given in cells A1 to B6.
   - Select your pilot in cell A11. Also fill in your name, organisation and e-mail address in cells J1 to M5. If more than one person contributed (recommended!), also add their details
   - Select the first sector (E10) and corresponding activity (F10) of your pilot
   - Place an x in column F in the yellow cells for each of those actions that are relevant for the ac-tivity. Three different phases (installation, operation and decommissioning) are distinguished. If needed, add new actions by adding additional rows
   - Re-do the exercise for each activity of your pilot by completing columns H, J, etc.

C. Pressures arise from actions and potentially result in impacts on the ecosystem. Pressures have been defined in the Marine Strategy Framework Directive (MSFD 2008, updated in 2017). Additionally, pres-sures have been identified and described in other fora, often to cover activities in relation to specific projects.
   A gross list of pressures was composed based on earlier lists included in the MSFD (2008, 2017), the EU projects Aquacross, TROPOS, MERMAID, Rozemeijer et al., (2019) and a Dutch project on Seaweed Farming (Tonk et al., 2021). This list was reviewed and discussed to select and further define pressures for the UNITED project (Table 4).
   - General remarks:
     - Pressures have been categorized in the MFSD as biological, chemical (substances and litter), or physical (including energy)
     - Pressures may exert on different compartments, i.e. the seafloor, sea water and the atmosphere
     - The change in pH, salinity, heath, nutrient concentrations, can be considered to be either negative or positive by deteriorating or stimulating environmental conditions for ecosystem components
     - Pressures from substances are specified to type of substance
     - Some pressures are introduced related to the presence of artificial structures
     - A number of previously defined pressures in other projects are omitted
     - To give an overview and understanding, in Table 4 in this text the most comprehen-sive oversight is given of evaluated, viable and realistic pressures encountered in liter-ature with their definitions.

D. **Ecosystem components**: it is necessary to determine which ECs are present in your pilot environment and might be impacted (positive/negative):
   - Go to the H2020-BG05-UNITED environment in Teams. (Do not forget to switch to the Sticht-ing Deltares account).
   - Go to Folder 04 – Environment -> Task 4.3 -> EIA -> 'Your Pilot'
   - Here the ready-to-fill-in files can be found. Open the 'Ecosystem Components' file
   - Applicable definitions of the glossary are given in cells A1 to B6.
   - Select your pilot in cell A11. Also fill in your name, organisation and e-mail address in cells J1 to M5. If more than one person contributed (recommended!), also add their details
   - Select the first sector (F10) and corresponding activity (G10) of your pilot

  - Place an x in column G in the yellow cells for each of those ecosystem components that are relevant for the activity.
  - On the one hand, higher level units are chosen like seabirds, marine mammals and reptiles, demersal fish, pelagic fish, broad habitat categories, etc. A lower number of elements facilitates to gain a coherent and integrated assessment across the ecosystem. Additionally, paucity of available information urges the use of available information in a more integrated approach. On the other hand, the status of specific species or habitats (in terms of being Habitat and Bird Directive species or IUCN red list species for example), or the potential to select species for which sufficient information is available so that they can serve as indicator species, might urge to integrate some specific species as well next to the higher-level ecosystem components. For example, Rozemeijer et al. (2019, in prep.) selected the categories vent-benthos and non-vent-benthos. Additionally, deep sea stony corals were singled out from non-vent-benthos because deep sea stony corals are magnitudes more sensitive to disturbance.
    As a first approach it seems wise to have specially defined resolution combining oversight and specific needs. Therefore, a first manageable set of ECs are distinguished: the higher levels. For each of these higher levels, the possibility exists to add 1-2 (max. 4) specific species/habitats/functional groups. Examples of this have already been suggested for Birds, Mammals and Habitats. Such an approach of higher-level ECs and a limited number of species of interest offers both reduction in anticipated high amounts of information oversight and special attention where really needed. For these species of interest, think on preferred MSFD Annex IV target species (like harbour porpoise, *Phocoena phocoena*), vulnerable species like the large, long-lived ocean quahog (*Arctica islandica*) and vulnerable habitats like gravel beds, both sensitive to abrasion by e.g. beam trawling.
  - Re-do the exercise for each activity of your pilot by completing columns I, K, etc.

E. Wageningen Marine Research (WMR) will combine actions to pressures and pressures to ecosystem components. Pilot leads and environmental experts will check those combinations in a workshop (see further).

F. In a next step, WMR will combine all A:P:EC linkages into a scoping tool to generate and visualise the figures comparable to Figure 5.

3.2 CALCULATING ICEA

To calculate the iCEA, two Excel-sheets are used: WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm (Linkages and qualitive impact estimate) and iCEA calculation sheet UNITED 210126 v1 MR.xlsx (quantitative impact estimate based on WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm).

A. The WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm gathers the actions, pressures, ECs into the Linkage Frame and A:P:EC linkages into an Excel-table. WMR converts the information into the table. This Excel is used to fill the expert estimates on the different criteria: Severity; Persistence; Dispersal; Resilience; Extent; Frequency (Table 3).

B. Table 3 and Table 3 (this manual) and the following tabs are relevant in WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm:
  - Tab LOOKUP: The Impact risk criteria with categories and the weightings of each category as used in Table 3 of this text. It is of eminent importance that the blue arched abbreviations are used of this tab and not those of Table 3. In the following steps WMR will take exactly these abbreviations, which will be automatically translated to quantitative estimates.
  - CS1Agg gathers A:P:EC linkages as separate rows, derived from the other sheets. These A:P:EC linkages have to be filled by hand. Some examples are given from an earlier North Sea study. NB: these are just examples. Since they use a different systematic, they need to be deleted once the demonstration has been given and the actual filling starts.

- Explaining in more detail, in tab CS1Agg columns A:L need to be filled with the new Activity:A:P:EC linkages (as determined in the linkage framework).
  - Column A: fill here the pilot at stake, the country; Column B: the (single-use) activity. Columns C and D: stage and sub-stage (when applicable) respectively.
  - Column E: the action as defined at (sub)stage level.
  - Column F and G: respectively the pressure and its categorisation according to main mechanism of operation.
  - Columns H:L represent meta-information and are highly functional in grouping afterwards. For the moment we leave these unfilled and will search for possibilities to automate this.
  - Column H: Domain: for now, Biota and Habitat to facilitate grouping according that axis. One could also think on the categories Biota, Marine Waters; Coastal Waters; Others., or another systematic. For the moment we leave these unfilled and will search for possibilities to automate this.
  - Column I: Realm, first level detailing of domain, the highest categories of Ecosystem Components are used (including habitat). For the moment we leave these unfilled and will search for possibilities to automate this.
  - Column J:L: scaling at different Eunis levels. For the moment we leave these unfilled and will search for possibilities to automate this.
  - Column M: the chosen EC: where appropriate, fill in species name.

C. The blue tinted columns N, O, P, Q, R, S need to be filled by means of an expert estimate as achieved by e.g. a mini workshop of 3-4 experts discussing the pressures and effects, using mostly tacit knowledge. The estimations are in the categories given in tab LOOKUP and tab "Table 2 manual" and the actual Table 3 in this manual. Use the categories and not the quantitative estimates. In the Excel iCEA calculation sheet UNITED 210126 v1 MR.xlsx the tab LOOKUP converts the categories to figures and calculates automatically the endpoints.

D. WMR will subsequently calculate the vulnerability, recovery speed and Time Lag for recovery of the EC in another sheet: iCEA calculation sheet UNITED 210126 v1 MR.xlsx. This Excel is not made available. The results are made available to the pilots. In addition, WMR has another back-up sheet ~ 7000 filled rows with Activity: A:P:EC linkages with estimations about sensitivity, recovery, etc. This sheet potentially offers an enormous library on how to interpret and deal with the different topics.

The idea at this stage is to have an WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm for each UNITED activity. Then fuse the activity sheets at the pilot level. When found useful, the three North Sea pilot sheets could be fused.

3.3 EVALUATING DATA AVAILABILITY FOR THE ICEA

As mentioned, the Confidence in the effect estimate is to be evaluated (section 2.4). The data availability, the quality of the models and their parameters are the measure for confidence. The evaluation of both Impact and Confidence combined yields insights where the Impact urgencies are and thereby informs on the direction of management measures. Additionally, insights are generated which A:P:EC linkage might deserve extra monitoring efforts based on urgency and lack of confidence. Classification criteria for confidence assessment were developed using the following generic hierarchy levels (but with deviations if needed): best possible; well-known; founded assumptions; unfounded assumptions; not used (Table 5, Piet et al, 2021a).

The process to generate these Confidence estimates has yet to be determined. For each A:P:EC linkage, a confidence estimate needs to be made. Since we have potentially an enormous quantity of linkages, we will define a selection procedure to reduce the number, in order to keep workload within limits and to keep the overview on the results. Most likely, workshop will be organised under the lead of WMR in which we jointly evaluate the selected, short-listed A:P:EC linkages.

4 PROCESS OF LEARNING THE ICEA

The following process will be adopted to learn all different steps:

1) First, the manual is sent and the representatives of the pilots are invited to fill in the sheets starting with "**Action table**" and "**Ecosystem Components**" in the Teams environment (see step in section 3.1).
2) WMR gathers all the information and fills in the WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm for each activity.
3) The representatives of the pilots are gathered in a workshop and the methodology will be explained to each pilot by Marcel Rozemeijer and Robbert Jak (WMR) and Thomas Kerkhove (RBINS). Given the efficiency, this will be most likely virtual through Teams although a real live workshop at one of the pilots (countries) might also be a possibility (opening up after COVID regulations). To this extent, each pilot will define a core team of a (co-)lead and one or two experts such as (general) ecological experts or technical activity experts. Note that experts might be shared between activities and pilots, e.g the North Sea pilots (Germany, The Netherlands and Belgium) could benefit from mobilising the same experts.
   a) Goals of the workshop:
      i) Describe the methodology to the pilot teams.
      ii) Check the A:P:EC linkage generated by WMR.
      iii) Fill in the blue tinted columns N, O, P, Q, R, S in the WMR estimation tool offshore infrastructures 210607 v1 MR.xlsm for each activity at stake, in a discussion between all experts present. These are, roughly, qualitive categories to be able to make a first selection. In doubt, select the more severe category and perform a second round to reassess doubtful cases. Don't fall in the trap to be too precise. The aim at this stage is to mobilise tacit knowledge: again, it is a first selection procedure.
4) WMR generates calculations with the iCEA calculation sheet UNITED 210126 v1 MR.xlsx and shares the results.
5) In a follow-up workshop:
   a) A group of A:P:EC linkages is preselected based on estimated Vulnerability (= Impact). The group with higher vulnerability/ impact is selected in order to reduce information.
   b) Data availability on the preselected A:P:EC linkages is evaluated.
   c) The results are evaluated (weighing Impact and Data availability). Together the most important A:P:EC linkages are selected based on Vulnerability and other criteria like protection and conservation status. Involvement of selected stakeholders might play an important role in this selection. When possible, the three North Sea cases will be combined into a single workshop to ensure all pilots are interpreting in a similar way. The Danish and Greek pilots will be treated at the individual level of the pilot.
      Overall, Marcel Rozemeijer, Robbert Jak and Thomas Kerkhove are available as back-up, helpdesk and linking pin between the pilots.
6) When all pilots have proceeded to a certain extent, a crosslink workshop might be organised, ensuring a similar approach and evaluating the selection of priority A:P:EC linkages. These will be used for precise impact estimates using more sophisticated tools such as laboratory testing or elaborate effect modelling.

Table 3. Impact risk criteria with their categories (after Robinson et al., 2013) and assigned numerical scores (adapted from (Knights et al., 2015)) used to weight each impact chain. These are also used by Borgwardt et al. (2019) and Piet et al. (2021b, in prep.).

Description	Abbre-viations used		Standar-dised score
Spatial extent		**Spatial overlap of each action-pressure combination with an ecosystem component**	
No overlap	NO	The action occurs outside of the area occupied by the ecosystem component, no pressure can reach the ecosystem component through dispersal	0
Exogenous	EX	The action occurs outside of the area occupied by the ecosystem component, but one or more of its pressures would reach the ecosystem component through dispersal	1
Site	S	The action overlaps with the ecosystem component by up to 5% of the area occupied by the EC in the pilot area	3
Local	L	The action overlaps with the ecosystem component by between 5 and 50% of the area occupied by the EC in the pilot area	37
Widespread patchy	WP	The action overlaps with the ecosystem component by between 50 and 100% of the area occupied by the EC in the pilot area, but the distribution within that area is patchy	67
Widespread even	WE	The action overlaps with the ecosystem component by between 50 and 100% of the area occupied by the EC in the pilot area, and is evenly distributed across that area	100
Dispersal		**Effect of the spreading of the pressure on realised area of spatial overlap**	
None	N	The pressure does not disperse in the environment	1
Moderate	M	The pressure disperses, but stays within the local environment	10
High	H	The pressure disperses widely and can disperse beyond the local environment	37
Frequency		**Temporal overlap of each action-pressure combination with an ecosystem component**	
Rare	R	Occurs approximately 1–2 times in a 5-year period but may (or may not) last for several months when it occurs	1
Occasional	O	Can occur in most years over a 5-year period, but not more that several times a year	2
Frequent	F	(1) occurs in most years over a 5-year period, and more than several times in each year, or (2) can occur in 1–2 years in a 5-year period but also in most months of those years	5
Very frequent	VF	Occurs in most months of every year, but is not constant where it occurs	9
Continuous	C	Constant in most or all months of a 5-year period	12

Persistence		**Length of time that is needed that a pressure disappears after action stops**	
Low	Low	0 to <2 years	1
Moderate	Mod	2 to <10 years	6
High	High	10 to <100 years	55
Persistent	Persis-tent	The pressure never leaves the system or > 100 years	100
Severity		**Likely sensitivity of an ecosystem component to a pressure where there is an interaction**	
Low	Low	An interaction that, irrespective of the frequency and magnitude of the event(s), never causes a noticeable effect for the ecosystem component of interest in the area of interaction	0.01
Chronic	Chronic	An impact that will eventually have severe consequences at the spatial scale of the interaction, if it occurs often enough and/or at high enough levels	0.125
Acute	Acute	A severe impact over a short duration	0.7
Resilience		**The resilience (recovery time) of the ecological component to return to pre-impact conditions. Recovery times for species assessments are based on turnover times (e.g. generation times). For predominant habitat assessments, recovery time is the time taken for a habitat to recover its characteristic species of features given prevailing conditions**	
None	N	The population/stock has no ability to recover and is expected to go "locally" extinct. The recovery in years is predicted to take 100+ years (100+)	100
Low	L	The population will take between 10 and 100 years to recover. A raw value taken as the midpoint between the range boundaries (55)	55
Moderate	M	The population will take between 2 and 10 years to recover. A raw value taken as the midpoint between the range boundaries (6)	6
High	H	The population will take between 0 and 2 years to recover. A raw value taken as the midpoint between the range boundaries (1)	1

Table 4. Overview of the **pressures** encountered by several authors. Used references were MSFD 2008, 2017, ODEMM (Options for Delivering Ecosystem-Based Marine Management) pressures (White et al., 2013). Aqua-cross (Pleterbrauwer et al., 2016, Borgwardt et al, 2019), Stelzenmüller et al., (2019). Rozemeijer et al. (2019).

Pressure	Definition	Comment
Biological		
Extraction of living resources	Intentional and unintentional extraction of wild species (by commercial and recreational fishing and other activities)	MSFD definition 2008, 2017, but without "or mortality/injury to,"
Introduction of genetically modified species	Introduction of genetically modified populations of indigenous species that may result in changes in genetic structure of local populations, hybridization, or change in community structure.	Part of the MSFD 2017 definition, but not including non-indigenous species (being a separate pressure)
Introduction of microbial pathogens into marine waters	Introduction of microbial pathogens including parasites and bacteria into marine waters	Modified from MSFD 2008, 2017
Introduction of non-indigenous species	Introduction of non-indigenous species by the activities of a particular sector (e.g. through exchange of ballast waters by shipping or from release of individuals from aquaculture)	Originates from MSFD 2008, 2017, but refined to non-indigenous species
Translocations of species	Translocation of indigenous species and genetically different populations of indigenous species that may result in changes in genetic structure of local populations, hybridization, or change in community structure.	MSFD 2017 In the description of the pressure "Native or non-native" non-native is taken out, as it is covered by the introduction of non-indigenous species
Chemical (Substances & Litter)		
Alter input of organic matter	Changes in input of organic matter — diffuse sources and point sources	MSFD 2017
Alter N&P concentrations	Enrichment or depletion of nutrients (N&P)	Combining enrichment (MSFD) and depletion
Introduction of Non-synthetic compounds	Introduction of heavy metals and hydrocarbons into marine waters	In MSFD 2017 "non-synthetic" is part of "other" substances, but better to keep separated, conform MSFD 2008.
Introduction of Radionuclides	Introduction of radionuclides into marine waters	In MSFD 2017 "radionuclides" is part of "other" substances, but better to keep separated, conform MSFD 2008.
Introduction of Synthetic compounds	Introduction of manmade compounds such as pesticides,	In MSFD 2017 "synthetic" is part of "other" substances,

	antifoulants and pharmaceuticals into marine waters	but better to keep separated, conform MSFD 2008.
Marine litter	Litter originating from numerous sources but entering the marine environment and consisting of different materials including: plastics, metal, glass, rubber, wood and cloth, including micro-sized litter	MSFD 2008, 2017
pH changes	Changes in pH (average, range or variability) e.g. due to run off from land-based industry	White et al. (2013), Borgwardt et al. (2019) Adapted from AQUACROSS
Salinity changes	Change in salinity (average, range or variability), e.g. due to outfalls from industrial plants or alterations in coastal structures affecting mixing	MSFD 2008
Alter sulphur input	Introduction of sulphur as atmospheric emission product of combustion processes (e.g., vessel engine)	UNITED
Alter carbon budgets and dynamics	Intentional or unintentional changes in carbon budgets of dynamics, resulting from carbon capture or changes in (CO_2, CH_4) emissions	Adapted from Narita et al. (2015, greenhouse gasses) and Tonk et al. (in prep)
Physical, including Energy		
Behaviour changing by being present (humans, objects, vessels, machinery etc.)	Presence of humans; objects, vessels, machinery etc. leading to change in normal behaviour of species (e.g., avoidance or attraction of an area by birds) due to the visual aspects	MFSD 2008, "objects" added, and impact may be positive and negative
Entangling in line-type or net-type structures	Entanglement of megafauna (cetacean, turtles etc.), in subsurface equipment including e.g. nets, umbilical tubes, anchor lines, mooring lines, marker buoy lines, power cabling or hydraulic lines	Coffey Natural Systems (2008), Ministry for the Environment (2011), considered relevant for offshore structures, especially those for aquaculture
Smothering	Cover habitat surface with materials falling to the seafloor from activities in the water column (e.g. waste substances from aquaculture cages), on land (e.g. in runoff or effluent), or around activities (e.g. around trawling gear), or from disposal of materials onto the seafloor (e.g. disposal of materials from dredging). Smothering may lead to reduced functioning (e.g. feeding) or mortality of benthic animals living on, or in the seafloor.	MSFD 2008
Sealing	Physical loss of habitat from sealing by permanent constructions (e.g. Coastal defenses, wind turbines)	MSFD 2008

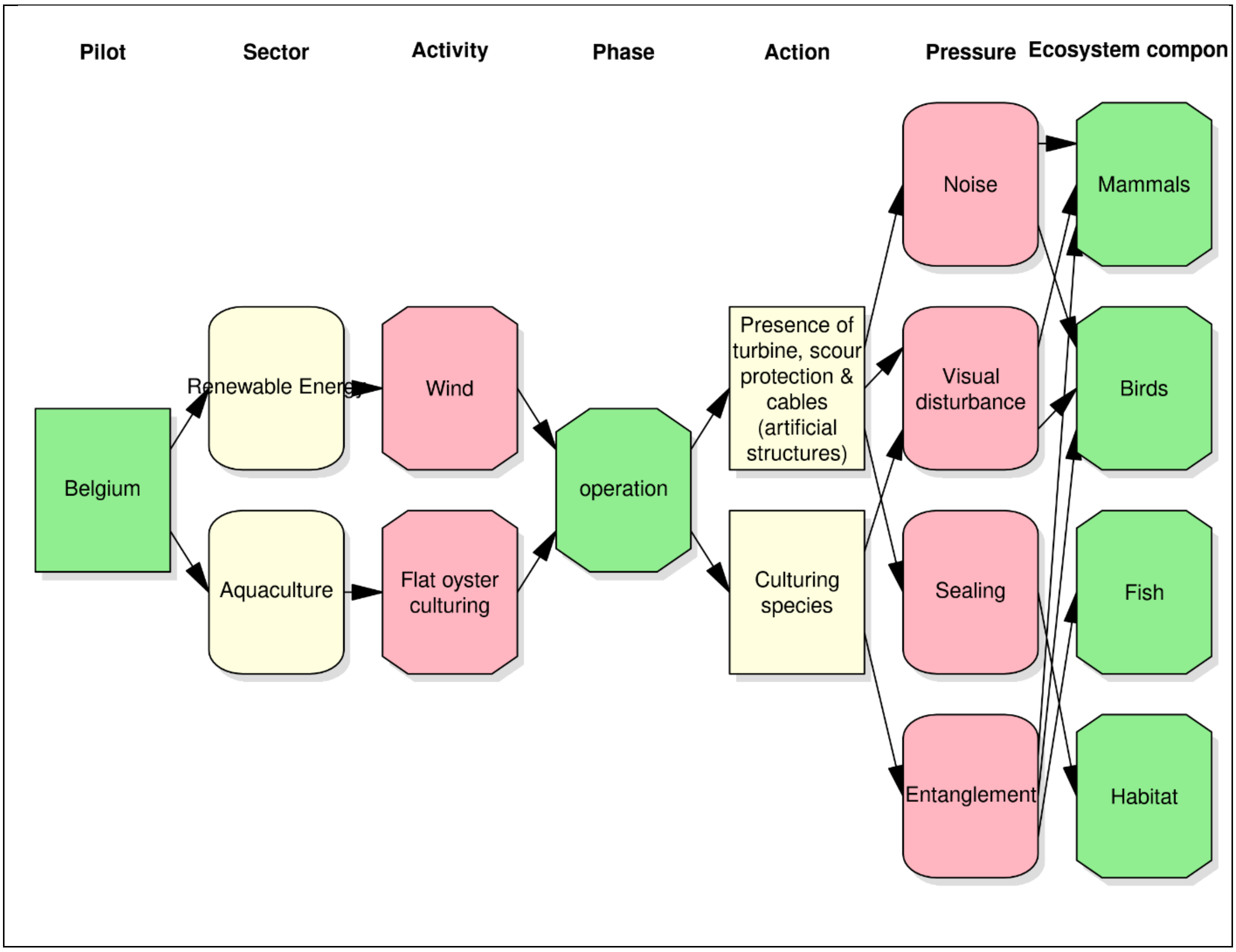
Abrasion	Physical anthropogenic disturbance/damage to the seabed (temporary or reversible)	MSFD 2008, 2017
Active adaptation of habitat	Intended change of (a)biotic habitat resulting from human made structures (e.g. platforms, ship wrecks, wind turbines, aquaculture structures, morphological interventions)	Adjusted from AQUACROSS, including "(a)biotic", intention and morphological interventions
Changing input and abstraction of water	Intentional or unintentional changes in water budgets of dynamics e.g. changes of direction of run-off systems leading to quantitative changes	Modified from MSFD 2017
Selective extraction of non-living resources: substrate e.g. gravel	Includes sand and gravel (aggregates) extraction, removal of surface substrates for exploration of seabed and subsoil	Modified from MFSD 2008, 2017
Blocking species movement (barrier mechanism)	Preventing the natural movement of motile marine fauna along a key route of travel (e.g. a migration route) due to e.g. barrages, causeways, wind turbines, and other man-made structures	Adapted from AQUACROSS
Causing collision	Death or injury of marine fauna due to impact with moving parts of an object used for human activity, e.g. marine mammals with ships/jet skis, seabirds with wind turbines etc.	White et al. (2013), Borgwardt et al. (2019)
Change in siltation	Change in the concentration and/or distribution of suspended matter/sediments in the water column from runoff, dredging etc.	MFSD 2008
Change in wave exposure	Change in the size, number, distribution, and/or periodicity of waves along a coast due to installation of coastal structures	White et al. (2013), Borgwardt et al. (2019)
Water flow rate changes	Changes in currents (speed, direction or variability) due to e.g. barrages or other manmade structures such as coastal defenses	MFSD 12017
Emergence Regime Changes	Changes to natural sea level regime (average, range or variability) due to e.g. barrages or other manmade structures such as coastal defenses	White et al. (2013), Borgwardt et al. (2019)
Electromagnetic changes	Change in the amount and/or distribution and/or periodicity of electromagnetic energy emitted in a marine area (e.g. from electrical sources such as underwater cables)	MSFD 2017

Input of light	Introduction of light e.g. from platforms, ships, under water equipment	Modified from MFSD 2017
Shading	Shading caused by floating object or fixed constructions	TROPOS, MERMAID
Noise (Underwater and Other)	Input of anthropogenic sound (impulsive, continuous)	MSFD 2017
Thermal change	Change in temperature of the water (average, range or variability) e.g. due to outfalls from industrial plants	MFSD 2008, 2017

Table 5. Confidence classification criteria for aspects and elements, i.e. Activity (A), Pressure (P), and Ecosystem Component (EC), addressed in this study. Aspect: those aspects that need to be distinguished for classification of confidence. Note that a reliable source is considered as any source that has competence in the field of interest. This includes but is not restricted to peer-reviewed literature or (broadly recognised as) authoritative (inter)national data portals.

Aspect	**High (1)**	**Moderate to high (0.8)**	**Moderate (0.6)**	**Low to moderate (0.4)**	**Low (0.2)**
Data processing	No data processing required	Some processing required, but only format change. No data transformation	Some processing required, including minor data transformation	Processing required, including data transformation	No spatial information. Single point value
Actual exposure	The actual exposure in the grid cells where EC and P co-occur is well known and fully quantified	The actual exposure in the grid cells where EC and P co-occur is well known but issues with quantification	The actual exposure in the grid cells where EC and P co- occur is not precisely known but based on assumptions from a reliable source	The actual exposure in the grid cells where EC and P co-occur is not precisely known and unfounded assumptions were required	The actual exposure in the grid cells where EC and P co-occur is unknown (but assumed to be 100%)
Metric suitability	Best possible representation	Is a proxy based on well-known relationships and covering the relevant pressure properties	Is a proxy based on founded assumptions and covering much of the relevant pressure properties	Is a proxy based on unfounded assumptions, covering only some of the relevant pressure properties	No metric used
Estimation metric Magnitude Abundance	Exact data from a reliable source, not based on assumptions and/or modelling	Data from a reliable source, not based on assumptions and/or modelling	Data from a reliable source, based on founded assumptions and/or modelling	Data, based on unfounded assumptions and/or modelling	No metric used. Single point value (presence/non- presence)
Spatial / Temporal resolution	Resolution exactly represents the element	Resolution is appropriate	Resolution is slightly lower	Resolution is much lower	Not used. Single point value

Spatial / Temporal coverage	Extent covers the entire relevant area and/or representative time period	No complete coverage, but sufficient to be representative (covering >80%, including the main parts)	Covers a substantial part of the area / time frame (covering appr. 50-80%)	Only a small part of the area / time frame (<50%) is covered	Not used. Single point value
Parameters P-E	The parametrisation of the relationship between magnitude and effect is known from a reliable source and is well established	The parametrisation of the relationship between magnitude and effect is known from a reliable source	Parametrisation of the relationship is estimated, based on data from a reliable source	Parametrisation of the relationship is estimated, based on assumptions from a less reliable source	Parametrisation of the relationship is estimated
Parameters population dynamics	Parameters are from reliable sources and with little variation	Parameters are from reliable sources and large variation	Parameters are from less reliable sources and little variation	Parameters are from less reliable sources and large variation	Parameters are based on (unfounded) estimations
C dynamics approach suitability	Best represents the dynamics of the ecosystem component, based on a reliable source, suitable for study aim and endpoint	Is a proxy based on a reliable source, suitable for study aim and endpoint	Is a proxy (partly) based on unfounded assumptions, suitable for study aim and endpoint	Is a proxy with poor suitability	No ecosystem components dynamics used


Pilot
Sector
Activity
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Action
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Ecosystem compon
Belgium
Renewable Energy
Aquaculture
Wind
Flat oyster culturing
operation
Presence of turbine, scour protection & cables (artificial structures)
Culturing species
Noise
Visual disturbance
Sealing
Entanglement
Mammals
Birds
Fish
Habitat

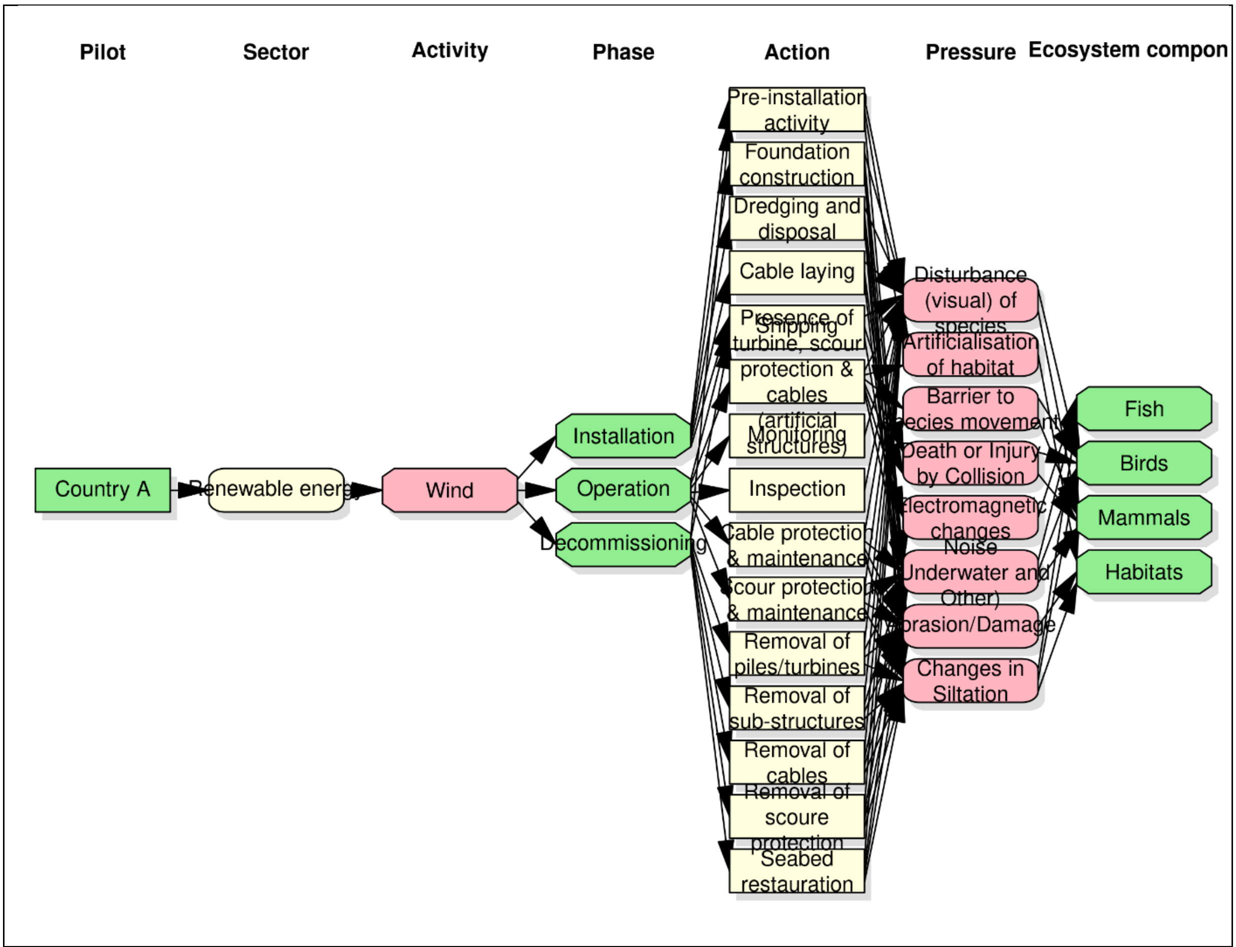

Figure 6: Examples of a linkage framework for a pilot and an activity, giving the Action -> Pressure -> Ecosystem Component linkages combinations. The framework represents the interactions (or impact chains) between ecosystem components, pressures and sub-activities per cultivation phase (installation [instal], operation [op], decommissioning [decom]. The interactions (or impact chains) are indicated in arrows. These figures have been constructed using the WMR scoping tool (Tonk & Jansen, 2020) and serves only for illustration purposes, hence the low readability of parts of the text boxes.

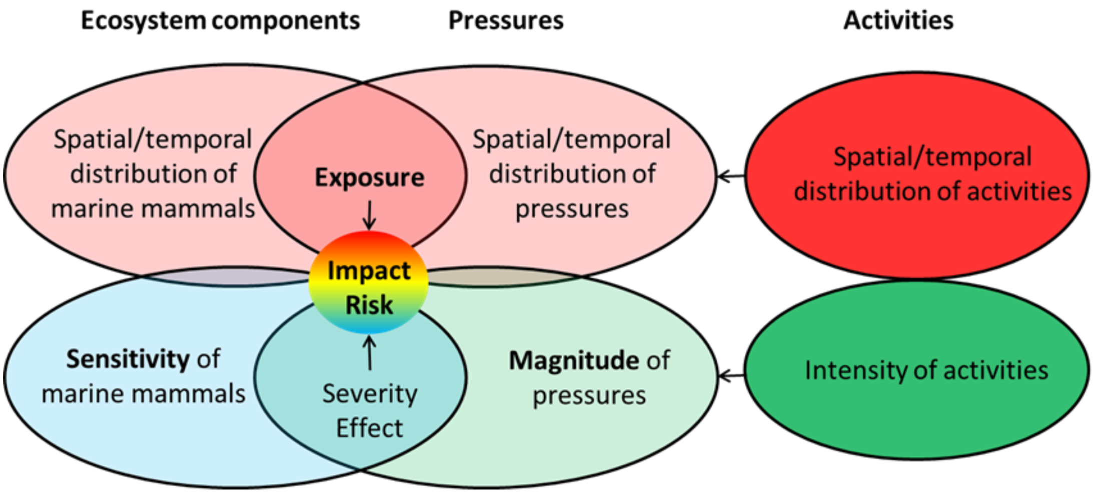

Figure 7: The iCEA, and its key concept Impact Risk, is based around the principles of environmental risk assessment where risk is based on Exposure and Effect. Exposure is determined by the spatio-temporal overlap between the anthropogenic pressure and the ecosystem component (here: marine mammals) and the severity of the effect is determined by the magnitude of the pressure and the sensitivity of the ecosystem component

5 ELABORATING ON ESSENTIAL ASPECTS

The text of this Chapter is based to a large extent on Piet et al., (2021: in prep). Vulnerability as the key concept to assess the potential impact of cumulative pressures on the capacity to supply ecosystem services: A North Sea case study. In prep.

To calculate the potential impacts of the different scenarios (single-use or multi-use) in the UNITED project, a combination of the results from Borgwardt et al. (2019) and Piet et al. (2021: in prep.) will be used (Table 3). For this we will commence with a comprehensive iCEA including all possible impact chains but initially with only qualitative scores based on expert judgement. After prioritising results and selecting the target priorities (= key impacts), the next stage will be to replace the qualitative scores with quantitative estimates where possible, based on the best information available.

5.1 BASIC PRINCIPLES

The following basic principles apply:

- Pressures should be comprehensive in that they should cover ALL the mechanisms through which human activities can impact the ecosystem (both biotic and abiotic components). Pressures should be mutually exclusive. Table 4 has been thoroughly checked for that.
- Human activities consist of sectors as the entity at the highest level of aggregation. A sector should also have a distinct place in the socio-economic system. A sector can be sub-divided into different activities if these are expected to interact differently (i.e. through different Pressures) with the ecosystem and/or are likely to be subject to different management actions. To avoid ambiguity all sectors including their potential sub-activities should be mutually exclusive and weighted with proportions that for each pressure add up to 1.

- Ecosystem components should also be comprehensive in that they are expected to represent all the different life forms, i.e. key phyla, and thus cover ALL the aspects of the ecosystem that contribute to its integrity and functioning at an appropriate level of detail. As there is always discussion on what an appropriate level of detail is we propose the use of hierarchies that allow each of the ecosystem components to be divided into increasingly more detailed sub-components but with the requirement that these should be mutually exclusive and ultimately represent proportions of the ecosystem component that add up to 1 (or 100%). Here it is suggested to use (Sea)birds, (Marine) mammals, Reptiles, Fish, Cephalopods, Benthos and Primary production and Zooplankton. These main groups are differentiated according type of sensitivity: see Excel WMR scoping tool offshore infrastructures 210204 v1 MR.xlsm. The tab Definitions gives already a suggestion how to deal with the biotic groups. Table 10 gives an overview of habitats and levels of details. For habitats it needs to be selected from Table 10 .

5.2 ESTIMATING SPATIAL EXPOSURE

Exposure is here defined as the probability of co-occurrence of the pressure and the ecosystem component and determined by their spatial and temporal overlap. For spatial overlap an "Exposure" score is calculated, based on the combined Extent and dispersal categories from Borgwardt et al. (2019, Table 3). To make the difference between Extent and Dispersal more tangible, the following example describes the differences: the activity sand extraction has the spatial overlap of the size of the concession of sand extraction: e.g. 100*200 m^2. The silt cloud disperses and its impacts on primary production have a spatial extent of 100's km^2s (dispersal).

However as compared to Borgwardt et al. (2019), the dispersal scores have been modified to come up with more realistic spatial overlap values. Instead of a dispersal score of 1 in case of high dispersal because "the pressure can disperse beyond the local environment" (Borgwardt et al., 2019) a score is assumed equal to the local Extent category, i.e. 0.37. By simply multiplying (numerical) scores of extent and dispersal (or frequency and persistence), spatial (or temporal) effects may be either underestimated (when the scores are both small) or overestimated when they are both large. Moreover, no overlap would always result in a 0 score even though a pressure with moderate to high dispersal may result in co-occurrence despite its lack of overlap. Therefore, the two scores are considered as chance processes when combining them into an overall spatial exposure score. This can be achieved by scaling the scores of both aspects between 0 and 1 and treat them as dependent chance processes. The combined 'chance' is then calculated according to a standard probability calculation as equal to the sum of both chances minus the product of both the chances (see Equation *1*, Table 6).

With regard to the temporal overlap, this aspect is settled in the calculation of Effect Potential (section 5.3, **Error! Reference source not found.**).

Equation 1	Spatial overlap =	$\left(\frac{E}{100}+\frac{D}{100}\right)-\frac{E}{100}*\frac{D}{100}$
E = Extent: distribution of Ecosystem Component at stake. D = Effect of the dispersal of the pressure beyond project site.		

Table 6. Exposure criteria with their categories and assigned numerical scores (Piet et al., 2021 in prep) used to weight each impact chain. Dispersal high adapted as compared to Borgwardt et al. (2019): 37 instead of 100.

	Dispersal		
Spatial Overlap	None	Moderate	High

Extent		1	10	37
No overlap	0	1	10	37
Exogenous	1	2	11	38
Site	3	4	13	39
Local	37	38	43	60
Widespread Patchy	67	67	70	79
Widespread Even	100	100	100	100

5.3 EFFECT POTENTIAL

Given an Exposure to a certain pressure (e.g. disturbance or stress), Effect Potential (EP) describes the susceptibility of an ecosystem component or the ecosystem as a whole. It expresses the degree to which the ecosystem component is likely to be affected by the magnitude of the pressure. EP is the inverse of sensitivity and we used this to interpret these concepts in a population dynamics context. EP would ideally be represented by the relationship between the pressure magnitude (or intensity) and the effect (or impact) it causes. As previous studies (Knights et al., 2015; Borgwardt et al., 2019) assessed risk of impact, EP is here expressed in terms of a change in abundance due to pressure-induced change. This could be depletion, loss or increase e.g. of biodiversity due to change of habitat. Likewise, resistance would reflect what remains of an ecosystem component after being exposed to a pressure. Next sections, EP will be expressed as a relation of Sensitivity, Pressure Load, and Recovery Potential.

5.3.1 Sensitivity

Severity as used in Knights et al., 2015 and Borgwardt et al., 2019 reflects sensitivity of an ecosystem component to hazard, i.e. when exposed to a certain (but unspecified) pressure magnitude. The frequency at which the ecosystem component is exposed to this hazard determines the EP but this is somewhat ambiguous without an indication of magnitude. Considering the importance of the Sensitivity concept it is unfortunate that it consists of only three qualitative Severity categories, i.e. Low, Chronic, Acute, but this is alleviated by combining this with the frequency to obtain enough EP categories (see **Error! Reference source not found.**) for the assessment resolution required to guide management. For the calculation in general, EP is interpreted as the proportion of the initial abundance decreasing, or increase by the frequency, and severity of the pressure which the standard formula estimates what remains of an ecosystem component relative to an undisturbed situation or chosen reference situation (Equation *2*, Equation *3*, Figure 8) (=proportion lost, the depletion or increased when stimulating e.g. biodiversity). However, it should also be considered that multi-use initiatives can be beneficial. In that case the figures should be applied with a contra-intuitive negative severity (resulting in a negative sensitivity).

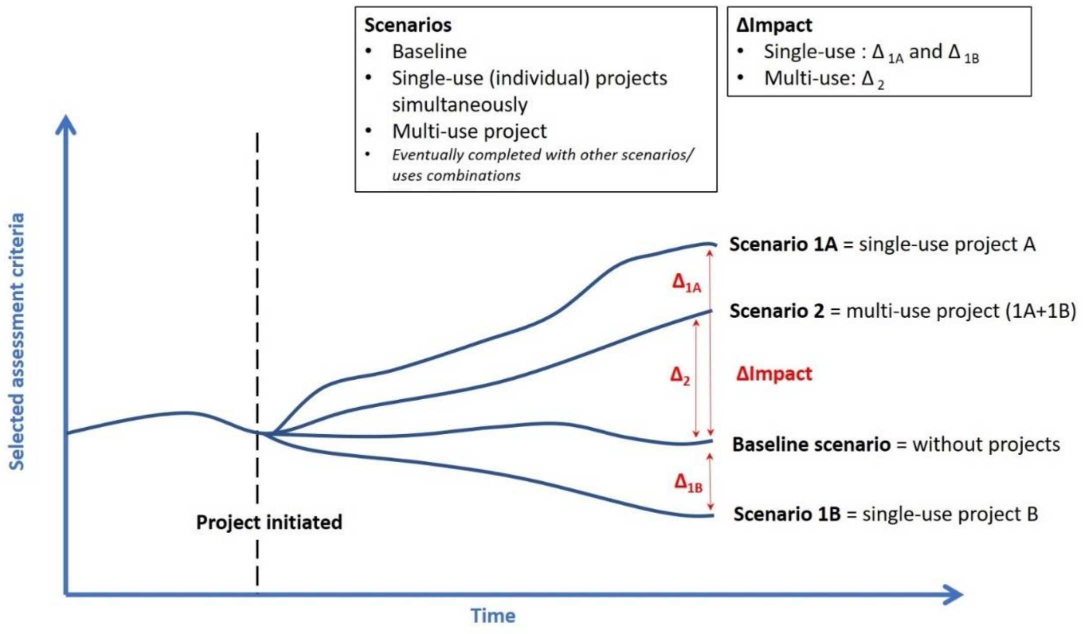

Figure 8: in the UNITED Assessment Framework, we aim to measure impact as a change against a reference/baseline scenario

In this new calculation, slightly different scores were applied for the frequency categories to ease interpretation and future estimation. Now the score reflects the number of months per year the ecosystem component encounters the hazard so that the "Continuous" category gets a score of 12. For the purposes of obtaining realistic EP estimates, the Borgwardt et al (2019) severity score for the "Acute" category was adjusted such that a rare occurrence of an acute hazard was equal to a very frequent occurrence of a chronic hazard (see **Error! Reference source not found.**).

Equation 2	Fraction of maximum =	$\frac{A}{K} = (1 - S)^F$
Equation 3	Depletion (d)=	$d = 100 * (1 - \frac{A}{K})$

A = Abundance (or density) of ecosystem component at a given moment (e.g. experiencing a pressure)

K = Carrying capacity representing an undisturbed situation

S = Severity expressed as the proportion depletion of an ecosystem component per encounter

F = Frequency of encounter. Here expressed as months/yr.

Table 7. Effect Potential (XEP) expressed as the proportion depletion (%) of an ecosystem component relative to undisturbed depending on adapted Severity (s) and Frequency (F) estimates Borgwardt et al (2019).

		Severity		
Frequency		Low	Chronic	Acute
		1	12.5	70
R	1	1	13	70
O	2	2	23	91
F	5	5	49	100
VF	9	9	70	100
C	12	11	80	100

5.3.2 Pressure Load

Pressure Load (PL) is the relative contribution of activities to the accumulated load of the pressure. The concept of PL has the advantage that it is a tangible concept from a management perspective. However, it fails that it is not easily translated to the concepts used in this approach, i.e. pressure magnitude or intensity, that actually determine the effect on the ecosystem component (depending on its resistance or sensitivity to that pressure). In a management context this PL also needs to be attributed to manageable activities, often sector-specific. Therefore, PL is expressed as a sector-specific contribution. The approach developed and applied here first identifies those activities that can be assumed to contribute >30% to the overall load. Often this applies to activities where the pressure is the primary purpose for this activity to take place (e.g. biological extraction in case of fishing). The PL of these activities is determined by the PL that remains after all the contributions of the minor activities are estimated using an expert judgement score according to the criteria in Table 8. Together all activities add up to 1 (or 100%) for each pressure.

Table 6. Categories to estimate the relative contribution of activities to the Pressure Load and hence the magnitude that determines the Effect Potential score.

Relative contribution action (%)	Pressure Load Score (%)
0.1	0.1
1	1
5	5 Unless there is no >30% action category. In that case the balanced distribution applies to these activities
>30	Balanced distribution of the remaining load after all minor activities have been scored (Scores≠0.1, 1, 5). This should add up to a total of 100% for the pressure

5.3.3 Recovery potential

The concept "Recovery Potential" reflects the necessary interaction between the resilience of the ecosystem component and the persistence of the pressure (Knights et al., 2015; Borgwardt et al., 2019). The resilience is the ability to return to pre-impact conditions. Resilience differs from ecosystem component to ecosystem component as is illustrated for habitats in Table 11. Resilience assumes an immediate response of the magnitude of the pressure if the PL changes due to management interventions. In reality, however, some pressures are likely to persist after an action stops and this can be incorporated into a more precautionary Resilience estimate determined by the slowest of the two aspects that determine recovery potential, i.e. Persistence and Resilience, as shown in Table 8. Where Knights et al (2015) assumed the two should be summed because recovery only commences after the pressure has completely disappeared, here Recovery Potential is the maximum value of one of either Persistence or Resilience (Equation *4*). This seems a less precautionary approach but it seems arguably a more realistic. Indeed, recovery commences once the magnitude of the pressure starts to decline but Recovery is determined by the slowest of the two aspects (Table 8). Instead of using scores 0-1 representing their contribution to risk, these scores were based on the actual number of years. In this manner it provides a real-world notion of recovery potential that is meaningful from a management perspective.

Table 8. Recovery Potential based on the resilience of the ecosystem component and the persistence of a pressure, calculated as the average of the Persistence and Resilience scores from Knights et al (2015).

Recovery Potential		**Persistence**			
		Low	Moderate	High	Continuous
Resilience		1	6	55	100
High	1	1	6	55	100
Moderate	6	6	6	55	100
Low	55	55	55	55	100
None	100	100	100	100	100

Equation 4	Recovery Potential =	$RP = Max(R:P)$

RP = Recovery Potential

P = Persistence

R = Resilience

5.3.4 Population dynamics as basis

The general idea of this technique is that the tacit expert opinions are translated through elaborate recalculations into quantitative figures. The first publications used were simple calculations (see e.g. Knight et al., 2015). Now these calculations are evolving resulting in a thorough theoretic approach. For all species, the principle of population dynamics is used to calculate effects and impacts.

The Effect Potential (EP) can be derived from population dynamics using semi-chemostat dynamics to model the abundance of the ecosystem component. Semi-chemostat dynamics are given by Equation *5*:

Equation 5	Population changes =	$dN/dt = r(K - N)$
N = population abundance r = maximum population growth rate K = carrying capacity (maximum abundance).		

Equation *5* can also be extended with a depletion d:

Equation 6	Population changes =	$dN/dt = r(K - N) - dN$
N = population abundance r = maximum population growth rate K = carrying capacity (maximum abundance). d = depletion		

Both d and r in Equation *6* can be affected by the pressure. By setting this to equilibrium (dN/dt=0) and rearranging, resulting in Equation *7*:

Equation 7	Population changes =	$\frac{N_{eq}}{K} = \frac{r}{r + d}$
N_{eq} = population abundance at equilibrium r = maximum population growth rate K = carrying capacity (maximum abundance). d = depletion		

When d=0, N/K=1 and N is present at maximum abundance (carrying capacity) K. The abundance of N as a fraction of K is here reduced by the sum of r and d. This quantity indicates the fraction of new-grown individuals which manage to reproduce before they die. The potential impact is 1-(N_{eq}/K) indicating the potential loss of the ecosystem component if this pressure continues at that magnitude *ad infinitum*.

For this population dynamics model we estimated the two parameters, r and d, from respectively the recovery capacity and sensitivity characterised using the categories from the risk-based assessment of impact risk. We solved the above equations for N_t:

Equation 8	Population at time t =	$N_t = N_{eq} + (N_0 - N_{eq}) * e^{-(r+d)t}$
N_t = population at time t N_{eq} = population abundance at equilibrium N_0 = population at time 0 r = recovery capacity in current approach d = sensitivity in current approach t = time t (duration)		

The rate of depletion (*d*) is then calculated as

Equation 9	rate of depletion *d*=	$d = \ln\left(\frac{K}{K-S}\right)$
S = sensitivity *d* = rate of depletion K = carrying capacity (maximum abundance).		

Where S is the sensitivity estimated as the annual proportion depletion (%) of an ecosystem component relative to undisturbed (= K).

To calculate the rate of recovery (r) the assumption was that, at least for fish, the abundance of a sustainably exploited stock is about half of its undisturbed abundance and assumed a recovery rate that would increase the ecosystem components from an N_0=0.5K (i.e. half of undisturbed) to an N_t=0.99K in the time in years t given by the Resilience score from Knights et al (2015) and assuming d=0 (Equation *10*)

Equation 10	rate of recovery (r)	$r = \frac{1}{Resilience} \ln\left(\frac{N_0}{K - N_t}\right)$
N_t = population at time t N_0 = population at time 0 K = carrying capacity (maximum abundance).		

Now EP can be calculated as the equilibrium abundance that emerges if a specific ecosystem component with known resilience and specific resistance to a pressure is exposed to that pressure, i.e. the PL proportion (%) caused by a specific action, resulting in an impact.

Equation 11	Effect Potential (EP)	$EP = PL * \frac{N_{eq}}{K} = PL * \frac{r}{r+d}$
PL = Pressure load (%) r = recovery rate d = depletion rate N_{eq} = population abundance at equilibrium K = carrying capacity (maximum abundance: 100%).		

Rewritten to sensitivity and recovery potential

Equation 12	Effect Potential (EP)	$EP = 100 * PL * \left(1 - \left(\frac{\frac{\ln\left(\frac{50}{100-99}\right)}{RP}}{\ln\left(\frac{100}{100-S}\right) + \frac{\ln\left(\frac{50}{100-99}\right)}{RP}}\right)\right)$
PL = Pressure load (%) RP = Recovery Potential S = Sensitivity		

=100*X3*(1-(LN(50/(100-99))/Z3/(LN(100/(100-Y3))+LN(50/(100-99))/Z3)))

5.4 VULNERABILITY

Ultimately for each causal relationship, i.e. impact chain, the vulnerability of an ecosystem component to the pressure caused by a specific action needs to be assessed. The aggregated vulnerability across all causal chains is then the basis to guide ecosystem-based management and Blue growth strategies.

Vulnerability is now calculated as Exposure* Effect Potential which is considered to capture best the translation of how each of the vulnerability aspects contribute to the overall concept. Both Exposure and Effect Potential are calculated such that they give a value 0-100%.

- For Exposure this then reflects the proportion (%) of the ecosystem component that is potentially perturbed by the pressure. In case of quantitative information on a spatial grid it is the proportion surface area of the spatial grid cells in which both the pressure and ecosystem component occur.
- For the Effect Potential (EP) this represents the proportion (%) of the ecosystem component that is actually perturbed to a level where its contribution to ecosystem integrity and functioning is compromised. For each grid cell where both the ecosystem component and pressure occur this is the % abundance (numbers, biomass) of that ecosystem component relative to undisturbed.

For each pressure-ecosystem component combination this should then always result in a vulnerability value 0-100%. However, when aggregating across all pressures in order to perform a CEA an overall vulnerability >100% may occur. This implies that across the entire study area, the cumulative effects may potentially result in the local extirpation of this ecosystem component but not necessarily the overall extirpation as this is the result of several pressures that differ in their overlap with the ecosystem component.

An alternative explanation is that the current interpretation of how the (sometimes modified) category scores should be used to assess Exposure and/or Effect Potential does not agree with the initial expert judgement. This, then, requires a check of the appropriateness of the initial expert judgement categories.

For the calculation of vulnerability, a requirement is that it needs to be understandable in a "real life" context as the iCEA results need to be communicated to the decision-makers. Another reason would be that at some point we should be able to replace these scores with something we have actually measured. Previously the type of risk assessments that are now at the basis of this iCEA assessed the "likelihood of an adverse ecological impact" and hence the "risk that policy objectives are not achieved" (Knights et al., 2015) (Piet et al., 2015) but it was unclear how to interpret this in ecologically meaningful terms. The advantage is now that with the current interpretation of Exposure and EP as these were used in the risk assessments, we now have a more tangible notion of what this risk actually represents. For a single impact chain vulnerability represents the risk that the abundance of a particular ecosystem component decreases by a certain proportion (%) due to a particular action-pressure combination. Similarly, the aggregation of vulnerabilities across causal chains represents the risk that the status and functioning of the overall ecosystem and its components is reduced by a certain proportion (%). The current qualitative Exposure scores are already reasonably aligned to the actual calculation of Exposure if information on the spatial distribution of components, activities and/or pressures is available. For the EP scores it is not that obvious but once sufficient causal chains become available with both qualitative and quantitative information then a validation exercise becomes possible.

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7 GLOSSARY OF TERMS

Table 9 Glossary of Terms and definitions used in an integrated Cumulative Effects Assessment (iCEA) in the context of UNITED

Activity	A defined project or business within a sector, with the aim of the production of goods and services, in general regarded as single-use.
Action	A clearly defined process or movement to which pressures can be unambiguously assigned to, derived from an activity.
Cumulative effect	the incremental impact of the action when added to the other past, present and reasonably foreseeable actions
Cumulative Effects Assessment (CEA)	A systematic procedure for identifying and evaluating the meaningfulness of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures. The analysis of the causes (source of pressures and effects), pathways and consequences of these effects on receptors is an essential and integral part of the process.
Ecosystem Component	Ecologically coherent elements of an ecosystem, that group together more disparate taxonomic groups into the minimum number of elements, based on the view that the lower the number of elements, the easier it is to gain a coherent and integrated assessment across the ecosystem.
Effect	A change caused by a pressure that is a departure from a baseline condition. An effect can be positive or negative.
Exposure	The contact of ecosystem components with chemical, physical, or biologic pressures over space and time.
Impact chain	Pathway linking action-pressure-ecosystem component that causes the specific impact.
Impact	A meaningful effect that reflects a change whose direction, magnitude and/or duration is sufficient to have consequences in comparison with the baseline condition. Like an effect, an impact can be positive or negative.
Linkage Framework	The combination of all the possible linkages through which the action may have an effect on the receptor. Each linkage is called an impact chain.
Magnitude	The (measurable) level or concentration of the pressure which is quantitatively and casually linked to the direct or indirect effects on the receptor.
Meaningful	Relevant in a broader setting, with consequences for the future; often used with effects or impacts
Persistence	Length of time that a pressure is able to remain in the environment after being introduced into it.
Phase	A temporal dimension of the activity indicating a specific process of the activity; e.g. installation, operation, decommissioning

Pressure	The mechanism through which an action has an effect on any part of the ecosystem. Pressures can be physical, chemical or biological.
Receptor	Physical (beaches, sandbanks, mudflats), ecological (ecosystem components, e.g. fish, birds, mammals, plants), economic (tourism, business) or social/cultural (public enjoyment of open space) entities which are susceptible to the pressures under investigation.
Recovery	The return of an ecosystem component towards its baseline state as the pressure is relaxed.
Resilience	The ability of an ecosystem component to return to its baseline state after being disturbed.
Risk	A function of exposure and effect which is more appropriate when an assessment of on-going (current) pressure is needed.
Risk Assessment	A methodology to determine the nature and extent of risk by analysing potential pressures and evaluating existing conditions of vulnerability that together could potentially harm exposed ecosystem components.
Scale	The spatial, temporal, quantitative or analytic dimension to measure and study objects and processes. Accordingly, scale is dependent on the extent (magnitude of dimension) and grain/resolution (precision in measurement).
Sector	A business that exploits the same or related product or service provided by the marine environment.
Sensitivity	The level of impact on a receptor caused by a pressure, mostly used in comparison to other pressures.
Spatial extent	The extent and distribution of the pressure from an action with the aim to determine its overlap (in time and space) with a particular ecosystem component (for which its spatial extent is also identified).

Table 10: Ecosystem components (headline ecosystem components in bold) used in the AQUACROSS project (gathered by Stelzenmüller et al. (2019, S) and ICES (in prep., I, explanations)

Mobile species	Explanation and examples by I	
Seabirds	Birds that are adapted to life within the marine environment, spending most of their time at sea and sourcing all or most of their food from the marine environment.	I
Fish	Limbless cold-blooded vertebrate animals with gills and fins living wholly in water. This includes both bony fish and elasmobranchs	S, I
Cephalopods	Any member of the class Cephalopoda, such as a squid, octopus, cuttlefish, or nautilus; characterised by bilateral body symmetry, a prominent head, and a set of arms or tentacle.	S, I
Marine mammals	A mammal that lives in marine, or in some cases, an aquatic environment and obtains all or most of its food there.	I
Reptiles	Cold-blooded air-breathing vertebrates which have epidermal scales covering part or all of their body. Includes marine turtles.	

Habitats		
Benthic habitat (and associated biota)	An ecological or environmental area inhabited by one or more living species. The ecosystem component also includes all benthos - the flora and fauna found on the bottom, or in the bottom sediments, of the sea not listed separately above.	I
Pelagic habitat (and associated biota)	An ecological or environmental area inhabited by one or more living species. The ecosystem component also includes plankton – small organisms that float or drift in great numbers in bodies of salt or freshwater. Includes zooplankton (including jellyfish) and phytoplankton, but does not include species groups listed separately above.	I
Ice habitat (and associated biota)	Habitat associated with ice. The ecosystem component also includes closely associated biota, both invertebrates and vertebrates other than those listed separately above.	I
Atlantic and Mediterranean moderate energy circalittoral rock		S
Pelagic water column		S
Sublittoral coarse sediment		S
Sublittoral mixed sediments		S
Sublittoral mud		S
Sublittoral sand		S

Table 11. Resilience scores for the North-East Atlantic (NEA) from Knights et al (2015). These scores are supposed to reflect the time in years it takes to recover from an impact.

Ecosystem component	**Resilience**	**Resilience score**
Littoral rock and other hard substrata	High	1
Littoral sediment		1
Pelagic water column		1
Circalittoral rock and other hard substrata	Moderate	6
Infralittoral rock and other hard substrata		6
Sublittoral sediment		6
Birds	Low	55
Deep-sea bed		55
Fish & Cephalopods		55
Mammals		55
Reptiles		55
	None	100

[1] Exposure Science in the 21st Century: A Vision and a Strategy (2012), National Academy of Sciences