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A Case – Study of Seaweed Cultivation

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Glossary and abbreviations

ES	Ecosystem Services, the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them.
Scoping phase	Part of a project where the research question is formulated and project needs and requirements are identified
DPSIR	Driver Pressure State Impact Response, a framework to provide a structure within which to present the indicators needed to enable feedback to policy
OWF	Offshore Wind Farms
NCP	Dutch continental shelf (Nederlands Continentaal Plat)
Saccharina latissima	Seaweed species, Sugar kelp
Ecosystem Components	Subsections of the ecosystem, such as functional groups of species (e.g. marine mammals) or ecosystem types (e.g. seaweed beds)
Pressures	The introduction of anthropogenic changes to the system that can affect the ecosystem
Cascading effects	An unforeseen chain of events that occurs when human generated pressures lead to events in a system that have a negative/positive impact on other, related systems
Impact Cascade	Cascading effects that form impacts to ecosystem services
Rubric tool	Typically an evaluation tool in education, a set of guidelines used to promote the consistent application of learning expectations, learning objectives. Here used as a guideline to form explicit choices in ES assessment frameworks
Impact	Any change to the environment, whether adverse or beneficial, resulting from a facility's activities, products, or services. In other words it is the effect that people's actions have on the environment.
ODEMM	Options for Delivering Ecosystem-Based Marine Management. This can be considered a precursor for the Aquacross project.
Framework Design	process of establishing an ecosystem service assessment methodology fit to a case study, including such aspects as defining the scope and the methodology for analysing impact cascades.
Scope	Part of the Rubric design phase where the temporal and spatial scale of the project is assessed, and in which measure some pressures are considered in the project.
SWF	Seaweed Farming Framework
Bottom-up	Unpublished draft conceptual ecosystem service assessment framework designed from scratch by Gerben IJntema to foster initial insights in ecosystem services effect cascades.
Top-down	Conceptual framework modified from the existing Aquacross framework.

Summary

With the growing ambitions of implementing low trophic aquaculture, a framework for cohesive and balanced assessment of effects resulting from seaweed cultivation was performed for a hypothetical case study in 2021. As, traditionally, such assessments tend to focus on the negative impacts, it was recommended to also assess the benefits from seaweed cultivation. The concept of 'Ecosystem services' (ES) is a sensible construct to express such benefits, as it focuses on the benefits supplied by the ecosystem.

The goal of the present study is investigating how these ecosystem services can be included in the comprehensive framework developed last year for a seaweed cultivation case. In order to achieve this, we specifically looked at the project design process, how to map the project needs and how to select or develop the instruments to meet those needs. Roughly, three phases can be distinguished in the study design process: the ideal design phase, where the project specifications required to fulfil the goal of an assessment are defined to ensure the most comprehensive assessment; the realistic design phase, where one performs a reality check on the ideal design, where practical issues, technical issues and resource availability are considered; and finally an adaptive phase: the phase where modifications are made resulting from new insights.

In order to facilitate the study design process we developed and applied a so-called 'rubric' tool. This rubric is a questionnaire that scores a wide range of elements that are relevant when evaluating ecosystem services for one or more activities (such as seaweed cultivation). This questionnaire considers and addresses elements of ecosystem services impact assessments grouped in the following three aspects:

- Which elements are relevant and considered for the study?
- What level of detail is required (for these elements)?
- How to quantify ES and process the data?

Each sub-question in the rubric is answered with a score between 0 and 5 (where the scale is arbitrary). In the present study, the questionnaire is applied to the case-study goals. But also two contrasting strategies (i.e. application of top-down versus bottom-up methodologies) are included as examples and are evaluated with the rubric for suitability. The top-down strategy uses an existing framework from the EU project Aquacross, which was also used last year to address seaweed cultivation impacts. This framework uses linear cause-effect chains where effects on the ecosystem components are linked to the capacity to supply ecosystem services. The bottom-up methodology is formulated from scratch. It focuses more on the desired outcome, and more attention is paid to benefits resulting from the activities (rather than impacts). Feedback mechanisms are also considered. It should be noted that both methodologies are only available as concepts and are not yet operational.

By applying the rubric to both set case-study goals (including ecosystem services in an assessment of the effects from seaweed cultivation) and the proposed methodologies, both results could be compared. It is shown that neither of the two strategies have a 100% match with the case-study goals. This means that neither methodology is preferable at the moment. Also, this means that the methodologies need to be adjusted or the case-study goals need to be revised. In order to make informed decisions on how to proceed in this process a final piece of the puzzle is still missing, which unfortunately is beyond the scope of the present study.

The missing puzzle piece is 'consequences'. The rubric approach had helped in structuring the project design phase and support underpinning discussions. It made insightful what the study intentions are, and what the proposed methodologies can and cannot offer. It also shows that there is a mismatch between the ideal design and the realistic design. In order to decide which changes (in either case-study goals or strategies to include ecosystem services) are necessary, it is required to know the consequences of these decisions. Several recommendations are made to generalize the assessment of

these consequences by linking case-study goals to requirements and their feasibility. This is not further developed in the present study.

In conclusion, the rubric approach can be used to score the capacity and limitations of methodological strategy (such as the top-down and bottom-up strategy evaluated here) on one hand and the improve specifications of requirements for a specific case or project on the other hand. As such the approach can be used to evaluate different methodologies, to determine which strategy is most suitable for a specific research question. The approach can also be used to refine research questions or identifying knowledge and data gaps in an early stage of a project. In addition, the approach can be used iteratively during a project execution to manage and adjust the project requirements (and indirectly stakeholder expectations of the project). As such the approach is suitable in each of the three identified study design phases (targeted design, realistic design, adaptive design).

In its current form the rubric approach shows promise, but is not yet able to fully support study design choices for evaluating ecosystem services from the seaweed cultivation case from Tonk et al. (2021). For that purpose the approach needs to be extended such that it addresses consequences of design choices, for which recommendations are made.

1 Introduction

1.1 Ecosystem services

The marine environment is a complex system, comprising many ecological components, habitats and (natural) resources. In the North Sea as many other marine waters, these resources are exploited, which can affect the (ecological) system and the services it provides.

Being aware that human activities can affect the ecosystem, such activities are often assessed for their effects. Traditionally, the focus of such assessments is on the impacts that human activities cause on the ecosystem through the pressures (such as littering, noise, pollution, etc.). This perspective, however, fails to recognize the benefits of such activities, but also how the impacts affect the ecosystem capacity to supply services. Ecosystem services are defined as (in)direct advantages that people can get out of an ecosystem (Beaumont, N., et al. 2007). These services can be split into Regulating, Supporting, Cultural or Provisioning services. It is important to note that these services should be regarded as either final ecosystem services (provisioning, regulating and cultural), providing direct benefits to humans or supporting ecosystem capacity (supporting underlying ecosystem functioning, eventually leading to effects on the capacity to supply final ecosystem services). For seaweed cultivation the direct produce of seaweed is for example a food production (provisioning service), while other ecosystem functions of seaweed can be biodiversity enhancement (supporting ecosystem capacity) and carbon sequestration (regulating service) (Hasselstrom et al., 2018). Nonetheless, seaweed cultivation can also have a negative impact. For instance when seaweed production is too high, competition for nutrients may take place with naturally occurring seaweed, seagrass or microalgae thereby impacting biodiversity but also other forms of seafood provisioning such as fisheries. The cultivation system itself, which consists of a combination of lines and buoys anchored to the seafloor can enhance biodiversity by providing additional habitat. However, the system may also attract invasive species or act as a physical barrier to species movement and therefore have a negative effect on the environment.

This is why the capacity to supply Ecosystem Services (ES) should also be considered in the assessment of effects of human activities. The literature currently focuses on indicators for specific ESs (Von Thenen et al., 2021; Galparsoro et al., 2021). Although helpful and meaningful, they do not address the need for an integrated evaluation of the system as a whole. This is currently being addressed in separate studies (Maes et al., 2016).

1.2 Problem definition and research question

As illustrated above, the marine environment and the evaluation of its capacity to supply services including potential negative impacts of human activities needs to be complemented with a consideration of positive and indirect effects of these activities beyond the intended provisioning of seafood. To that end, the scoping phase (where the research question is formulated and project needs and requirements are identified) is crucial in any new initiative. A structured strategy for scoping is key, which is currently lacking. The present study therefore addresses the following main research question: How should a framework for assessing ecosystem services be designed for the seaweed cultivation case from Tonk et al. (2021), where positive indirect effects of human activities are present? The focus of the present report is thus on the evaluation of study designs and corresponding methodological strategies for achieving a comprehensive assessment of ecosystem services. The tools are only described conceptually here. Their actual development, or application could be taken up in follow-up studies.

More specifically, this results in the following sub-questions:

1. What is a general conceptual structure of a framework to assess ecosystem services?
2. What should be considered when designing a framework to assess ecosystem services?
3. What would be the desired form of the outcomes of question 2) for the seaweed cultivation case?
4. Which of the outcomes of question 2) are of more or less importance in the seaweed cultivation case?
5. What form do the outcomes of question 2) take in other (if any exist) frameworks assessing ecosystem services?
6. Evaluating the similarities and differences of the seaweed case and existing frameworks, does an existing framework already provide a good enough fit to the seaweed case?
7. If, not what would be a realistic framework design for the seaweed cultivation case?

2 Materials and Methods

2.1 Outline

A case-study is required as a starting point and to formulate a research question. The case-study is used as a practical example to test the approach developed in the present study, the case study is based on principles first developed in the Aquacross project and further applied in the study of Tonk et al., 2021. The case study entails seaweed cultivation as an activity to evaluate affected ESs. The case study is described in more detail in section 2.3.

In order to identify and evaluate the case-study requirements and needs (i.e., scoping), we applied a so-called 'Rubric' tool. This Rubric scores individual aspects associated with the design of the case study, including the scope, the level of detail and how the desired outcome (e.g. indicators) needs to be qualified or quantified. This framework is described in more detail in section **Error! Reference source not found.**.

Two contrasting hypothetical methodological strategies (top-down and bottom-up) are introduced as an example as there are no 'off the shelve' methods for holistically evaluating consequences to ES emanating from an activity. Both are described in section 2.5.

These two ES strategies are evaluated using the Rubric to qualify their capabilities. The rubric is also applied to the case-study in order to identify its needs and requirements. Finally, the two ES strategies are compared, in order to identify which is best suited for the case-studies need.

It is important to note that the ES strategies are not (yet) developed, which is beyond the scope of this project. Here they are only described conceptually. The same is true for the case-study, which is only described conceptually; the actual consequences for the supply of ESs are not addressed in the present study.

2.2 General Form of an Ecosystem Service Assessment framework

In this study, we define an overarching generic form of ecosystem service impact chains. We define five different discrete steps that may or may not be included in assessments: Human Activities, Pressures, Ecosystem Components, Final Ecosystem Services and Supporting Ecosystem Capacity.

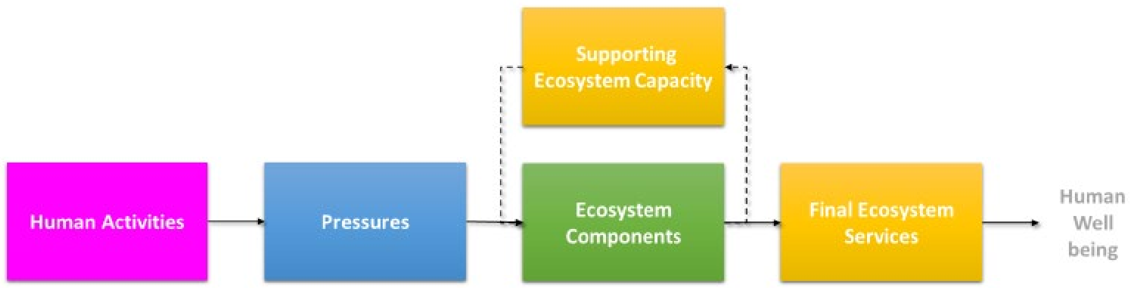


Figure 1: Most Generic Form of Impact Cascades in Ecosystem Services Assessment Frameworks

Human Activities cause the impacts on the ecosystem and pressures are the mechanisms through which this occurs; such modifications can affect the ecosystem and its components which can either be considered (negative) impacts or (positive) benefits in terms of their contribution to human well-being. Ecosystem Components are defined as subsections of the ecosystem consisting of mobile species (e.g. marine mammals) or habitats (e.g. seaweed beds). The Ecosystem Components are the suppliers of Ecosystem Services, the benefits of nature to human well-being. Human well-being is beyond the scope of this study and not further considered. Supporting Ecosystem Capacity is different from final ecosystem services in that it may enhance the ecosystem components which, in turn, contributes to ES (MEA, 2005; Potschin et al., 2011;2016). Potential impacts by human activities are then assessed by considering direct and indirect pathways identified in the impact cascades (see figure 1).

2.3 Application of the Rubric to evaluate framework design

In this section we present a newly developed Rubric assessment tool for designing and evaluating ecosystem service assessment frameworks. The goal of the tool is to provide widely applicable and clear guidelines in the form of explicit choices that have to be made or identified in ecosystem service assessment frameworks. The section starts with a description of the Rubric tool, then we describe how the Rubric tool made can be applied in projects that aim to develop and execute an ecosystem service assessment and we describe how the tool can be used to compare the choices in different (existing) ecosystem services assessment frameworks and enable the user to systematically compare the limitations and choices of ecosystem service assessment frameworks.

2.3.1 Description of the Rubric

At the core of the Rubric tool is the aim to make the choices made in designing an ecosystem service assessment explicit. In doing so, we identified three design aspects in building an Ecosystem Service Assessment Framework, each requiring explicit choices in terms of:

- Scope
- Level of Detail
- Impact Cascades

And a set of design elements that may have to be addressed in (some of) the study design aspects, based on the discrete parts of the generic ecosystem service assessment framework outlined in the sections in section 2.2 above, expanded with other relevant elements.

- Human Activities
- Pressures
- Supporting Ecosystem Capacity
- Ecosystem Components
- Final Ecosystem Services
- Spatial resolution
- Temporal resolution
- Impact Cascade

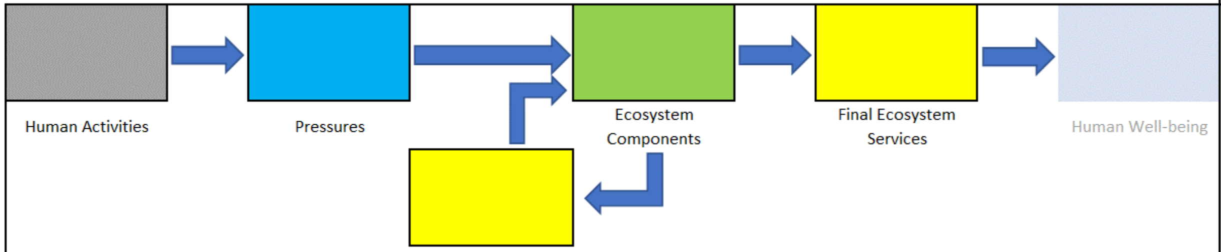
Each of the elements mentioned above will have to be addressed in one or more of the design aspects as outlined in table 1 below.

Next we make the choices comparable between the different choices that can be made in the case study by defining a semi-quantitative scale (0-5) for each element, inspired by the widely used Rubric assessment tools in education. It should be noted that this score doesn’t reflect any value judgments (i.e., whether a scored element is either good or bad), it merely reflects in which end of a spectrum a specific aspect lies. This will become more clear in the results where the specific scored aspects are presented and discussed.

The scales were defined based on the design choices made in a small initial set of ecosystem services assessment frameworks (Potschin & Haines-Young, 2011;2016;de Vries et al, 2012; Borgwardt et al. (2019); Everard and Waters, 2013; Robinson et al. 2014; Culhane et al., 2018;2019; Hasselström et al. 2018; Schep, IJntema & van Beukering, 2021), environmental impact assessments (Knights et al., 2015; Judd, Backhaus & Goodsir, 2015; Tamis et al., 2015; Piet et al., 2017a; 2017b;2019; Borgwardt et al., 2019; Tonk et al. 2021) and, finally, classification schemes in both Ecosystem Services (Potschin et al., 2018; MEA) and environmental impacts (AQUACROSS classification: Borgwardt et al., 2019). The full 'Rubric' containing all identified choices made explicit and the scales to score the choices by is added in Appendix 1.

By scoring each aspect for different frameworks according to description given in the scales of the rubric, any assessment design is incentivised to explicitly consider all choices already in the design phase, making the user aware of all relevant choices and making the resulting framework easily comparable with other frameworks.

Table 1: Overview of the questions asked in the rubric tool in every section on every aspect of the design of the rubric. On the horizontal axis the different elements of the general form of an ecosystem services assessment framework (section 2.2 above) and several additional elements are represented. On the vertical axis the tree main aspects when designing an ecosystem services assessment framework are represented (what is the scope, how detailed is the assessment and how are the impacts/ results quantified . For the full set of questions and the associated scales, see the full Rubric in ANNEX 1.



	Human Activities	Pressures	Supporting Ecosystem Capacity	Ecosystem Components	Final Ecosystem Services	Human Well-being	Spatial Components	Temporal Components	Cascade Linkages
Scope	What Human Activities does the Assessment include?	What Pressures does the Assessment include?	How does the Assessment include feedbacks?	What Ecosystem Components does the Assessment include?	What Ecosystem Services does the Assessment include?		What is the Spatial scope of the assessment in 2D? What is the Spatial scope of the assessment over the vertical axis?	What is the Temporal Scope of the assessment?	How does the Assessment include feedbacks?
Level of Detail Considered	To what level are the human activities disaggregated in the assessment?	To what level are the Pressures disaggregated in the Assessment?		To what level are the ecosystem components disaggregated in the assessment? To what extent are ecosystem services composed of interactive subparts?	To what level are the ecosystem services disaggregated in the assessment?		What is the Spatial resolution of the Assessment in 2D? What is the Spatial Resolution of the assessment over the vertical axis?	What is the Temporal Resolution of the Assessment?	NA
Consequences of Impact Cascades	NA	NA		NA	NA		How is spatial overlap (in 2D) considered in the assessment? How is spatial overlap over the vertical axis considered in the assessment?	How is temporal overlap considered in the assessment?	How are the cascades of effects included (qualitative, (semi) quantitative etc.)?

2.3.2 Applying the Rubric to design a best-fit ecosystem service assessment framework

In this section we present the possible use for the rubric tool in designing an ecosystem service assessment framework. In the design of ecosystem service assessments the Rubric tool can be used in three different phases (see figure 2) while executing ecosystem service assessments to answer three core design questions:

1. *What would be the **ideal** framework to assess the Ecosystem Services in the considered case study? (Ideal design): What do we want in the considered ecosystem service assessment?*
2. *What would be a **realistic** framework to assess the Ecosystem Services in the considered case study? (Realistic design): What is possible to assess the Ecosystem Services in the considered case study?*
3. *How should the current ecosystem service assessment framework **be adapted** to preliminary findings and/or methodological insights arising during the assessment? (Adaptive design): How can we further improve on assessing the Ecosystem Services in the considered case study?*

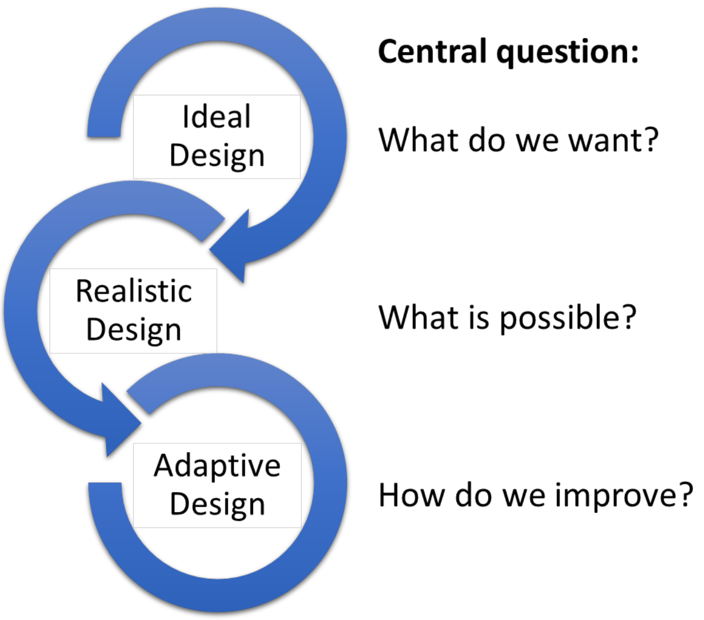


Figure 2: Overview of the different design phases for developing an ecosystem service assessment framework: What framework would be ideal? (ideal design); What framework is possible (in advance) (realistic design)?; what framework is possible given the insights gained during the application of the framework (adaptive design)?

The first question relates to defining the Ideal design for a considered case study. In this case we define the ideal framework design. This is the design that will be best able to ensure the goal of an assessment is met. This design phase is focused on the mental modal of the framework and design choices without being inhibited by practical constraints. By using the rubric tool the user is forced to make design choices explicit and reveal consequential requirements.

The second question (realistic design) is then assessed to go from an ideal framework design to a framework assumed to be realistically possible, through considering practical constraints. In this phase, practical trade-offs on matters such as available time, management complexity or constraints,

data availability and biological robustness are identified. Here, the choices made in the ideal design phase can be seen as 'dials on a dashboard' to turn until a realistically feasible framework design emerges. For example, if time constraints are an issue, an analysis can apply available data on a more coarsely defined spatial grid to cut time needed for the analysis.
An additional step in tackling design trade-offs can include the weighting of the design choices as defined through the rubric tool. In this study it was chosen to assign each design choice a relative score on a scale from 1 to 5 (with 1 indicating the exact form of a specific design aspect is less relevant to analyse the case, while 5 indicates any proper analysis of the case requires the design to specifically include the design aspect in the exact form defined by the score given). Based on the relative importance assigned the user can then identify what design aspects can be adjusted to fit a more realistic framework design. If for instance a specific case study requires an increased spatial resolution (e.g. <1km^2 grid cells), but could do with lesser temporal resolution (e.g. data collection at yearly instead of monthly or weekly intervals), then the latter choice can be more easily adjusted than the former. Based on the combination of identified trade-offs and weightings, the framework design can then be adapted to a framework that is still close to a target design, but is now realistic to apply.
Another way to find a realistic design, as employed in this study (section 2.5), is by using the rubric to chart the choices in existing frameworks, which can then be compared to the (weighted) choices in the target design to see if existing frameworks (in development) may already provide a sufficient fit to the case study requirements.

The third question (adaptive design) becomes relevant when the ecosystem service assessment is already being executed. The adaptive design phase runs parallel with the actual analysis in the sense that any practical or methodological concerns and insights acquired whilst performing the analysis can be used to adapt the framework to what is more realistic. The adaptive design phase repeats (parts of) the ideal and/or realistic design phases using the acquired insights on practical design trade-offs gained while executing the analysis. While the ideal design and the realistic design phase are only applied once before starting the analysis, the adaptive design phase is intended to be applied as many times as needed to revise the design of the framework during the ecosystem services assessment.

The analysis in this report is limited to the ideal and realistic design phase, as the execution of an ecosystem service assessment is beyond the scope of this report.

2.4 Case study: seaweed cultivation

In a previous effort a conceptual framework to map potential ecosystem impacts caused by seaweed farms was developed based on a DPSIR (driver, pressure, state, impact, response) approach to describe the activities related to seaweed farming (drivers) and the potential impacts that apply to the different ecosystem components involved (Tonk et al., 2021). A case study of 500 km^2 seaweed cultivation area assumed evenly spread over offshore windfarm (OWF) areas in the Dutch part of the North Sea (NCP, Dutch continental shelf) was used to prioritize risks and identify knowledge gaps based on a combination of expert judgement and available data (Tonk et al., 2021). The 631 impact chains were used in the risk assessment based on expert judgement of six aspects of risk (spatial extent, dispersal, frequency, persistence, severity and resilience) to identify knowledge gaps. One of the recommendations from the previous framework was to investigate the inclusion of ecosystem services into the impact assessment and demonstrate potential benefits from the services compared to negative impacts from the same activity so as to provide a more comprehensive assessment of low trophic aquaculture (Tonk et al., 2021). In this follow-up effort to include ecosystem services the same case study is used.

The area of interest for the impact assessment is the total NCP area (60.000 km^2). The case study area is based on the total potential seaweed cultivation in 25% of the current Dutch OWFs (approx. 2000 km^2). As seaweed farming in the North Sea is currently still in a start-up phase, a case study at a much smaller scale (1-6 km^2) is perhaps more appropriate from a business-case point of view. However, the case study of 500 km^2 was chosen assumed to represent seaweed farming at a larger scale, a scenario that can be expected to include all relevant impact chains.

The following assumptions are made:

1) The seaweed farming area of 500 km^2 is equally divided over currently operational OWF's on the Dutch continental shelf (5 OWF's, total distance from the coast is 166.2 km, Table 15).
2) The area of interest for the impact assessment is the total NCP area (60.000 km^2).
3) The time period chosen is 5 years, according to the time frame after which seaweed farming structures need to be renewed.
4) The amount of shipping movements involved depends on various factors, such as the size of the ship, the type of cultivating system, whether the system can be left over summer etc. Assumptions are based on activities per km^2 seaweed farm using ships with capacity for deployment of 0.02 km^2 (2 hectare) cultivation system per ship per day (Table 16). However, considering the large scale of the case study the use of larger ships or a floating platform to reduce shipping movements is recommended.
5) Assumptions concerning the distribution of the various ecosystem components involved are stated in Table 17.
6) For the dispersal criterium 'local' is defined as 4x the seaweed farm size (total 2000 km^2)
7) The seaweed species *Saccharina latissima* (sugar kelp), is one of the main cultivated species in Europe and therefore used in this case study.
8) The case study applies the most commonly practiced seaweed cultivation system of longline systems, with use of droppers for inoculation.

Note that in the present study the assumptions listed above are not assessed by themselves, but are used to design frameworks for assessing the effect on Ecosystem Services for this case study. Two different strategy are applied as described in section 2.5. Both of these strategy are evaluated for their appropriateness using the 'Rubric' as described in section 2.3.

2.5 Methodological strategies for evaluating Ecosystem Services

In developing a potential framework to assess ecosystem services for the seaweed cultivation two separate frameworks were considered, as examples of employing different design strategies. Firstly, a top-down strategy was applied by modifying an existing framework. For this purpose a framework based on the AQUACROSS approach that was adopted and is further developed at Wageningen Marine Research and its potential performance in the seaweed cultivation case was evaluated. Secondly, a bottom-up strategy was applied. This was done by drafting conceptual framework from scratch, focusing on the case study needs.
This section aims to introduce both strategies and resulting frameworks more into detail.

2.5.1 Top-down strategy

Aquacross was an EU research project which was originally designed to implement ecosystem based management of freshwater, coastal and marine ecosystems (Borgwardt et al., 2019). It adopted a network of cause effect chains, where the impact on ecosystem components was the end-point. The network uses three different types of 'nodes': 'Human activities', 'Pressures' and 'Ecosystem components' which represent the flow from cause to effect. These relationships are assumed to be direct and linear, meaning that that the information can only flow in a single direction (from cause towards effect and not backwards) and that there are no feedback mechanisms considered.

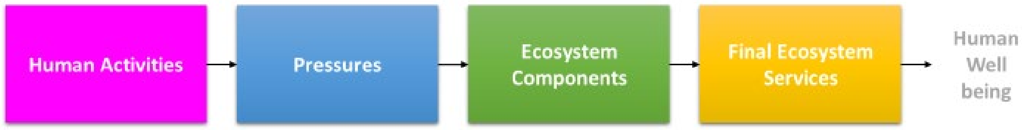


Figure 3: Linear cascades in Ecosystem Service Assessment as they are represented in the top-down strategy

The Aquacross project was set up to include all relevant human activities, their resulting pressures and impacts to all relevant ecosystem components by applying a cumulative impact assessment (CIA). As such, the CIA approach required a high level of aggregation of information in order to represent all causal impact chains.

Aquacross makes use of a linkage framework from Borgwardt et al. (2019) which contains 7771 causal impact chains for the North Sea. These are all semi-quantitatively assessed using (scientific) knowledge from literature supplemented by expert judgement by a large team of international experts. This assessment was based on five qualitative aspects: extent, dispersal, frequency, persistence, and severity (Borgwardt et al., 2019). This can be supplemented with an additional criterion, i.e. resilience (Knights et al., 2015), or further elaborated using other aspects, e.g. magnitude or hazard, and is currently being developed as part of the ICES WGCEAM (Working Group on the use of Cumulative Effects Assessments for Management) (Piet et al., in prep).

The endpoint in this framework is impact risk, which is calculated through a risk assessment of the potential impact on ecosystem components as the combination of two aspects of risk, i.e. exposure and potential effect, where the exposure is based on: The area of the activity (Extent); Potential spreading of the related pressures (Dispersion); Relative contribution of the activity to the related pressures (Pload). The potential effect is based on: The sensitivity of the ecosystem component to the pressures (Severity); The number of times the activity interacts with an ecosystem component (Frequency); The recovery time of the ecosystem component (Resilience); The length of time it would take for the pressure to disappear after cessation of the activity(s) causing the particular pressure (Persistence).

The current CIA approach currently does neither address nor consider ecosystem services, as this was outside the scope of the original study. This approach is being adapted such that it can address ecosystem services (Piet et al. in prep.) but this is not used in the present study. The linear impact cascade strategy requires the ecosystem services to be directly linked to the providing ecosystem components. For this purpose information from Culhane et al. (2018) is used. They categorized ecosystem service indicators into provisioning, regulating, maintenance and cultural services according to CICES and linked those to biotic groups in specific habitats. By matching these biotic groups with the ecosystem components used in the CIA, the information can be combined.

Consequently, the extension of the linkage framework to include ecosystem services allows an assessment of which services are most at risk. In its current state of development the top-down strategy does not account for positive contributions to services: It only expresses risks formed by pressures to providing specific services by the ecosystem. It is possible to include such positive contributions, but it requires further modifications of/additions to the CIA framework. On a more philosophical note, one can wonder whether seaweed cultivation is the beneficiary party, benefiting from an ecosystem service (at least for food provisioning), rather than improving the conditions of the ecosystem to provide such services (supporting ecosystem capacity). This is not the case for supporting ecosystem capacity function such as biodiversity enhancement.

2.5.2 Bottom-up strategy

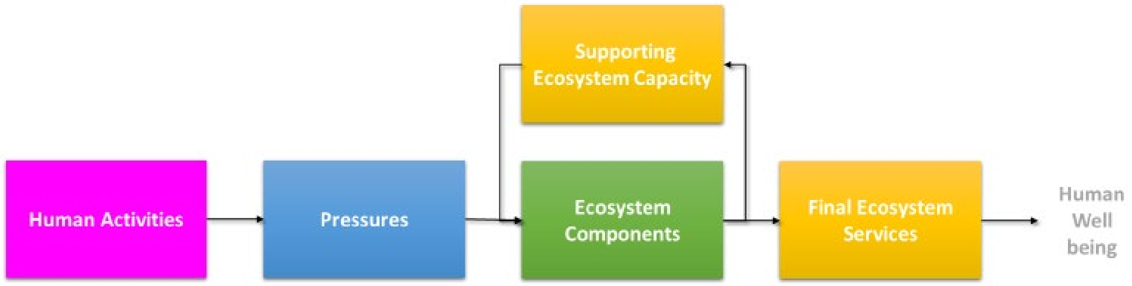


Figure 4: Feedback cascades in Ecosystem Service Assessment as they are represented in the bottom-up strategy.

In the present study the bottom-up strategy is used to design a framework as an extension of Tonk et al. (2021), as described in section 2.4. The goal of the draft framework here was to provide a more detailed, intricate understanding of the cumulative assessments of impacts on ecosystem services, specifically to chart the qualitative linkages with as much detail as possible. Following from the focus on the qualitative aspects of impact cascades the framework assumes the most detailed scales in the rubric when considering the discrete section of the basic generic impact cascade described in section 2.2, figure 1. What makes the framework unique is the extensive and explicit inclusion of feedback mechanisms (as supporting ecosystem capacity). As a result, the generic impact cascade structure consisting of Human Activities, Pressures, Ecosystem Components, Final Ecosystem Services and Feedbacks in the system is at the core of the approach. An important side note is that one of the main goals of this report is explicitly to identify limitations, trade-offs and other methodological concerns in designing an ecosystem services assessment framework. Therefore the draft framework presented in this section is specifically not tested on being realistically possible, remaining in the ideal design phase (see section 2.3.2). Whether or not the framework is realistic is part of the analysis in this study.

Feedbacks are explicitly and specifically included as Supporting Ecosystem Capacity, generated by Ecosystem Components, and modifying (other) ecosystem components (see figure 4 for a graphic overview). Whether such mechanisms are feasible to assess is addressed by the Rubric tool presented above. To clarify the abstract concepts presented here, we illustrate the process with two examples from Seaweed Cultivation:
The first example includes the installation of seaweed farms (Human Activity) which then creates new habitat (Supporting Ecosystem Capacity) for fish (ecosystem component), potentially leading to an increased supply of seafood (Provisioning Ecosystem Service) (suggested in Hasselström et al., 2018).

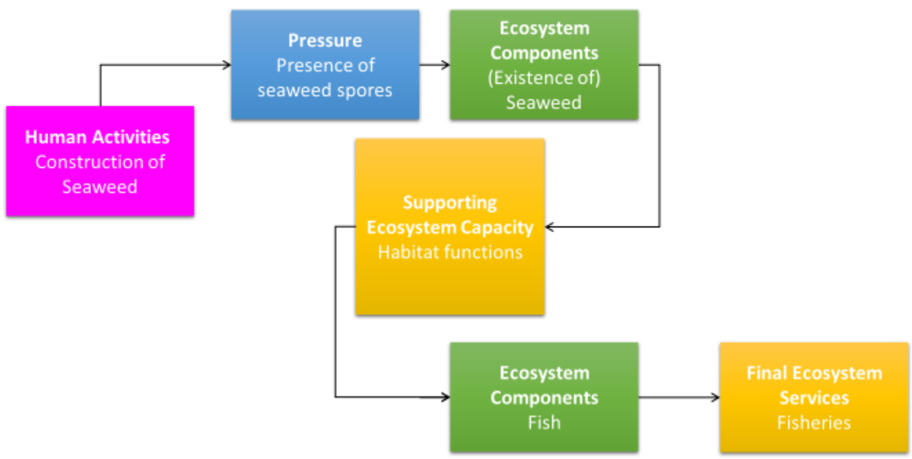


Figure 5: Example of a feedback cascade through a single feedback loop.

The second example describes the introduction of seaweed farms (Human Activity) changing the habitat into seaweed habitat (Ecosystem Component) that filters the water column and creates water clarity (Supporting Ecosystem Capacity), influencing the growth of photosynthetic primary production (Ecosystem Component) serving as food source (Supporting Ecosystem Capacity) for (commercial) fish species (Ecosystem Components) potentially modifying commercial fishing (Final Ecosystem Service) (suggested in Hasselstrom et al., 2018).

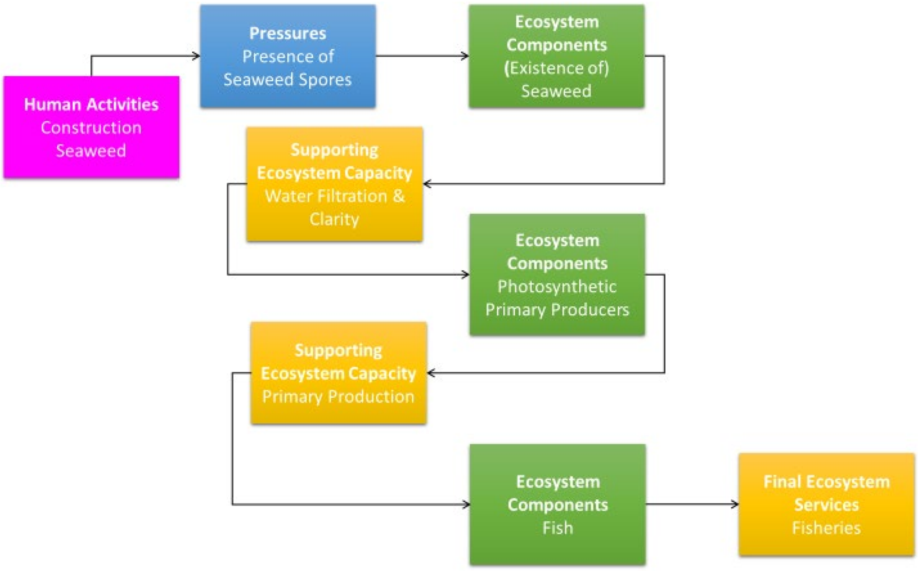


Figure 6: Example of an feedback Cascade through multiple feedback loops in an impact cascade.

3 Results

3.1 Study design phases

When designing an ecosystem services impact assessment several phases can be distinguished as depicted in figure 2.. In the present study we address several aspects of the first two phases (ideal design and realistic design). The realistic design is covered by focusing on the methodologies for quantifying or qualifying ecosystem services and what is possible from that perspective for which the results are presented in section 3.2. The ideal design is covered by using the case study described by Tonk et al. (2021) as a starting point and what ideally is required for addressing ecosystem services for that case. The latter is described in section 3.3.

3.2 Evaluation of methodological strategies

3.2.1 Top-down strategy

3.2.1.1 Scoping

As described in the methods section, the top-down strategy uses the CIA developed within Aquacross which is developed using a very wide scope. It covers a wide array of human activities, pressures, and ecosystem components. When compared with the case study requirements, the CIA approach would be suitable to make comparisons with other activities. The approach currently does neither include feedback mechanisms nor means to evaluate positive contributions to ecosystem services. This requires further modifications. Feedback mechanisms can only be included implicitly, and positive contributions require an expansion of the conceptual model.

3.2.1.2 Level of Detail / Resolution

As a result of the broad scope, the level of detail provided by the CIA in Aquacross is relatively low. Indeed the case study generally desires more details than the CIA strategy in Aquacross can offer. For instance in the CIA distinguishes are made between (industrial) sectors, whereas the in the case study phases of a specific subsector (seaweed cultivation) or even specific activities (e.g. shipping movements, harvesting, etc.) are distinguished. Hence, when the CIA strategy would be selected, either the method needs to be refined (requiring a lot of effort) or the expectations from the case study need to be tempered.

3.2.1.3 Quantification of (the Consequences of) Impacts

The CIA strategy used in Aquacross as is qualifies impacts on ecosystem components using a scoring system. This is currently being adapted to evaluate the risks posed to services provided by these ecosystem components. There are still challenges that need to be addressed in those updates, most importantly: how should the contributions of risks to the services be weighed. Another important aspect is that the case study also requires positive contributions to the services to be addressed (and not only the risks). This would require further modifications of the approach.

3.2.2 Bottom-up strategy

3.2.2.1 Scoping

The model is aimed as a case study of Seaweed Cultivation and therefore takes only the human activities related to a practice/collection of activities. However, all Pressures generated by the considered activities are included in the scope of the framework. There is no distinction on which ecosystem components are included and which are excluded, therefore the framework included all Ecosystem Components. Concerning the Ecosystem Services, the framework includes all ecosystem

frameworks that may be affected through the cascades originating from the selection of human activities. Regarding feedbacks, the framework is explicitly designed to include feedbacks as much as possible and therefore all indirect impact cascades are considered, no matter how many feedback loops have to be charted.
The geographical scope of the analysis is not defined and therefore is unlimited in the current draft of the framework over the horizontal axis (global). Over the vertical axis the scope is cut off below the benthos as the depth limit and the lower regions of the troposphere at the height limit. The temporal scope is (nigh) unlimited and therefore concerns any effect that may occur as a result of the human activities into the foreseeable future.

3.2.2.2 **Level of Detail / Resolution**

Following from being built on Tonk et al (2021), the framework considers human activities at a low disaggregation level, specifically on a level between individual activities executed and process phases (see figure 8 and ANNEX 1 for clarification) within the seaweed cultivation (e.g. the shipping of materials, building of structures and during construction are considered separately). In the Pressures, a similar very low disaggregation level was chosen to mirror the disaggregation of human activities into detail. Consequently, the Pressures are included in the level of detail of individual pressures (e.g. the presence of substance x in the environment rather than the total amount of pollutants, with x being 'lost synthetic fibre' rather than the more generic term 'litter' for example). For the Ecosystem Components, the framework considers a detailed level of functional species groups (e.g. plankton, fish, macroalgae and birds). The ecosystem components are not considered to be interacting (e.g. fish in seagrass is not a separate group from fish in pelagic columns). The benefits from Ecosystem services into society are considered at a level similar to (sub)sectors, such as, for example, benthic fisheries and nature tourism.
Since spatial effects are not within the scope of this framework, the framework considers no spatial resolution over neither the horizontal nor vertical axis. Similarly, due to the qualitative focus no distinction is made in temporal resolutions.

3.2.2.3 Quantification of (the Consequences of) Impacts

The framework is explicitly aimed at charting qualitative information on impact chains. Spatial overlap between impacts is not considered in the model as space is not taken into account within the framework impact chains, neither on the horizontal nor vertical axis. Lastly, since time is not explicitly considered in the framework, temporal overlap is not considered as an aspect of impact chains.

3.3 Evaluation of case-study needs

In order to evaluate the feasibility of the case-study needs (with the Rubric), they first need to be made explicit. The following sections present the intended study needs and corresponding Rubric scores. It needs to be stressed that in the present design phase consequences of design choices were not considered and therefore not leading. Of course this is something that deserves further attention in future studies. Ultimately, the bottom-up and top-down Rubric scores are compared with those respective scores of the case-study needs.

3.3.1 Ideal Case Study Framework Design

3.3.1.1 Scoping

The different elements of the scoping phase are described in figure 7. The intention of the case-study is to include all human (sub-)activities that are involved with a certain practice within a sector to obtain a comprehensive overview of the impacts of that sector, i.e. all activities involved with seaweed farming within the aquaculture sector. The considered Pressures are limited to the pressures that are relevant for the case study. Relevant interactions with ecosystem components within a certain region or ocean are considered. Feedback loops are preferably considered, however in order to keep the framework both comprehensive and manageable indirect cascades are simplified, presenting them as direct cascades or as shorter indirect cascades. The 2D geographic scope considered is small (MPA) or intermediate (territorial waters). The full water column and benthos are considered in the vertical spatial scope and besides immediate effects longer term effects (within a set time window) are also taken into account.

Scope	Description Of Rubric Score		Rubric score	Importance Rank
Human Activities Considered	Case Study for a collection of activities (e.g. Seaweed Farming, Pelagic Fishing)		2	3 to 4
Pressures Considered	Only Pressures relevant for a specific case study		3	3 to 5
Ecosystem Components Considered	Only Ecosystem Components in Climatologic regions or oceans (e.g. temperate, Atlantic, North Sea?)		3	3
Ecosystem Services Considered				
Feedbacks Considered	Indirect Cascades Simplified, presenting them as direct cascades (e.g. human activities that affect fish as ecosystem component, through the modification of primary production are presented as having direct effects on fisheries)	Indirect Cascades Simplified, presenting them as much shorter indirect cascades	2 to 3	2 to 5
2D Geographic Scope Considered	E.g. small an MPA or basin	Intermediate area considered, like terratorial waters (e.g. Nederlands Continentaal Plat - NCP)	2 to 3	4 to 5
Vertical Spatial Scope Considered	Full Water column and Benthos Considered		5	2
Temporal Scope Considered	Effects occuring in set time window (e.g. lifetime duration of human structure; policy cycle duration)		3	2

Figure 7: Rubric Scores in the Scoping aspect for the Ideal Design of the Seaweed Cultivation case framework. Importance score refers to the methodology described in 3.3.1.4.

3.3.1.2 Level of Detail / Resolution

The required level of detail (currently considered) in human activities is high, between including process phases (see figure 8 and ANNEX 1 for clarification) and individual activities (score 4 to 5). To fully consider all interactions and impact chains knowledge on individual activities related to seaweed farming, such as shipping of materials or maintenance of the infrastructure, is most informative. However, in terms of complexity and applicability the level of process phases is a more realistic choice. Also taking into account that compared to other assessments the level of process phases is in fact quite detailed. Pressures are relatively aggregated (e.g. AQUACROSS: marine litter). However, this lack of specificity in pressures entails that certain assumptions are made regarding the impact (for instance the effects of hazard caused by different pollutants may differ significantly, while they are both considered as effects caused by a uniform Pressure ‘pollutants’ in relatively aggregated classifications) which needs to be taken into account in the interpretation of the results. Perhaps a worst case scenario versus average scenario can be included to make this distinction. Ecosystem Components are considered at the detail level of functional species groups (e.g. plankton, fish, macroalgae and birds). The relevant Ecosystem services supplies are considered to the level of the sector (e.g. fisheries) or subsector (e.g. benthic fisheries they supply to) , such as, for example, benthic fisheries and nature tourism. The spatial and temporal resolution of the seaweed case study are quite detailed, looking at a >500m resolution to be able to monitor the impacts of the farms which are roughly that size. The vertical resolution can be limited to the Photic zone of the water column. Because of the growth cycle of seaweed seasonal differences in activities are involved therefore a seasonal temporal resolution was chosen.

Level of Detail Considered	Description Of Rubric Score		Rubric Score	Importance Rank
Level of detail in Human Activities	Process Phases (e.g. Installation, Operation, Harvest, Decomissioning)	Individual Activities	4 to 5	4
Levels of Detail in Pressures	Relatively aggregated (E.g. AQUACROSS: e.g. Marine litter)		3	4
Level of detail in Ecosystem Components (Aggregation)	Functional Groups (functional species aggregation and Habitats)		3	4
Level of detail in Ecosystem Components (Interaction)	Non Mutually exclusive components are considered seperatly		1	2
Level of detail in Ecosystem Services	Ecosystem Services Aggregated to an intermediate level like sectors (e.g. Fisheries, Nature Tourism etc.)	Ecosystem Services Aggregated to a detailed aggregation level like subsectors (E.g. Benthic Fisheries, Nature Recreation Tourism)	3 to 4	3 to 5
2D Spatial Resolution Considered	>500m		4	3
Vertical Spatial Resolution Considered	Broad qualitative resolution (e.g. Benthic-Pelagic-Above Water)		2	2
Temporal Resolution Considered	Seasonal		4	3

Figure 8: Rubric Scores in the Level of Detail/ Resolution aspect for the Ideal Design of the Seaweed Cultivation case framework. Importance score refers to the methodology described in 3.3.1.4.

3.3.1.3 Quantification of (the Consequences of) Impacts

The different elements of the quantification of the impacts are described in figure 9. The analysis of Cascades is semi-quantitative of nature (e.g. Risk Factors or Severity Scores etc.). The Impact cascades are given semi-quantitative descriptions of spatial overlap (e.g. weight factors: 10% of North Sea is affected). Concerning the vertical overlap the choice lies between broad qualitative descriptions of vertical spatial overlap (e.g. Local, Oceanic Zone) or semi-quantitative descriptions (e.g. weight factors: 10% of the benthic zone is affected). Ideally semi-quantitative descriptions are included since these are most informative. The temporal overlap of the Impact cascades are given broad qualitative descriptions (short term, long term, infinity).

3.3.1.4 Relative importance of specific rubric scores

The importance or flexibility of the rubrics described within the categories scope, level of detail and consequences may differ. Some rubrics are of more importance to the framework approach while choices for a certain score in other rubrics are more flexible (figure 7, 8 and 9). For instance the human activities considered are relatively important, because here the distinction is made in level of detail in activities (between e.g. AQUACROSS and SWF as in report) whereas the ecosystem components that are considered depend on the case study and are more flexible. The level of feedbacks considered poses a dilemma, since they are important for a complete overview of the impacts but in terms of complexity/work/manageable it is not desirable not to have too many.

Consequences of Impact Cascades	Description of Rubric Score		Rubric Score	Importance Rank
Quantification of Linkages in the Cascade	The analysis of Cascades is semi-qualitative of nature (e.g. Risk Factors or Severity Scores etc.)		2	2
Quantification Spatial Patterns (in 2D) in the Cascade	the Impact cascades are given semi-quantitative descriptions of spatial overlap (e.g. weight factors: 10% of North Sea is affected)		3	3
Quantification Spatial Patterns (Vertical) in the Cascade	the Impact cascades are given broad qualitative descriptions of vertical spatial overlap (e.g. Local, Oceanic Zone)	the Impact cascades are given semi-quantitative descriptions of vertical spatial overlap (e.g. weight factors: 10% of the benthic zone is affected)	2 to 3	1
Quantification of Temporal Patterns in the Cascade	the Impact cascades are given broad qualitative descriptions of temporal overlap (short term, long term, Infinity)		2	3

Figure 9: Rubric Scores in the Quantification of (the Consequences of) Impacts aspect for the Ideal Design of the Seaweed Cultivation case framework

3.3.2 Comparison of ideal case study framework design with bottom-up and top-down strategies

In this section we compare the choices between what we would preferably make for the seaweed cultivation case (ideal design) with the choices made within the proposed top-down and bottom-up strategy. The goal of this comparison is to assess if either the top-down or bottom-up strategy: would present a sufficient fit for the seaweed cultivation case; if a new framework will need to be developed; the research questions need to be revised; or a combination of these.

To this end the rubric scores on every element are presented in figure 10 and 11. Both figures depict the same information on the exact rubrics coring for the targeted seaweed case, the top-down and bottom-up based strategy. The difference between figure 10 and Figure 11 is the coloring, where, in figure 10 the colors represent the type of information considered and , in figure 10, the colors represent the section of the framework design considered (scope, level of detail and quantification of effects).

As part of the analysis this study also assigned weights on the rubric score (on a scale of 1 to 5, with 1 representing that a choice in the rubric is of lesser importance to the case study, whereas 5 indicates that it is of paramount importance that the exact form as chosen in the rubric will be in the final framework design). These weights are additionally represented in Figure 10 and Figure 11 as the width of the bars.

Note that the only design choice that is similar for both the ideal case study, bottom-up and top-down design is the delimitation of the vertical spatial scope, which is also considered of lesser importance to the case study (relatively low weight assigned).

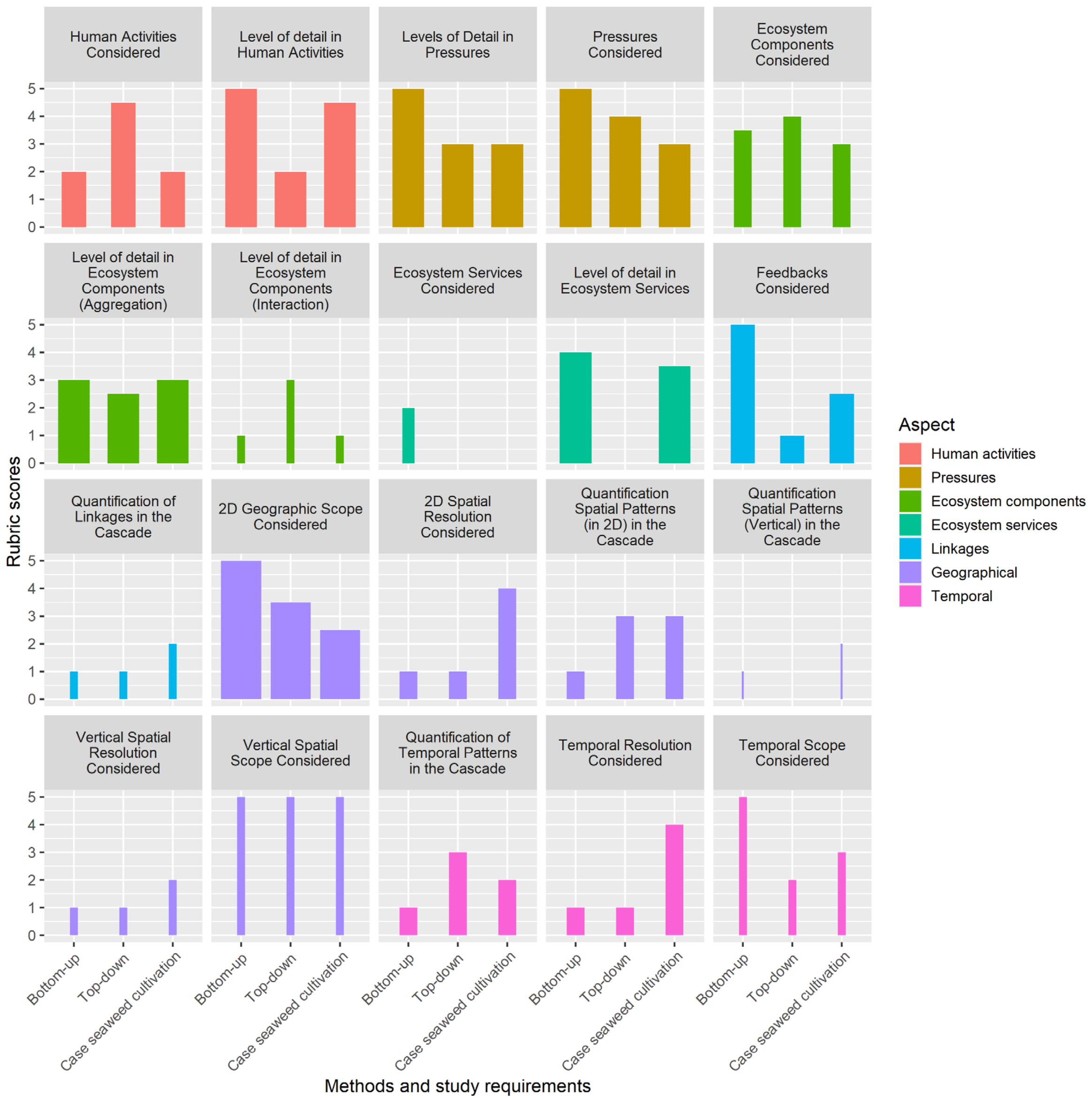


Figure 10 Rubric scores (vertical axis) for each application choice (panels). Horizontal axis show which method (bottom-up and top-down) or study requirements (case study). The width of the bars indicate the relative importance of the criterion for the specific case study. The panels are arranged per element of the scoring criteria (see legend).

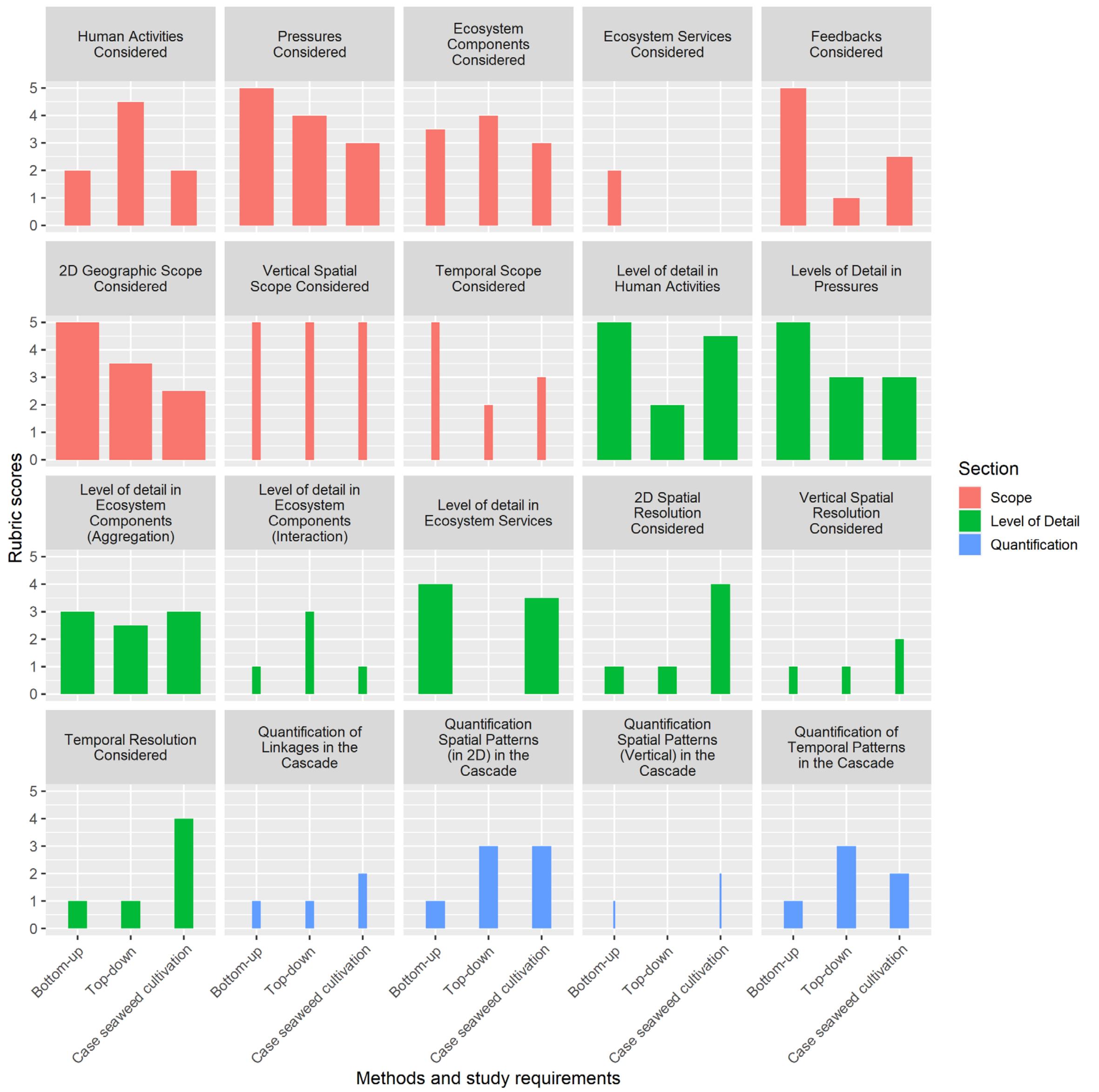


Figure 11 Rubric scores (vertical axis) for each application choice (panels). Horizontal axis show which method (bottom-up and top-down) or study requirements (case study). The width of the bars indicate the relative importance of the criterion for the specific case study. The panels are arranged per aspect of the scoring criteria (see legend).

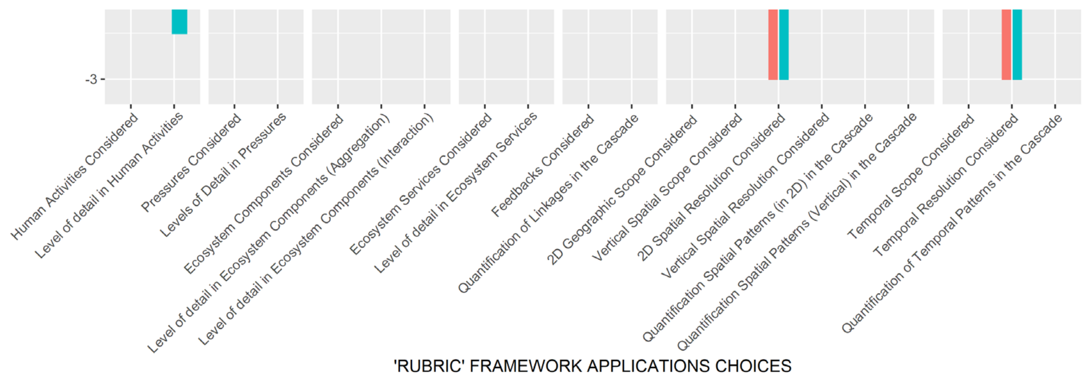


Figure 12), and the section of framework design (scope, level of detail and quantification; Figure 13). The width of the bars again reflects the assigned relative importance of the scores. As can be seen, neither of the evaluated methodologies align seamlessly with the case-study requirements. This means that either concessions have to be made in the case study to allow the fit of one of the considered frameworks, or a newly developed framework needs to be used to match with the case study needs.

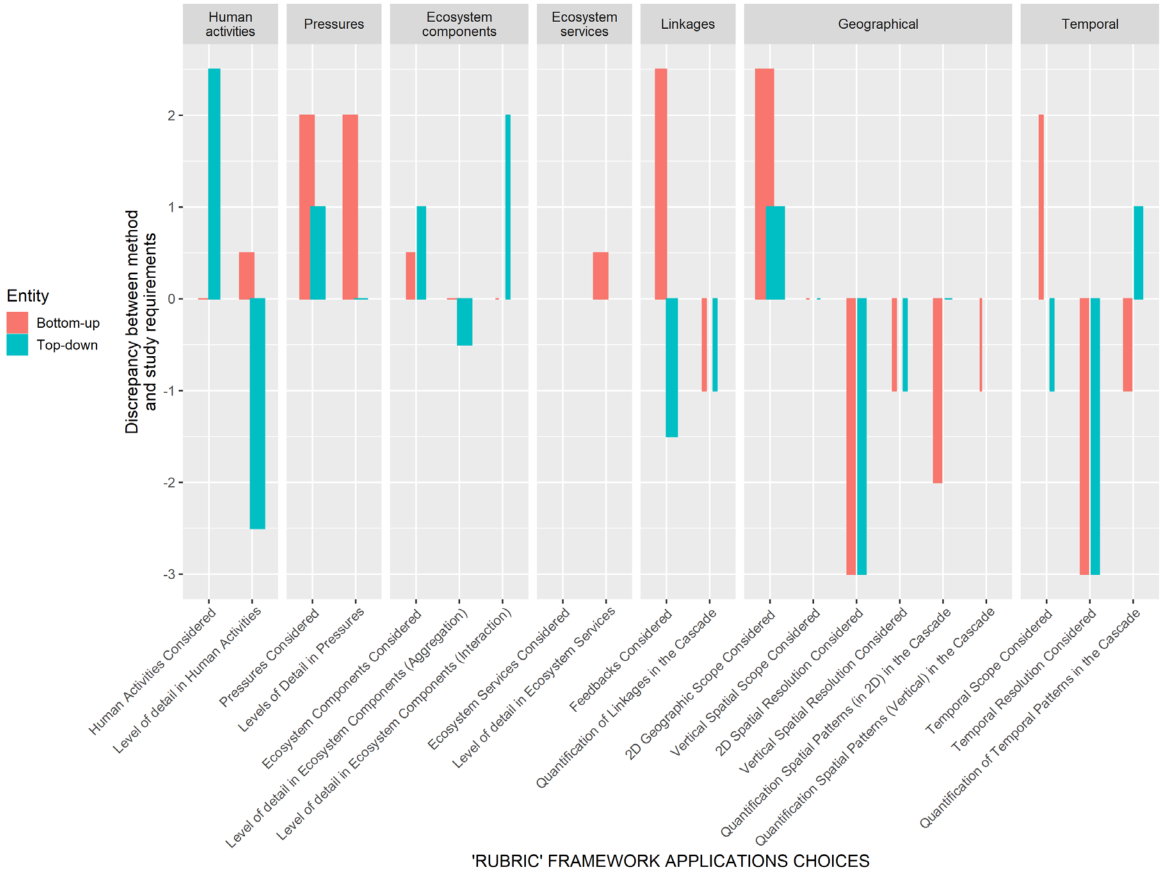


Figure 12 The discrepancy between the rubric scores for each method (bottom-up and top-down, see legend) and the study requirements (case study). The width of the bars indicate the relative importance of the criterion for the specific case study. The panels are arranged per element of the scoring criteria. Bars of zero height indicate that the method meets the study requirements. When the discrepancy is positive, the method scores higher than the study requirements, and vice versa. The consequences of either positive or negative discrepancies depend upon the definition of the criterion and its importance.

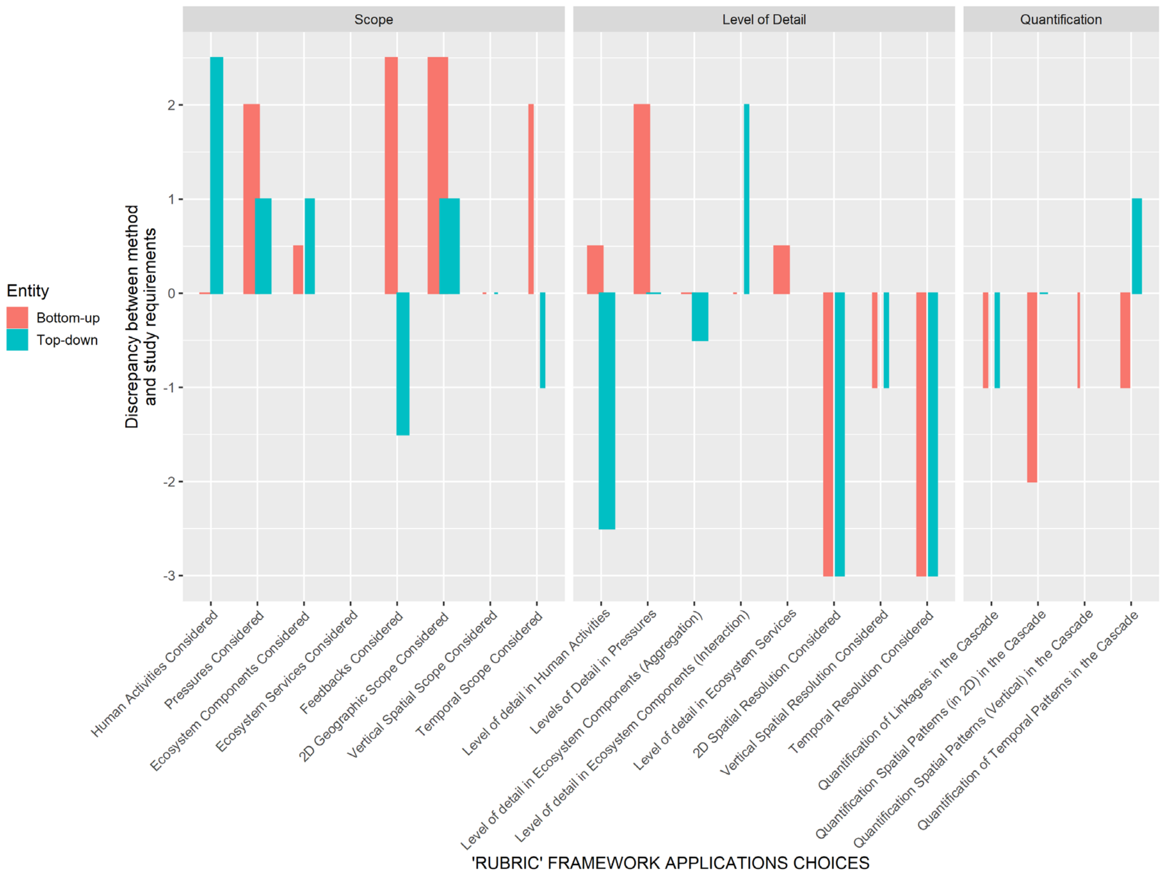


Figure 13 The discrepancy between the rubric scores for each method (bottom-up and top-down, see legend) and the study requirements (case study). The width of the bars indicate the relative importance of the criterion for the specific case study. The panels are arranged per aspect of the scoring criteria. Bars of zero height indicate that the method meets the study requirements. When the discrepancy is positive, the method scores higher than the study requirements, and vice versa. The consequences of either positive or negative discrepancies depend upon the definition of the criterion and its importance.

4 Discussion

In the present study it is evaluated how ecosystem services can be addressed in a complex framework of human activities (in a case-study of seaweed cultivation) which affect the ecosystem. A rubric framework is designed to score the research requirements and needs for the intended case-study and the capabilities of two different methodological strategy for assessing ecosystem services. The rubric framework is a helpful tool when making informed decisions in a study design phase. Several lessons have been learned, and some challenges remain, as described below.

4.1 Lessons learned

4.1.1 The Rubric Tool

The rubric developed to assist the scoping process is a valuable tool as it provides structure to the process and forces the user to make all relevant choices and considerations explicit. Consequently, the approach can be laborious and requires clear and unambiguous guidance.

Similar to the risk assessment framework, the Rubric tool is subject to evolution and will require adjustments upon implementation. It is important to document the framework each time it is used, and preferably address changes made to the framework.

4.1.2 Ecosystem Services

The evaluation of impacts on or consequences for the various ecosystem components resulting from human activities is already a complex matter. Adding ecosystem services (ES) to the equation increases this complexity and a structured approach of the scoping of the project (where the research question is formulated and project needs and requirements are identified) is crucial.

When addressing ES, it is important to establish whether the aim of the study is to: 1) quantify the benefits of ecosystem services without consideration of impacts; 2) demonstrate benefits from the services opposed/compared to impacts from the same activity; 3) consequences of a pressure to the ecosystem and therewith its services. On top of that is the consideration of consequences for services from competing ecosystem components.

In any of these cases, ESs are evaluated for specific activities (in the present study activities related to seaweed cultivation). Conceptually, ES are however not directly linked to activities. Obviously, the services are provided by the ecosystem. Consequently a framework translating activities to effects on the ecosystem is necessary (which is handled by both proposed bottom-up and top-down strategy). Additionally, many indicators for ES are instead linked to pressures as a precursor to ecosystem effects. How to handle these different type of ES indicators is beyond the scope of the present study.

Ecosystem services can be included on various levels of detail and forms of provisioning. There are many different forms of provisioning (food for human or animal consumption, medicine, fertilizer) each with differences in (monetary) value. The present study doesn’t tackle these differences, but the rubric tool could be used in prioritising and streamlining the harmonisation process. Furthermore, the level of detail of the ES should be in line with the level of detail that is selected for the remainder of the elements (activities, pressures).

4.1.3 Proposed ES methodologies

4.1.3.1 Top-down

The top-down strategy uses an existing qualitative framework for evaluating ecological impacts (CIA). Using an existing framework is time-effective but also limits design choices, as many choices are already made which are automatically inherited. Consequently, the strategy uses rather course definitions and do not distinguish highly detailed (sub)activities. Also, the framework consists of a directed acyclic graph, meaning the information flows in a single direction (from cause to effect) and does not allow to include feedback mechanisms explicitly.

A link to ES is not yet available for the Aquacross framework, although progress in that area is made (Piet et al., in prep.).

4.1.3.2 Bottom-up

At the moment the bottom-up strategy only exists as a conceptual model and remains to be implemented. Compared to the CIA approach it is therefore expected to be a more time-consuming endeavor. However, there are advantages when selecting this strategy. For one, it does foresee and includes feedback mechanisms. Adding feedbacks of supporting ES that modify ecosystem components provides more insight in the various impact-chains at play in the marine ecosystem however it is difficult to maintain overview of, quantify and assess the various chains and loops.

4.2 Remaining challenges

4.2.1 A practical application of a case study

The current seaweed cultivation case study is descriptive but not yet highly specific on the end goals. The rubric approach did help to expose implicit or missing considerations, and uncovered choices that are yet to be made. In order to facilitate further specifications of the study design an important piece is missing from the puzzle: what are the consequences of making specific choices. Before the case study can actually performed, these consequences need to be addressed as described in section 4.2.3.

4.2.2 Development of methodological strategies for evaluating ES

Both top-down and bottom-up strategy require further development in order to assess ES. Ideally, these developments are tailored to the needs and requirements of the case study. This will require balancing between study goals, feasibility and thus consequences of the choices that are made during the study and ES model design. It is therefore vital that the rubric approach recognizes and addresses consequences of specific choices before specific recommendations for the ES evaluation can be made.

4.2.3 Refinement of the Rubric approach

4.2.3.1 Definitions and interpretation

One of the challenges while applying the rubric approach as developed here was the interpretation of each rubric or its scoring categories. For instance, the scale of the rubric can be counterintuitive as the extremes of the scale do not necessarily indicate good or bad qualities. Ideally, the description is unambiguous and does not allow room for interpretation. For some rubrics and/or categories, the definition and their description could be refined. However, it is impossible to rule out any interpretation by the end user.

Another solution is to let multiple users perform the rubric scoring, where the users can discuss their results afterwards, especially when evaluations among users vary. In addition, scoring categories could be linked to consequences (of study outcome/goals). Not only will this help in the interpretation of the rubric scales, it will also assist in the decision making process of a study design. This will be elaborate more in the section below.

The current scale used for scoring uses values ranging from 0 to 5 linked to discrete categories. How this scale affects the scoring process is not evaluated in the present study. Future studies may want to consider a more refined scale, or study the effect of applying different scales.

4.2.3.2 Goals, options, consequences and feasibility

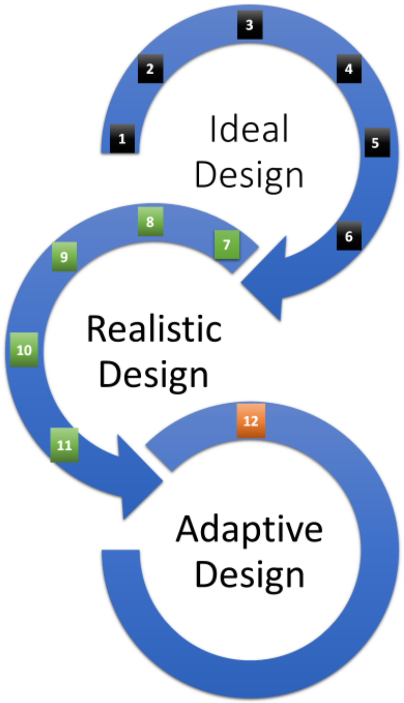
In applying the rubric approach so far the focus has been on structuring the design of ecosystem service assessment frameworks and the discussions surrounding the design. However, so far, a much needed part of the discussions has been omitted in developing the rubric approach: What determines if a framework design is ideal or realistic? To achieve at the answer to this several integral parts of the rubric approach need to be further developed further. An overview of the parts that need further development is given in this section, a visual representation , implementing suggestions given in this section is presented in figure 14.

First, before the rubric tool itself is approached the user needs to define a clear goal for the analysis: What will the analysis (preferably) be used for? For instance, an ecosystem service assessment can be developed to serve as input for policy building, to foster scientific insights in the complexity of a system, to educated the public about trade-offs in ecosystem services, to serve as a basis for simulation models or another purpose altogether. Clarifying the goal, puts the choices design made using the rubric tool into context and helps link consequences of design choices to what is needed to fulfill the goal of the analysis:

Having defined a goal, the next step would be tailor the ideal design to fulfill the goal, executing the targeted design phase of the methodology proposed in this report with the goal in mind. This is done by identifying the consequences of design choices that could prevent the goal from being met. Examples of consequences that need to be addressed when defining ideal design, can be found in how complex or detailed an assessment becomes. For instance if an assessment (outcome) becomes too complex for a policy maker to understand, any goal regarding policy building becomes impossible or alternatively, if an assessment assumes many relations to reduce complexity, does the assessment picture reality accurately enough for policy building to have the desired effect.

Having a more clear picture of how design choices relate to how the goal of the assessment can then be used to define why some design choices are more important than others to fulfill the goal. As a result, the discussion on relative importance of some design choices over others, as executed in our analysis by scoring the relative importance of each choice in the realistic design phase, becomes much more structured.

Next, in the realistic design phase, consequences of design choices that determine if the ecosystem service is realistic possible should be taken into account. Central to this part is to determine how the design choices made in the targeted design phase, translate to practical matters of the analysis, such as data and model availability, data and model quality, time budget needed, financial budget needed. As a result, the targeted design can be reviewed using such questions as: will the assessment be possible given the budget available and will the data available be enough or is new data collection needed to execute the assessment, requiring additional budget and time. Some of these practical matters may also hinder the goal of the assessment from a content based- perspective: for instance, if the data available is of low quality or includes high rates of uncertainty will this prevent reliable outcomes that cannot be used to build policies with or, if the goal of an assessment is to be part of a yearly repeated monitoring scheme, does the time needed for the assessment not exceed a year?



Steps to define a framework design	Examples of Considerations in the step
1. What is the goal of the assessment?	• To serve as input to policy making • To foster scientific insights on the cascading effects from one oceanic zone to another • To communicate ecosystem service dependencies
2. What choices (rubric scores) are ideally made in the framework design, considering the goal?	• See Rubric Tool (appendix 1)
3. What consequences of choices could hinder fulfilment of the goal	• Will complexity or detail be an issue in communicating to non-experts? • If the goal includes a periodic re-evaluation, will duration of the assessment be an issue?
4. How do the intended design choices (rubric scores) relate to 2.	• How complex and detailed will the (outcome of) the assessment be?
5. Assess of if the consequences do not hinder the fullfillment of the goal	• Will the outcome of the assessment not be too complex for a policy maker to understand?
6. Adjust choices (rubric scores) to make fulfilment of the goal possible	• How complex can the outcome of the assessment be for a policy maker to still be able to interpret it?
7. How important is it for each choice to be in the form chosen (=to have that exact rubric score)? (e.g., ranked on a scale from 1-5)	• If the goal is to understand linkages between different oceanic zones, the goal will not be possible (importance rank of 5) without a vertical resolution that distinguishes between oceanic zones
8. Does an existing or framework in development have a similar enough design (rubric scores), specifically on the most important (high ranked), to fit the case sufficiently?	• Do the design choices (rubric scores) in the Aquacross framework differ enough to not be applicable to the consider case study and goal
9. What consequences of choices could be constrained by the practical issues(e.g. data availibility, data quality, time needed, budget needed)	• data quality or availability? • time availability? • Financial budget?
10. How do the intended design choices in the rubric relate to 8.	• What data will be needed, and in what quality, to execute the defined assessment design • How much time will be needed? • How much budget will be needed?
11. Assess of if the practical consequences are not constrained by practical issues and adjust design (rubric scores) if needed	• Is the data needed available in the quality needed? • Does the time needed exceed the time available? • Does the budget needed exceed the budget?
12. repeat any of the applicable previous steps based on newly obtained insights	• If the goal should be adjusted based on client preferences, start the process again at step 1 • If the time needed proves to be more than anticipated, start at step 3 or 10 (depending on the goals' dependency on time needed)

Figure 14: Overview of the three assessment framework design phases (extension of figure 2) in the rubric approach and the steps taken in each design phase, extended with suggestions to include considerations for consequences. The left side of the figure represents the design phases and includes moments in the phase when separate design steps occur. The middle column defines the steps themselves, corresponding to the numbers in the left section. The right column represents examples of considerations that are relevant for each step in the middle column. Colours in the left and middle part correspond to the different design phases (black for ideal design, green for realistic design and orange for the adaptive design)

In this phase it can also be sensible to screen for existing tools that possibly align with the defined goals. These tools provide examples of which concrete options are available to reach the set goals. From these options their feasibility for reaching the goals can be addressed, or the feasibility of modifying the tools to reach the goals. For that purpose the feasibility needs to be defined and specified such that it can be assessed and evaluated. Feasibility needs to be defined such that it adheres to principles used in the SMART criteria (Specific, Measurable, Assignable, Realistic and Time-related).

Consequently, at the core of the challenges for the rubric approach is to find a structured approach to make the goal of the assessment explicit and a structured way to hold the consequences on assessment form and practical implications to the possibility to fulfill the goal and the practical constraints of the assessment.

4.3 Future perspectives

4.3.1 EU context

Recently, recommendations for guidelines have been suggested for applying an Ecosystem-based Approach in Maritime Spatial Planning (EBA-MSP) (Piet et al. 2021). To enhance its applicability we attempted to align this to these guidelines. It is important to understand the outline of these guidelines and how the rubrics approach would fit in.

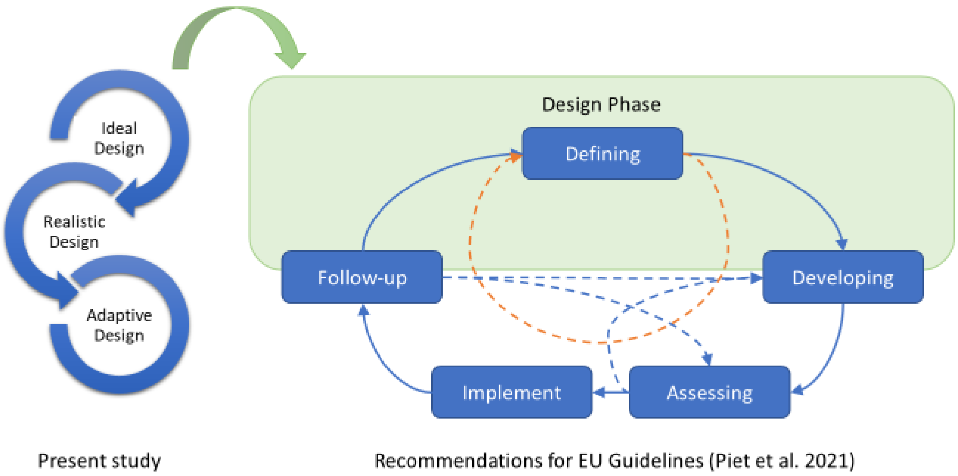


Figure 15: A visual comparison between the design phases presented in the present study and the stages in ecosystem based management of marine spatial planning as described in the recommendations for EU guidelines. Circular arrows on the left-hand side represent the diagram for study design as proposed in the present study. The rectangular blocks on the right-hand represent the stages as published in the recommendations for EU guidelines. Blue arrows connecting the rectangular blocks are pathways as suggested by the recommendations for EU guidelines. The dashed orange line reflects how our design phases can be implemented iteratively in combination with the recommendations EU guidelines. The green block roughly indicates how our design phases overlap with the stages from the recommendations for EU guidelines.

The recommendations for EU guidelines have a much wider ambition (see figure 15): where the present study only addresses the design phase of a study, the recommendations for EU guidelines also encompass the implementation and execution phase. The recommendations for EU guidelines describe an ecosystem based approach in marine spatial planning (EBA-MSP) as a cycle, which usually starts with definitions. Once all relevant aspects are defined, the recommendations focus on development of required methods and collection of data, followed by the actual assessment (and modification) of planned activities and consequences for the ecosystem. This is then followed by the implementation of the planned commercial activities. Once activities are deployed, they can be followed up by monitoring and evaluating consequences to the ecosystem. This loops back in to the definition stage, where improvements can be introduced (see Figure 15).

The rubrics approach introduced in the present study can be used to bridge the step from the defining to the developing step as described by Piet et al. (2021). The present study proposes to iteratively cycle through the definition stage by following the three design stages described here, before entering the usually costly executive stages described in the recommendations for EU guidelines.

In future work it is advised to adhere to existing frameworks and (recommended) guidelines for optimal acceptance and compatibility with other studies.

4.3.2 Potential applications of the Rubric approach

In this report the rubric approach is presented as a comprehensive tool to develop ecosystem service assessment methodology, tailored to any case study. In that respect the approach is used as a project start-up to clearly define the frameworks in advance, assisting in the interpretation of definitions and an explicit understanding of the various aspects involved. The potential applications of the rubric tool, however, are not limited to designing of an ecosystem service assessment. This section suggests several other applications for the tool.

Firstly, the tool excels at structing discussions in ecosystem impact and service assessment designs, both in the process of the actual designing and in evaluating existing frameworks, as is also shown in the current analysis by comparing the preferred seaweed case design to the bottom-up and top-down strategy. In a broader context such evaluation can help make sense of the different ways to assess ecosystem services, facilitating large scale comparative analysis of ecosystem services assessments and discussions on (the consequences of) their (implicit) choices, especially so if assessments also start using a uniform framework, such as the rubric approach, to design their assessment frameworks.

Secondly, while the tool presented here is applied to an aquaculture production case, the tool was explicitly developed to be broadly applicable to any cascading effect on ecosystem services arising from human activities. Where human activity is explicitly not limited to negative impacts from damaging industries, but very much so also includes the positive effects of human activities on ecosystem services. This broad applicability allows for structured assessment design in a myriad of topics, foreseeing its applicability in examples like assessing the environmental impacts of harbours on ecosystem services, assessing the cascading beneficial effects of building with nature projects and proper analysis of human activities in which both negative and positive effects may occur, such as the seaweed case suggested here.

Thirdly, since the tool allows for clear, structured frameworks designs to assess cascades from human activity to ecosystem service endpoint, discussions can be easily extended to include partners from economic or social sciences. Extensions developed in conjunction with partners from social and economic sciences may even assess cascades from human activities to as far as social or even monetary impacts, if the current endpoint of ecosystem services are linked to further cascading effects or monetary valuations in society and the economy.

5 Conclusions

The Rubrics approach can be used to score the capacity and limitations of a methodological strategy on one hand and the requirements for a specific case or project on the other hand. As such the approach can be used to evaluate different methodologies, to determine which approach is most suitable for a specific research question. The approach can also be used to refine research questions or identifying knowledge and data gaps in an early stage of a project. In addition, the approach can be used iteratively during a project execution to manage and adjust the project requirements (and indirectly stakeholder expectations of the project). As such the approach is suitable in each of the three identified study design phases (ideal design, realistic design, adaptive design).

In its current form the rubric approach shows promise, but is not yet able to fully support study design choices for evaluating ecosystem services from the seaweed cultivation case from Tonk et al. (2021). For that purpose the approach needs to be extended such that it addresses consequences of design choices, for which recommendations are made.

Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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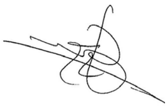
Justification

Report C063/22
Project Number: 4318300156, KB-34-007-004

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen Marine Research.

Approved: Dhr. Gertjan Piet
Senior Researcher Marine Ecology

Signature: 

Date: 21 October 2022

Approved: Drs. Jakob Asjes
MT Member Integration

Signature: 

Date: 21 October 2022

Annex 1 Full Rubric Questionnaire Tool

See next pages

'RUBRIC' FRAMEWORK APPLICATIONS CHOICES	Section Code	Aspect Code	0	1 e.g.: - Simplified - Focused - Aggregated - Proxy	2	3	4	5 e.g.: - Complex - Holistic - Disaggregated - Realistic
Scope	**Sc**					**Description of Score**		
Human Activities Considered	Sc	HA	NA	Case Study for a single activity (e.g. Seaweed Harvesting, Trawler Towing, Tourist diving trip)	Case Study for a collection of activities (e.g. Seaweed Farming, Pelagic Fishing)	Case Study for a collection of practices (e.g. Aquaculture, Fisheries, Nature Tourism etc.)	Activities for a collections of sectors considered (e.g. Food production, Tourism Etc.)	All Human Activities considered
Pressures Considered	Sc	Af	NA	A single Pressure considered	A subselection of Pressures relevant for a specific case study	Only Pressures relevant for a specific case study	Pressures beyond scope of specific case are considered	All Categories of Pressures considered
Ecosystem Components Considered	Sc	EC	NA	A small selection of ecosystem components (e.g. invertebrates)	A subselection of ecosystem components (e.g. Benthic groups; Wadden sea groups)	Only Ecosystem Components in Climatologic regions or oceans (e.g. temperate, Atlantic, North Sea?)	Only Marine Ecosystem Components	All
Ecosystem Services Considered	Sc	ES	NA	Effects on a single service only considered	Effects on a small collection of other services (e.g. Sector or subsector) considered	Effects on a part of an economy (e.g. food production) considered	Effects on a large subsection of Ecosystem Services (e.g. provisional services) considered	All Ecosystem Services Included in the analysis
Feedbacks Considered	Sc	LINK	NA	Only Direct Cascades Considered	Indirect Cascades Simplified, presenting them as direct cascades (e.g. human activities that affect fish as ecosystem component, through the modification of primary production are presented as having direct effects on fisheries)	Indirect Cascades Simplified, presenting them as much shorter indirect cascades (Human activities th	Indirect Cascades up untill an (arbitratry) cutoff point considered (e.g. indirect effects chains that need more than three feedback loops before the effetc on Eocystem servives can be assessed are excluded)	All Indirect Cascades considered, no matter the length of indirect links
2D Geographic Scope Considered	Sc	GEO	NA	Small Area defined (e.g. a single beach	E.g. small an MPA or basin	Intermediate area considered, like terratorial waters (e.g. Nederlands Continentaal Plat - NCP)	Very Large Area Considered (e.g. an ocean or a continent)	Global Area considered/ No Geographic Scope Defined
Vertical Spatial Scope Considered	Sc	GEO	NA	Only Specific Vertical Zone (e.g. Benthos)				Full Water column and Benthos Considered
Temporal Scope Considered	Sc	TEMP	NA	Only directly occuring effects considered		Effects occurin in set time window (e.g. lifetime duration of human structure; policy cycle duration)		Indefinite time considered/ no temporal scope considered

'RUBRIC' FRAMEWORK APPLICATIONS CHOICES	Section Code	Aspect Code	0	1 e.g.: - Simplified - Focused - Aggregated - Proxy	2	3	4	5 e.g.: - Complex - Holistic - Disaggregated - Realistic
Level of Detail Considered	**LoD**							
Level of detail in Human Activities	LoD	HA	NA	Industries	Sectors	Subsectors	Process Phases (e.g. Installation, Operation, Harvest, Decomissioning)	Individual Activities
Levels of Detail in Pressures	LoD	Af	NA	Very Aggregated Affector Typology (e.g. Physical, Chemical, Biological)		Relatively aggregated (E.g. AQUACROSS: e.g. Marine litter)	Little Aggrgation (e.g Heavy metals, PCBI chemicals, etc.)	Specific Affector Inputs (e.g. Ghostnets)
Level of detail in Ecosystem Components (Aggregation)	LoD	EC	NA	Ecosystems/ Biospheres	Habitats/Taxonomical phyla	Functional Groups (functional species aggregation and Habitats)	Functional Traits	Species
Level of detail in Ecosystem Components (Interaction)	LoD	EC	NA	Non Mutually exclusive components are considered seperatly		Ecosystem Components are defined as the combination of several non-mutually exclusive ecosystem components (e.g. Habitats x Functional Species Groups)		Ecosystem Components are defined as the combination of all non-mutually exclusive ecosystem components (e.g. Habitats x Functional Species Groups x Predators Present)
Level of detail in Ecosystem Services	LoD	ES	NA	Ecosystem Services Aggregated to a most basic level (e.g. MEA, 2001: Provisional, Regulating and Cultural)	Ecosystem Services Aggregated to a Higher level (E.g. Food Production, Tourism etc.)	Ecosystem Services Aggregated to an intermediate level like sectors (e.g. Fisheries, Nature Tourism etc.)	Ecosystem Services Aggregated to a detailed aggregation level like subsectors (E.g. Benthic Fisheries, Nature Recreation Tourism)	Ecosystem Services Aggregated to a a very detailed aggregation level like specific activities (E.g. Herring Fisheries, Diving Tourism)
2D Spatial Resolution Considered	LoD	GEO	NA	No 2D spatial distinction	Broad qualitative resolution (e.g. MPA, Coastal Zone Etc.)	>1 km	>500m	<500m
Vertical Spatial Resolution Considered	LoD	GEO	NA	No vertical spatial distinction	Broad qualitative resolution (e.g. Benthic-Pelagic-Above Water)	>100 m	>10m	<10m
Temporal Resolution Considered	LoD	TEMP	NA	Undefined/ ≥century	Decadal	Yearly	Seasonal	Weekly or Lower

'RUBRIC' FRAMEWORK APPLICATIONS CHOICES	Section Code	Aspect Code	0	1 e.g.: - Simplified - Focused - Aggregated - Proxy	2	3	4	5 e.g.: - Complex - Holistic - Disaggregated - Realistic
Consequences of Impact Cascades	**CoI**							
Quantification of Linkages in the Cascade	CoI	LINK	NA	The analysis of Cascades is purely Qualitative of nature	The analysis of Cascades is semi-qualitative of nature (e.g. Risk Factors or Severity Scores etc.)	Every linkage is seperatly assessed and the relation is seperatly assessed (e.g. single or multiple regression, without interaction factors)	The analysis is fully quantitative but does include interaction terms (e.g. multiple regression wit interaction factors or Intricate modelling tools)	The analysis of cascades is done in a fully quantitative way (for example multiple regressions, with an interaction factor, for the combined effect of every linkage in the framework)
Quantification Spatial Patterns (in 2D) in the Cascade	CoI	GEO	NA	The impact cascades are not given any spatial attributes	the Impact cascades are given broad qualitative descriptions of spatial overlap (e.g. Local, MPA, North Sea, Ocean)	the Impact cascades are given semi-quantitative descriptions of spatial overlap (e.g. weight factors: 10% of North Sea is affected)	the Impact cascades are given specific quantitative descriptions of spatial overlap (e.g. in the same 10km2)	2D Spatial overlap is Fully quantified and non-binary spatial heterogeneity is included in the analysis (e.g. diffusion)
Quantification Spatial Patterns (Vertical) in the Cascade	CoI	GEO	NA	The impact cascades are not given any spatial attributes	the Impact cascades are given broad qualitative descriptions of vertical spatial overlap (e.g. Local, Oceanic Zone)	the Impact cascades are given semi-quantitative descriptions of vertical spatial overlap (e.g. weight factors: 10% of the benthic zone is affected)	the Impact cascades are given specific quantitative descriptions of spatial overlap (e.g. in the same +-100m in the water column)	Vertical Spatial overlap is Fully quantified and non-binary spatial heterogeneity is included in the analysis (e.g. diffusion)
Quantification of Temporal Patterns in the Cascade	CoI	TEMP	NA	The impact cascades are not given any temporal attributes	the Impact cascades are given broad qualitative descriptions of temporal overlap (short term, long term, Infinity)	the Impact cascades are given semi-quantitative descriptions of temporal overlap (weight factors: 10% of Ecosystem Component x is affected in the short term)	the Impact cascades are given quantitative descriptions, with high temporal dinstinction, of temporal overlap (e.g. occurs in the same week)	Temporal overlap is Fully quantified and non-binary temporal heterogeneity is included in the analysis (e.g. toxin decay)

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