

2597

NINA Report

Opportunities and challenges for marine ecosystem accounting at Hywind Tampen

Evert J. Mul



NINA Publications

NINA Report (NINA Rapport)

This is NINA's ordinary form of reporting completed research, monitoring or review work to clients. In addition, the series will include much of the institute's other reporting, for example from seminars and conferences, results of internal research and review work and literature studies, etc. NINA

NINA Special Report (NINA Temahefte)

Special reports are produced as required and the series ranges widely: from systematic identification keys to information on important problem areas in society. Usually given a popular scientific form with weight on illustrations.

NINA Factsheet (NINA Fakta)

Factsheets have as their goal to make NINA's research results quickly and easily accessible to the general public. Fact sheets give a short presentation of some of our most important research themes.

Other publishing.

In addition to reporting in NINA's own series, the institute's employees publish a large proportion of their research results in international scientific journals and in popular academic books and journals.

Opportunities and challenges for marine ecosystem accounting at Hywind Tampen

Evert J. Mul

Mul, E.J. 2025. Opportunities and challenges for marine ecosystem accounting at Hywind Tampen. NINA Report 2597. Norwegian Institute for Nature Research.

Tromsø, April 2025

ISSN: 1504-3312

ISBN: 978-82-426-5415-1

COPYRIGHT

© Norwegian Institute for Nature Research

The publication may be freely cited where the source is acknowledged

AVAILABILITY

Open

PUBLICATION TYPE

Digital document (pdf)

QUALITY CONTROLLED BY

Tone Kristin Reiertsen, NINA

SIGNATURE OF RESPONSIBLE PERSON

Research director Amanda Poste

CLIENT(S)/SUBSCRIBER(S)

Equinor

CLIENT(S) REFERENCE(S)

CLIENTS/SUBSCRIBER CONTACT PERSON(S)

COVER PICTURE

Hywind Tampen © Equinor ASA

KEY WORDS

Marine ecosystem accounting, offshore floating wind park, ecological impacts

CONTACT DETAILS

NINA head office

P.O.Box 5685 Torgarden
NO-7485 Trondheim
Norway
P: +47 73 80 14 00

NINA Oslo

Sognsveien 68
0855 Oslo
Norway
P: +47 73 80 14 00

NINA Tromsø

P.O.Box 6606 Langnes
NO-9296 Tromsø
Norway
P: +47 77 75 04 00

NINA Lillehammer

Vormstuguvegen 40
NO-2624 Lillehammer
Norway
P: +47 73 80 14 00

NINA Bergen:

Thormøhlens gate 55
NO-5006 Bergen.
Norway
P: +47 73 80 14 00

www.nina.no

Abstract

Mul, E.J. 2025. Opportunities and challenges for marine ecosystem accounting at Hywind Tampen. NINA Report 2597. Norwegian Institute for Nature Research.

This report aims to investigate the possibilities and challenges for ecosystem accounting in the marine environment around Hywind Tampen; an offshore floating wind park. Ecosystem accounting is introduced as a robust statistical framework to assess the extent and the condition of ecosystems. This report includes four main parts: 1) A literature study to identify vital differences between terrestrial and marine ecosystems, different typologies for the classification of ecosystems into ecosystem types, selection procedures for indicators for ecosystem condition and the overall status of marine ecosystem accounting. A list of (international) case studies is also presented in this part of the report. 2) The key conclusions from a workshop that was held in December 2024 are presented. 3) Ecosystem impacts resulting from offshore floating wind parks are described and a brief overview of potential mitigation measures is provided for each impact. 4) Finally, this report provides suggestions for relevant ecosystem types, ecosystem condition indicators and an overview of the impacts on each of these indicators. The potential for ecosystem extent accounts and ecosystem condition accounts are discussed. The report concludes with a list of recommendations for ecosystem accounting at Hywind Tampen.

The literature study indicated that frameworks and methods for marine ecosystem accounting and biodiversity change assessments (e.g. no net loss) in marine ecosystems are much less developed and have received much less attention in literature than their terrestrial counterparts. This is largely due to the complex, 3-dimensional structure of marine ecosystems, which poses great challenges in identifying spatial explicit marine ecosystem types, measuring marine ecosystem conditions and poor data availability and quality, compared to terrestrial systems. However, recent developments in typology and selection methods for indicators can help to address these constraints. Many of the case studies for marine environments highlighted the need for transparent statistical methods, which include an evaluation of the uncertainty.

The potential effects of offshore floating wind parks can be grouped into 6 overarching categories: 1) Entanglement, 2) Habitat alteration (including displacement effects), 3) Collision, 4) effects of sound, light or electromagnetic fields, 5) water quality, and 6) atmospheric and oceanic effects. For each of these impacts, mitigation measures are presented. Four ecosystem types are identified for the Hywind Tampen area: Aphotic saltwater sediment bottom (soft-sediment bottom habitat, where no light penetrates), Aphotic marine water systems (lower part of the water column, where no sunlight penetrates), Euphotic marine water systems (upper part of the water column, where sunlight is available) and Heavily modified or new marine structures (artificial hard substrate at the bottom or at the surface). For each ecosystem type a list of ecosystem condition indicators is presented.

Habitat loss is a much more important driver in terrestrial ecosystems than in marine ecosystems, where changes in ecosystem condition are often more complex. Indicating the status of ecosystem health based on biodiversity alone may therefore not be sufficient for marine ecosystems. A more suitable approach would be the assessment of a range of ecosystem indicators, including biodiversity, through a Panel-Based Assessment of Ecosystem Condition (PAEC).

Perhaps the greatest potential for offshore floating wind parks in mitigating ecological impacts is by addressing ecological issues that may not be caused by the wind parks themselves. This can be achieved for example by the implementation of nature-based solutions, or by the development of coexistence with other human activities or with offshore carbon capture and storage initiatives.

Contents

Abstract	3
Contents	4
1 Background	5
2 Status of marine ecosystem accounting	7
2.1 Ecosystem accounting	7
2.2 No net loss of biodiversity	8
2.3 Challenges in marine ecosystem accounting	9
2.3.1 Differences between marine and terrestrial ecosystems	9
2.3.2 Data availability	10
2.4 Marine ecosystem accounts and marine no net loss assessments	10
2.4.1 Marine ecosystem typology	11
2.5 Examples of marine ecosystem accounting	11
2.5.1 International examples	11
2.5.2 Marine ecosystem accounting in Norway	12
3 Workshop – Challenges and opportunities for marine ecosystem accounting, case study: Hywind Tampen	13
3.1 Workshop content and participants	13
3.2 Main conclusions from the workshop	13
4 Impact from offshore wind on biodiversity, case study: Hywind Tampen	15
4.1 Generic ecosystem effects of offshore floating wind parks	15
4.2 Potential mitigation measures for offshore floating wind parks	19
4.3 Biodiversity near Hywind Tampen	20
4.4 Ecosystem types relevant to Hywind Tampen	21
4.5 Ecosystem condition indicators relevant to Hywind Tampen	23
5 Suggestions for ecosystem accounting at Hywind Tampen	24
5.1 Ecosystem extent account	24
5.2 Ecosystem condition account	25
6 Further recommendations	29
7 References	31
8 Annex	36

1 Background

In 2015, the United Nations adapted 17 global goals for sustainable development or SDGs (United Nations, 2015). However, some of these goals have been incongruous throughout much of human history. Specifically, the increasing global demand for infrastructure expansion (SDG 9) has long interfered with societies' desire to reduce the global loss of biodiversity, which are incorporated in SDGs 14 & 15 (zu Ermgassen *et al.*, 2021). To reconcile these SDGs, industrial development aim to incorporate strategies to achieve no net loss (NNL) outcomes (Edwards-Jones *et al.*, 2024). One particularly promising development to reconcile these two intervening goals is the development of offshore floating wind parks (Danovaro *et al.*, 2024). Hywind Tampen represents the first offshore floating wind park in Norway.

In this report, opportunities for offshore floating wind parks to quantify, report and communicate the net effect on biodiversity are explored, and possibilities to reduce biodiversity loss are discussed. Similar to a preceding NINA report from 2024 (Mul *et al.*, 2024), Equinor has asked NINA to investigate possibilities for the Norwegian offshore floating wind park Hywind Tampen. In the 2024 report, NINA assessed whether *Naturpoeng*, a method that was recently developed for use in terrestrial systems (Liebel and Haukland, 2024), could be used in a marine system. Unfortunately, the difference between terrestrial systems and marine systems is too large, and it was concluded that this approach was not suitable for use in marine systems (Mul, 2024). The three main reasons were 1) Marine pelagic ecosystems are poorly defined and mapped in terms of area-based habitats, 2) Area loss (one of the main parameters in the *Naturpoeng* method) is a less important driver in marine systems than in terrestrial systems, and 3) most species in (off-shore) marine ecosystems are highly mobile, and live in a highly dynamic, 3-dimensional environment.

After these conclusions, NINA was asked by Equinor to further investigate opportunities for ecosystem accounting at Hywind Tampen. The aims of the current report are:

- 1) to investigate the possibilities for marine ecosystem accounting in general, including providing a detailed literature overview of potential methods and solutions that have been developed in other countries, or that are under development in Norway. The project will include a detailed literature review of methods proposed for marine ecosystem accounting in the rest of the world. Existing approaches will be compared, and their feasibility, complexity and transparency will be evaluated. Transparency refers to the degree of transparency of the approach, and whether others can review the different aspects of the approach themselves;
- 2) to investigate potential individual mitigation or compensation measures for floating offshore wind parks for all species groups individually (fish, benthic organisms, seabirds and marine mammals). Examples include: the use of bubble net curtains to reduce the impact of noise on marine mammals during the construction phase, or temporarily reducing the energy production process during seabird migration. The focus will be on local measures, which can be used in Hywind Tampen or other floating wind parks;
- 3) to collaborate with the various Norwegian initiatives that are currently exploring potential ways of accounting for marine ecosystems. This will stimulate the development of a unified approach for nature accounting in marine ecosystems. For this purpose, we will arrange a workshop with experts from relevant research institutions in Norway to discuss how the issues can be addressed.

Specifically, four deliverables for this project were proposed:

- 1) A literature review of marine ecosystem accounting, mainly from other countries.
- 2) An overview and description of potential compensation measures for floating wind parks.
- 3) A one-day workshop with experts from other research institutes on marine ecosystem accounting in Norway.
- 4) A detailed summary of the results of this workshop.

The remaining chapters of this report roughly follow the structure of these four deliverables: in chapter 2, the status of marine ecosystem accounting is described and discussed, based on a detailed literature review of peer-reviewed studies from around the world. This chapter includes an introduction to the topic of ecosystem accounting, a detailed comparison between ecosystem accounting in marine systems and in terrestrial systems, an overview of common issues that are identified in ecosystem accounting in marine systems and an extensive overview of examples of marine ecosystem accounting, in Norway and abroad. In chapter 3, the workshop is described in detail, including an overview of the conclusions that can be drawn from the discussions during the workshop. Chapter 4 combines the information from chapter 2 (literature study) and chapter 3 (workshop), to discuss issues and opportunities at Hywind Tampen. In this chapter, an attempt is made to identify relevant ecosystem types and ecosystem indicators, following the structure of existing frameworks, such as Natur i Norge, the IUCN Global Ecosystem Typology and the overall ecosystem accounting framework from the United Nations. For each of these indicators, the quality and availability of data are described, and the potential effects of floating wind park for these indicators are discussed. Furthermore, this chapter includes a detailed overview of potential mitigation measures for each of the indicators. In chapter 5 an initial set-up for an ecosystem extent account and an ecosystem condition account for Hywind Tampen is sketched and discussed. This chapter includes a list of recommendations for the further development of ecosystem accounting in marine ecosystems.

2 Status of marine ecosystem accounting

2.1 Ecosystem accounting

Changes in an ecosystem can be identified by comparing datasets that were collected at different times, e.g. before and after an event like construction of industrial infrastructure. This requires a standardized approach for collecting and organizing environmental data. Ecosystem accounts can be used to document changes in an ecosystem in a consistent and structured way (Lange *et al.*, 2022). The System of Environmental-Economic Accounts – Ecosystem Accounts (SEEA-EA) was adopted by the UN Statistical Commission in 2021 as the principal statistical framework for ecosystem accounting (UN Statistical Commission, 2021). This framework consists of a set of physical and monetary accounts, which can be divided into stock accounts (ecosystem assets) and flow accounts (ecosystem services) (Figure 1).

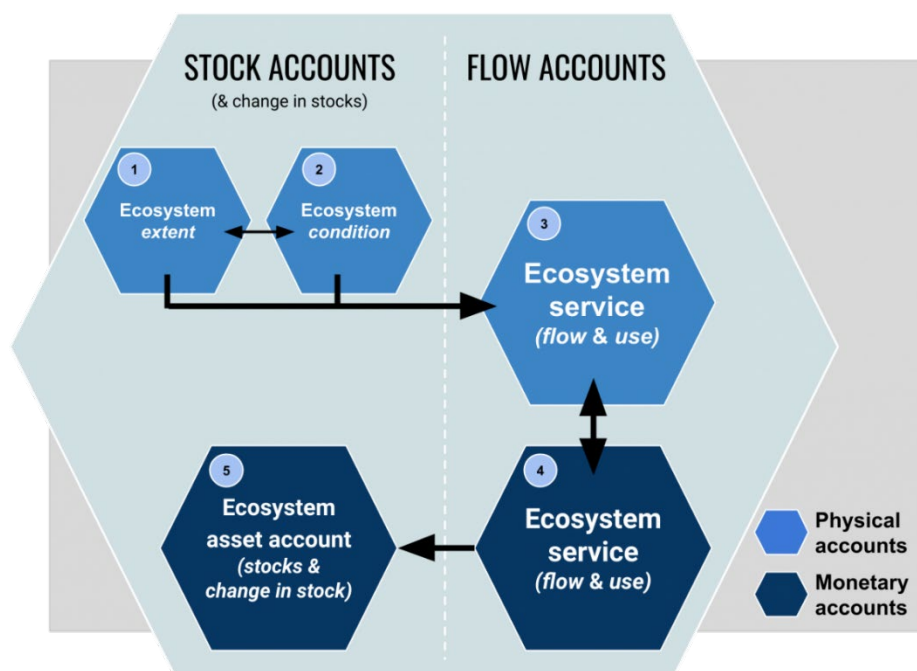


Figure 1 – Schematic overview of the elements of the SEEA-EA framework. Source: www.seea.un.org

Of this framework, the ecosystem extent account and the ecosystem condition account are the most relevant for determining the (physical) status of an ecosystem, and any changes in ecosystem status¹. Ecosystem extent accounts “record the total area of each ecosystem, classified by type within a specified area (ecosystem accounting area)” (United Nations, 2024). This requires a typology (or classification) of ecosystem types that accurately describe the ecosystem, and which can be measured in a spatial context. Ecosystem types are defined as: “specific classes of ecosystem assets of comparable ecology and ecosystem use” (EUROSTAT, 2023). Examples of ecosystem types include: “forests”, “grasslands”, “croplands”, “coral reefs”, “seagrass meadows” etc. Several ecosystem typologies have been developed for use in ecosystem accounting, such as the *Ecosystem Typology for Mapping* (Maes *et al.*, 2013), the *IUCN Global Ecosystem Typology* (Keith *et al.*, 2022), the *SEEA EEA Ecosystem Condition Typology* (SEEA ECT) (Czucz *et al.*, 2021), the *EU ecosystem typology* (EUROSTAT, 2023), and the European Nature Information System (EUNIS) (European Environment Agency, 2023). In addition, many countries have developed their own national ecosystems classification, such as the Norwegian Natur i Norge (NiN – Nature in Norway) (Halvorsen *et al.*, 2023). An ecosystem extent account typically consists of a table listing the area size (in km² or in hectares) for each ecosystem type

¹ This report is focussed on the ecosystem extent accounts and ecosystem condition accounts for Hywind Tampen. Therefore, in this report, the term “ecosystem account” refers specifically to accounts for ecosystem extent and condition.

within an area of interest: the Ecosystem Accounting Area. The sum of the area sizes of all ecosystem types cannot exceed the total area of the Ecosystem Accounting Area; there should be no spatial overlap between ecosystem types.

Ecosystem condition accounts “*record the condition of ecosystem assets in terms of selected characteristics at specific points in time. Over time, they record the changes to their condition and provide valuable information on the health of ecosystems*” (United Nations, 2024). They describe the condition of ecosystem type through a set of ecosystem characteristics (e.g. vegetation, biodiversity or carbon content). In turn, ecosystem characteristics are approximated or represented through one or more condition indicator (e.g. native vegetative cover, species richness, or net primary productivity). Determining the condition of an ecosystem is considered the most complex task of ecosystem accounting, due to the complicated interactions between species within an ecosystem, between species and their (abiotic) natural environment, and between species and human activities (Czúcz, 2021; Niner *et al.*, 2021; Luisetti and Schratzberger, 2023). Due to this complexity and the variability between ecosystems, there is no standard measuring approach, it is up to the user to determine exactly how the ecosystem condition is measured and how each indicator is scored (United Nations, 2019). As a result, the scoring of ecosystem condition indicators can take different forms, such as presence or absence (binary), percentage of coverage (range 0-100), or they can be weighted (e.g. range 0-5). In Norway, two general approaches have been proposed to assess ecological condition: the Panel-Based Assessment of Ecosystem Condition (PAEC) and the Index-Based Ecological Condition Assessment (IBECA) (Jepsen *et al.*, 2020, 2024; Jakobsson *et al.*, 2021).

Ecosystem condition is normally accounted at multiple stages (e.g. before & after an intervention, or at the beginning & end of the year or other timeframe). Alternatively, the condition of an ecosystem type can be assessed relative to a reference condition, or a baseline condition (United Nations, 2019; Maes *et al.*, 2020). Without a reference condition, one can only describe the current situation of an ecosystem indicator but not assess whether it is good or bad (increasing or decreasing).

2.2 No net loss of biodiversity

Some frameworks have been developed to use (elements of) ecosystem accounting to quantify required offsets to achieve no net loss (NNL) or biodiversity net gain (BNG) (zu Ermgassen, 2021). An example of this is the Statutory Biodiversity Metric that was developed for the calculation of biodiversity value of terrestrial habitats in the United Kingdom (Department for Environment Food & Rural Affairs, 2024). The starting point for these frameworks is typically a detailed environmental impact assessment, which include a baseline review and population assessments (Tucker *et al.*, 2020). In order to perform these assessments in a transparent and structured way, ecosystem extent and ecosystem condition accounts should be constructed (Gacutan, Pınarbaşı, *et al.*, 2022). Expected changes in ecosystem extent or condition (impacts), as a result of human interference can then be addressed according to the mitigation hierarchy (Tucker, 2020). Mitigation measures in the mitigation hierarchy include: a) measures to avoid the impact altogether, b) measures to minimize the number of different impacts, c) measures to rectify impacts (e.g. nature restoration), d) measures to reduce the severity of impacts, and e) measures for compensation or offsetting (C.E.Q., 2005). Quantify net gain or net loss in biodiversity is a major challenge in achieving NNL and requires the use of metrics (or multipliers) to standardize ecosystem accounts and their expected changes. Due to the complexity of this task, there is no common statistical approach for the identification and calculation of these metrics (Tucker, 2020). Both the environmental impact assessment and the standardization process are (at least partly) based on expert evaluation. However, this judgment evaluation is highly susceptible to bias (zu Ermgassen, 2021). In particular, the results of NNL assessments are heavily influenced by uncertainty in the identification of habitat type, such that a relatively small variation in judgment could easily lead to doubling of the required compensation area. To illustrate this, a group of seven expert grassland ecologists was asked to identify the type of grassland, based on all the available information of a pilot area (zu Ermgassen, 2021). It was found that this group of experts could not agree on the type of grassland, thus indicating the quality of information in

NNL (or similar policies) is often insufficient to reach a reliable conclusion. Furthermore, compensation measures for biodiversity loss should ensure that compensated habitats are ecologically equal to the lost areas (Souza *et al.*, 2023). Given the time scale for offset areas to reach potential equality, measuring equality is complex, time consuming and expensive. For example, replanting a forest to compensate for a lost forest might result in a similar forest, but there is no guarantee that it will attract the same animals. An alternative might be to evaluate (different) biodiversity values separately (Souza, 2023).

2.3 Challenges in marine ecosystem accounting

The development of ecosystem accounting has been geared primarily towards terrestrial systems, with little regard to the processes, typologies, and definitions that apply to marine systems (Findlay *et al.*, 2022; Gacutan, Lal, *et al.*, 2022). However, the field of marine ecosystem accounting (sometimes referred to as Ocean Accounting), is currently receiving much attention, and several pilot studies have been performed in marine systems around the world (Cummins *et al.*, 2023; Perkiss *et al.*, 2024). An overview of these attempts is presented at the end of this chapter. While standardized approaches for the accounting of marine ecosystems have not yet been fully developed, various Norwegian and international research institutes are working hard to fill this gap. It is likely that the future of marine ecosystem accounting will be based on developments from cumulative impact assessments (Halpern *et al.*, 2008, 2015) and the ODEMM (Options for Delivering Ecosystem Based Marine Management) approach (Robinson *et al.*, 2014). Still, the development of marine ecosystem accounting is lacking far behind the development of terrestrial ecosystem accounting, in terms of knowledge, methodology and the number of practical case studies (Findlay, 2022; Addamo and La Notte, 2023). To better understand why marine ecosystem accounting is so far behind in its development, it is important to understand how fundamentally different marine ecosystems are compared to terrestrial ecosystems and how the level of knowledge and available information differ between marine and terrestrial ecosystems.

2.3.1 Differences between marine and terrestrial ecosystems

Marine ecosystems are generally more complex and more dynamic than terrestrial ecosystems (GOAP, 2021; Findlay, 2022). Terrestrial ecosystems occupy a more or less 2-dimensional space, since the highest concentration of both biomass and biodiversity is in or on the ground. While most animals are mobile, they are often closely linked to ecosystem elements, such as vegetation, which are relatively stationary. In contrast, most marine organisms (including vegetation) are dynamic and may move in time and space, especially in deeper waters. They occupy a 3-dimensional space that is highly dynamic itself due to physical processes, such as currents, waves, and up- or downwelling events etc. (GOAP, 2021). As a result, seasonal variations in species composition are often more prevalent in marine ecosystems than in terrestrial systems. While entire terrestrial ecosystems may be represented by stationary species (e.g. vegetation), marine ecosystems are often insufficiently represented if only stationary species (e.g. bottom flora & fauna) are considered. A noticeable exception might be shallow (coastal) seas. Here, light reaches the seafloor, allowing macroalgae (seaweed) to grow. These algae fulfil several valuable ecological functions, including primary production and providing shelter for many marine organisms (Brodie *et al.*, 2018). Their ecological function is not unlike that of vegetation in terrestrial systems. This means that they are valuable indicators for coastal ecosystems (Juanes *et al.*, 2008). Since these algae are attached to the seafloor, they can be mapped to provide a spatial information about coastal habitats. However, mapping macroalgae is still a challenge, as they are not visible on satellite sensors struggle to penetrate the water surface. As a result, research to map macroalgae is lagging far behind the mapping terrestrial vegetation (Brodie, 2018).

Even though the marine environment is considered to be highly dynamic (e.g. currents and nutrients flow), many physical characteristics, such as temperature, salinity, and acidity (pH) are much more stable than on land (Steele *et al.*, 2019). This means that many marine organisms are not adapted to handle even small environmental changes, leaving them more vulnerable to perturbations in their environment. Despite the relative stability of some environmental characteristics (such as temperature and salinity), and despite the homogeneity of the open ocean,

marine ecosystems tend to be more biologically diversified than terrestrial ecosystems (Tadesse, 2018). Many marine species tend to be less bound to a specific location compared to terrestrial species (Carr *et al.*, 2003). In addition, the spatial scale of many marine habitats, as well as the distribution of many species, is (much) greater than that of their counterparts on land. There is also generally more interaction with prey and predator species from adjacent areas in marine ecosystems (Carr, 2003). These differences between terrestrial and marine ecosystems, and in particular the dynamic nature of marine ecosystems drastically impede the quality of marine data, compared to that of terrestrial systems (Findlay, 2022; Navarro *et al.*, 2024; Virtanen *et al.*, 2024). This leads to a high level of uncertainty in marine ecosystem accounts, which can have significant implications for management decisions (Virtanen, 2024). A particular concern is that marine ecosystem accounting currently does not include reporting of uncertainty (Navarro, 2024). This issue is acknowledged in the technical guidance for the SEEA-EA framework, but no solution is provided (United Nations, 2019).

2.3.2 Data availability

Due to the predominantly 2-dimensional characteristics of terrestrial ecosystems, ecosystem types can often be identified using satellite imagery, aerial photographs and maps. This means that information from essentially every location on earth can be relatively easily obtained. In addition, it is possible to detect changes in the landscape throughout time (at least throughout the past several decades), by comparing satellite images taken at different times. Such datasets do not exist for most of the world's oceans (Findlay, 2022; Loureiro *et al.*, 2023). For some abiotic factors, such as bathymetry, currents, salinity, and temperature, maps can be constructed, although they are often based on modelled estimates, rather than measurements. However, other abiotic factors, such as sediment type and the distribution of nutrients are often only mapped locally or in poor resolution, providing an incomplete map that may not be suitable for area-based calculations. Data on many biotic factors (including most marine organisms) is often highly fragmented and sampled at irregular time intervals (Navarro, 2024). These data often consist of samples taken at different locations and different times. While these samples inform about the species that can be found at the locations where the samples were taken, ecologists have noted that such datasets do not represent the entire ecosystem (Addamo, 2023).

2.4 Marine ecosystem accounts and marine no net loss assessments

To guide the application of the SEEA EA framework to marine systems, the Global Ocean Accounts Partnership (GOAP) developed a technical guidance on marine ecosystem accounting (GOAP, 2021). The technical guidance is compliant with the SEEA EA framework (Addamo, 2023), thus following the same structure to account the status of marine ecosystems through ecosystem extent and condition accounts. Despite this technical guidance document, there is currently no statistical standard for marine ecosystem accounting as a whole (Cummins, 2023), and in particular for the assessment of the condition of ocean ecosystems (GOAP, 2021; Luisetti, 2023). The challenges in marine ecosystem accounting (described in chapter 2.3) are consistently reflected in marine ecosystem accounting case studies. For example, most case studies were limited to marine habitats that are relatively easy to map, such as kelp forests (Chen *et al.*, 2020; Cummins, 2023). Offshore ecosystems, or ecosystems in deeper water were typically avoided. In addition, most marine ecosystem extent accounts had limited transparency, and consistently lacked information regarding data uncertainty (Cummins, 2023).

As is the case for marine ecosystem accounting, developments in NNL or Net Gain policy have been predominantly terrestrial (Edwards-Jones, 2024). One of the main challenges in marine biodiversity offsetting to achieve NNL or Net Gain is the complexity of quantifying changes in marine biodiversity, and the uncertainty this generates for restoration and compensation efforts (Niner, 2021).

NNL assessments focus specifically on the change in biodiversity, as a result of human interventions. Terrestrial NNL assessments are exclusively focused on measures to mitigate habitat loss (Edwards-Jones, 2024). While habitat loss is indeed the most important driver of biodiversity loss in terrestrial systems, it is a much less important driver in marine systems (Jaureguiberry *et al.*,

2022). Instead, climate change and direct exploitation of natural resources are far more important drivers. Effective conservation of marine ecosystems (including NNL policies) therefore require a shift in focus towards these drivers (Jaureguiberry, 2022; Edwards-Jones, 2024). On a more local scale, ecosystem impacts such as habitat displacement, artificial reef effects, area avoidance by certain species and barrier effects may be more relevant than habitat loss in marine ecosystems.

2.4.1 Marine ecosystem typology

A key requirement of ecosystem accounting is the classification or typology of (all) nature into spatially explicit ecosystem types, based on ecological functions, species composition and chemical or physical characteristics (EUROSTAT, 2023). Together, these ecosystem types should form a complete land cover, so that no part of nature is unaccounted for (Maes, 2020; Alden Hull *et al.*, 2022; EUROSTAT, 2023).

In the past, ecologists have used a similar classification to divide the world's oceans into 50 Large Marine Ecosystems, based on depth, oceanography, productivity and marine species composition (Larkin, 1996). However, each of these ecosystems has a spatial extent of at least 200.000 km², which means that they are simply too large to be of use in ecosystem accounting on a national scale, let alone a regional or project-based scale. Therefore, marine ecosystem accounting may require a slightly different classification approach than terrestrial ecosystem accounting. Nonetheless, a conceptually consistent typology is crucial for ecosystem accounting, so that it can be applied for any ecosystem, for multiple purposes and by various users (Keith *et al.*, 2020). To date, there is no clear consensus on how ecosystem types should be defined in general (Maes, 2020; Keith, 2022; Petersen *et al.*, 2022). As a result, there is little consistency in the typology of ecosystem types, especially in marine ecosystems. While there is no consensus on how to divide the seas into ecosystem types, there are some specific marine habitats that do form measurable and meaningful spatially explicit ecosystem types, such as seagrass areas, coral reefs, wetlands and mangroves (Dvarskas, 2019; Gacutan, 2022; Addamo, 2023). However, these habitats only account for a relatively small portion of the worlds' oceans.

In Norway the condition of Norwegian Sea pelagic ecosystem, the Norwegian Barents Sea shelf ecosystem and the North Sea shelf ecosystem have been assessed through a Panel-Based Assessment of Ecological Condition (PAEC) (Arneberg, Husson, *et al.*, 2023; Arneberg, Siwertsson, *et al.*, 2023; Siwertsson *et al.*, 2023). These assessments were based on the seven characteristics that represent the health of an ecosystem: 1) Primary productivity, 2) Biomass distribution among trophic levels, 3) Functional groups within trophic levels, 4) Functionally important species and biophysical structures, 5) Landscape-ecological patterns, 6) Biological diversity, and 7) Abiotic factors (Nybo and Evju, 2017). Characteristic 5 (Landscape-ecological patterns) was not considered relevant for the Norwegian Sea pelagic ecosystem. Changes in these characteristics are indicative of changes in ecosystem health (Nybo, 2017; Arneberg, 2023). Based on these seven characteristics, 23 indicators were identified to assess the condition of the Norwegian Sea pelagic ecosystem (Arneberg, 2023), 46 indicators were identified for both the Norwegian Barents Sea shelf ecosystem and the North Sea shelf ecosystem (Arneberg, 2023; Siwertsson, 2023). An overview of these ecosystem indicators is presented in Annex I.

2.5 Examples of marine ecosystem accounting

2.5.1 International examples

A number of marine ecosystem accounts have been developed in recent years. These include accounts on a national scale and regional accounts, often focussed on one specific ecosystem type (e.g. seagrass). Offshore ecosystem accounts for the open sea were severely underrepresented in the literature. Two (partial) ecosystem accounts have been made for the Dutch part of the North Sea (Schenau *et al.*, 2019; Bogaart *et al.*, 2023). A national account was made for marine ecosystems in Finland (Virtanen, 2024). Two regional marine ecosystem accounts have been made in Italy, one of which focussed on a specific region in central Italy (MPA near the Islands of Ventotene and S. Stefano) (Franzese *et al.*, 2017), while the other was focussed on one specific habitat type (seagrass beds) (Bartolini *et al.*, 2024). A regional study in Long Island

(USA) struggled to compile a complete ecosystem account, due to insufficient data availability. However, an attempt was made to create an extent and condition account, based on physical characteristics of the environment and concentrations of two species of bacteria in the water (Dvarskas, 2019). Two ecosystem accounts were made for two different mangrove areas: Illawarra and Port Phillip. These accounts used a simple indicator for vegetation degradation to account for the loss of mangrove area (Carnell *et al.*, 2022; Gacutan, 2022). A national account for marine ecosystems was made for the UK (Engledew, 2021). A regional ecosystem account was made for the Great Barrier Reef (Australia), although this account was particularly focused on ecosystem services (Yuan *et al.*, 2024). In 2023, an ecosystem account was made for a seagrass area in the Mediterranean (Addamo, 2023). Finally a national ecosystem account was developed for the island nation of Grenada in the Caribbean (Mengo *et al.*, 2022). Table 1 shows these ecosystem accounts, what sources were used for ecosystem typology and condition indicators, and whether the ecosystem account was regional or national. No project-based ecosystem accounts were found.

Table 1 – Marine ecosystem accounts throughout the world, including the sources used for identification of ecosystem types and condition indicators.

Area	Year	Ecosystem typology	Condition indicators	National or regional	Reference
Netherlands (North Sea)	2019	National typology	MSFD	National	(Schenau, 2019)
Netherlands (North Sea)	2023	EUseaMAP	MSFD	National	(Bogaart, 2023)
Finland (Baltic)	2024	MSFD, IUCN	WFD	National	(Virtanen, 2024)
Italy (2 islands central Italy)	2017	Own typology	Own indicators	Regional	(Franzese, 2017)
Italy (Posidonia seagrass beds)	2024	EUNIS, EU-seaMAP	Seagrass density	Regional (1 habitat)	(Bartolini, 2024)
USA (Long Island)	2019	Own typology	Own indicators	Regional	(Dvarskas, 2019)
Australia (Illawarra mangroves)	2022	Own typology	Own indicators	Regional	(Gacutan, 2022)
Australia (Port Phillip)	2022	Own typology	IUCN	Regional	(Carnell, 2022)
United Kingdom	2021	EUNIS	WFD	National	(Engledew, 2021)
Australia Great Barrier Reef	2024	Own typology	Own indicators	Regional	(Yuan, 2024)
Mediterranean Sea (seagrass)	2023	Only seagrass	Species	Regional	(Addamo, 2023)
Grenada	2022	Own typology	Own indicators	national	(Mengo, 2022)

2.5.2 Marine ecosystem accounting in Norway

In Norway, only one ecosystem account has been published so far. This is an ecosystem account for kelp forests along the Norwegian coast (Chen, 2020). An ecosystem extent account was made for two species of kelp, with a single indicator for biomass to express ecosystem condition. This study focused specifically on kelp, as this is a resource that is (relatively) stationary, and for which data was available. The study recognised that for other marine resources this might not be the case.

Currently two pilot projects are under development, one in Oslofjord (<https://www.marea-oslofjord.no/>) and one in the Lofoten area (Faglig Forum for Norske Havområder, 2024). However, the results have not yet been published.

3 Workshop – Challenges and opportunities for marine ecosystem accounting, case study: Hywind Tampen

3.1 Workshop content and participants

On December 11th 2024, a workshop was held at NINA in Oslo, to discuss challenges and opportunities for ecosystem accounting in the marine environment, with a particular focus on Hywind Tampen. In total 14 participants joined the workshop, including representants from Equinor and researchers from six Norwegian research institutes. In addition to NINA, researchers from NIVA, the Norwegian Mapping authority, Akvaplan-Niva, the Norwegian Environment Agency and the Norwegian Institute of Marine Research joined the workshop. Eight of the participants were present in person, while the remaining six persons joined digitally.

During the workshop, the following topics were discussed:

1. Identification of ecosystem account area & influence area
2. Relevant typology and the selection of marine ecosystem types
3. Selection procedures for indicators for ecosystem condition
4. Issues regarding differences between terrestrial and marine ecosystems
5. Issues regarding data availability
6. Limitations of ecosystem accounting frameworks for marine ecosystems
7. The potential for combining ecosystem accounts to contribute to a national ecosystem account
8. Future requirements for reporting (project-based and/or national)

3.2 Main conclusions from the workshop

One of the main conclusions from the workshop was the importance of transparency and the value of a standardized statistical framework. The SEEA EA provides such a framework, even though it is a labour-intensive task to collect the required data. Linked to this framework are several typologies for the delineation of ecosystems in ecosystem types, such as Natur i Norge and EUNIS. A comparison of the most relevant typologies is presented in chapter 4. These typologies are often broad and general, especially for marine ecosystems. Still, it is recommended to use these classifications and build on them by evaluating indicators within each classification.

It was highlighted that ecosystem accounting is used to organise and present data in a standardised way, so that it can be compared to other areas, or to assessments at a different time. Ecosystem accounts typically do not include estimations or predictions of effects. It would be possible to include modelled predictions, but it is important to validate them over a period of time.

Changes in the extent of ecosystem types and their condition can be quantified from ecosystem accounts, but they do not provide information about the cause of these changes.

There are several issues regarding ecosystem accounting in marine ecosystems. First, frameworks, definitions and statistical approaches are still under development, and especially the identification of ecosystem types and ecosystem condition indicators is not always done in a consistent manner. In order to be transparent and comparable, these standard statistical approaches need to be further developed for marine ecosystems.

Spatial scales can be challenging in marine ecosystem accounting, especially in offshore areas. Different options were discussed during the workshop, including a variable ecosystem accounts area, based on the area of impact from Hywind Tampen on different ecosystem indicators. The problem with this approach is that a uniform ecosystem account area is required in order to compare the status of different ecosystem indicators and ecosystem types.

The issue of data availability is problematic for ecosystem accounting, the main recommendation from the participants was to account for what is available and use the ecosystem accounting framework to highlight knowledge gaps.

4 Impact from offshore wind on biodiversity, case study: Hywind Tampen

This chapter starts with an overview of generic ecosystem impacts from offshore floating wind, followed by a paragraph on generic potential mitigation measures. While there is little information available about documented ecosystem effects of Hywind Tampen specifically, each of the generic ecosystem impacts described in the first paragraph can potentially occur near Hywind Tampen, and are therefore considered relevant. Some of the potential mitigation measures are less relevant for Hywind Tampen than others (some of these should be applied during the construction phase of an offshore wind park, for example), but perhaps inspiration for Hywind Tampen-specific measures can be drawn from this generic overview. The third paragraph describes the ecosystem around Hywind Tampen. In the last two paragraphs, ecosystem types and ecosystem condition indicators that are relevant to Hywind Tampen are suggested.

4.1 Generic ecosystem effects of offshore floating wind parks

An important part a no net loss assessment is to evaluate the net effect of the intervention on the ecosystem. For floating wind parks, long-term data is not yet available, which means that it is difficult to evaluate long term ecological effects (Maxwell *et al.*, 2022a). However, some potential ecosystem impacts of fixed offshore wind parks (Perrow, 2017) can be relevant for floating wind parks as well. Recently, some studies have highlighted potential impacts of floating wind parks specifically (e.g. Farr *et al.*, 2021). Finally, ecosystem impacts of floating structures in general have been discussed in a NINA report from 2022 (Follestad *et al.*, 2022).

The potential effects of offshore floating wind parks can be grouped into 6 overarching categories: 1) Entanglement, 2) Habitat alteration, 3) Collision, 4) effects of sound, light or electromagnetic fields, 5) water quality, and 6) atmospheric and oceanic effects (Farr, 2021; Maxwell, 2022a; Alawady *et al.*, 2024). Figure 2 shows some of the most important impacts of floating wind parks.

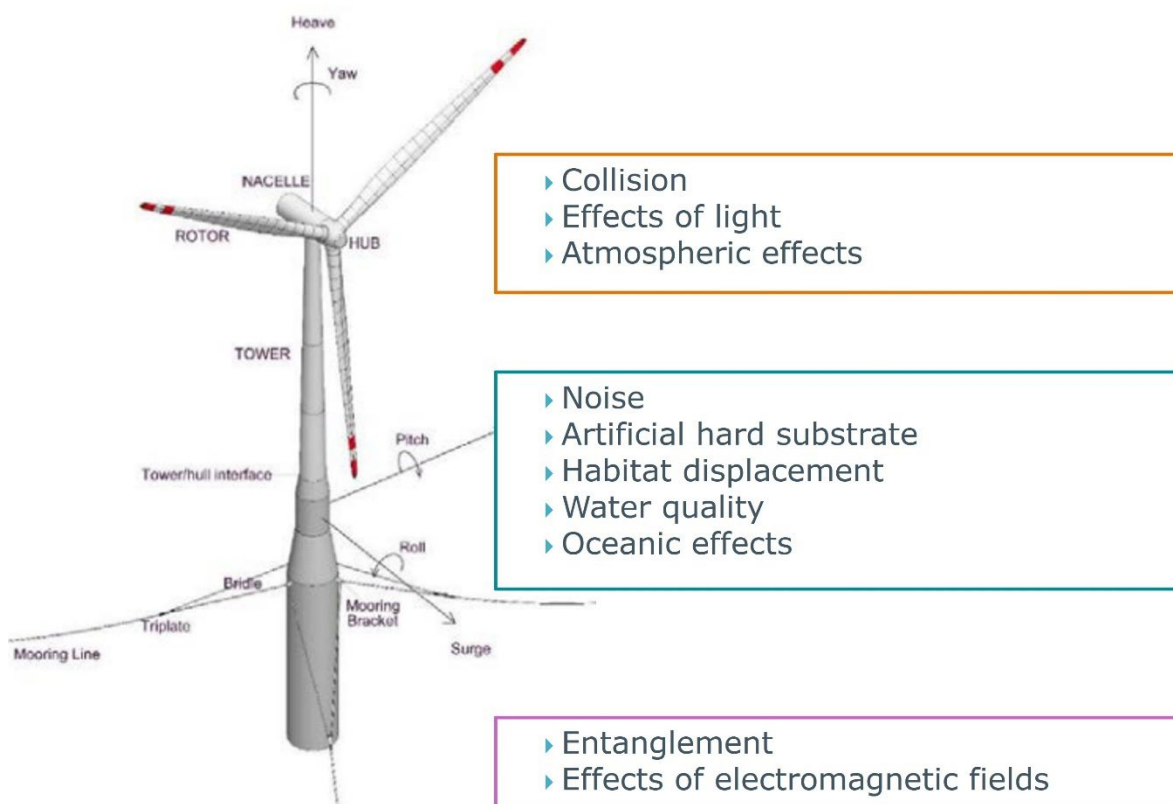


Figure 2 – Schematic representation of a floating wind turbine with the potential ecosystem effects. Image source: (Equinor, 2019)

Entanglement

Each of the 11 wind turbines at Hywind Tampen is secured to the bottom via three anchor lines, consisting of a combination of steel cables and 138mm chains (Equinor, 2019). Each anchor line is approximately 900 meters long, bringing the total combined length of anchor lines to 29.7 km. In addition, the dynamic cables (28.3 mm diameter) between the turbines have a combined length of approximately 28 km. Finally, Hywind Tampen is connected to the Gullfaks-A and Snorre-A Platforms via two electricity cables of 16 km and 12.9 km respectively. Potentially, large megafauna, specifically large whales, may become entangled in these lines and cables, especially since they occasionally use them to rub against in order to get rid of parasites. However, the risk can be regarded as relatively low, as the lines and cables are large, and relatively rigid (Benjamin *et al.*, 2014; Harnois *et al.*, 2015).

There is also a secondary risk of entanglement, which may occur when lost fishing gear or other debris gets caught in mooring lines or cables. The risk for many organisms to become entangled in this lost fishing gear or debris is perhaps greater than the risk of entanglement in the lines and cables themselves (Benjamin, 2014). However, there is little knowledge of the likelihood of this threat. No records of entanglements related to offshore floating wind have been found during the writing of this report. However, entanglement is still considered to be a potential risk, as occurrences may not be noticed. Entanglement is potentially deadly, specifically for seabirds and fish.

Habitat alteration

Habitat alteration impacts include habitat destruction or disruption, habitat displacement, barrier effects, and the creation of new (artificial) habitat (Farr, 2021; Maxwell, 2022a). The anchoring lines and cables that lay on the floor may move and interact with the bottom sediment, thus disturbing or damaging the bottom habitat. Habitat displacement occurs when the behaviour of animals is altered, because of the wind park. For example, animals might avoid the wind park, stop foraging near the wind park or travel around the wind park (Moe *et al.*, 2018). These behavioural alterations increase the energy requirements for the animal or reduces the foraging success. It is also possible that animals are attracted to the wind farm, for example due to increased foraging opportunities. Habitat alteration also includes the creation of new habitat. Anchors, cables or the submerged part of the floating turbine towers may provide artificial hard substrate for benthic organisms. This can have positive effects for the overall species richness, but it may also attract non-native species (Farr, 2021).

Collision

Two main types of collisions can be associated with offshore floating wind parks (Maxwell, 2022a). Seabirds might collide with rotating blades (Fauchald *et al.*, 2024), or marine mammals may collide with vessels that are involved with construction, maintenance or decommissioning of offshore wind parks (Rockwood *et al.*, 2017; Maxwell, 2022a). The risk of collision for birds is relatively low, due to the offshore location of Hywind Tampen. However, some risk potential was reported for the Northern Fulmar (Moe, 2018). Risk of vessel collisions with marine mammals might be lower for floating wind parks, compared to fixed-foundation wind parks, as there may be less traffic during the construction phase (Maxwell, 2022a). This is because part of the floating turbines can be constructed on land.

Effects of sound, light or electromagnetic fields

Offshore floating wind parks produce relatively low sounds, that can travel over long distances (Stöber and Thomsen, 2021). Modelled soundscapes suggest that operational sound may influence the behaviour of marine mammals within 10s of kilometres from the wind park (Madsen *et al.*, 2006; Baldachini *et al.*, 2025). Other studies suggest a more conservative radius of behavioural impact for marine mammals of 1.4 km from the wind park (Stöber, 2021). It may be theoretically possible for some marine mammals to experience temporary or even permanent shifts in hearing thresholds, but only if they are within 10s of meters from the turbines, and if they are exposed to these sound levels for 24 hours or more (Baldachini, 2025). However, this is highly unlikely, and operational sound levels from wind parks are most likely lower than that of other anthropogenic sound sources, such as sounds from cargo vessels (Madsen, 2006). The modelled soundscapes used in these studies may not adequately represent Hywind Tampen, as they

are based on different types of turbines and different environmental characteristics (depth, sediment etc.). No other studies were found that have addressed the ecological effects of sound from operational floating wind parks. Sound may also impact fish, plankton and invertebrates (Stöber, 2021), but there is insufficient information to assess the impact of sounds from offshore floating wind parks on these species groups.

It is possible that light emission from wind farms attract birds, or in other ways interfere with the behaviour of seabirds (Farr, 2021). In addition, light might have an effect on fish and plankton, but information of light effects of offshore floating wind parks on these species groups is currently lacking. The electromagnetic fields emitted from high voltage direct current cables might influence the behaviour of fish or the development (growth) of invertebrate species (Farr, 2021). However, there is currently little information available on the ecological effects of electromagnetic fields from offshore floating wind parks.

Water quality

Measures to prevent corrosion and biofouling may be used on offshore floating wind structures. These measures may emit chemical compounds and metals, which could reduce the water quality near offshore wind parks (Farr, 2021). However, given recent developments in regulations regarding anti-corrosion and biofouling coatings, impacts of offshore floating wind parks on water quality are most likely minor.

Atmospheric and oceanic effects

Offshore floating wind parks can potentially influence wind flow (Farr, 2021). Specifically, the windspeed downstream from the wind park may be reduced. However, such atmospheric effects on regional climate are most likely small. Similar effects could occur underwater, as floating wind parks have the potential to influence water movement, thus altering the stratification of water layers or the transport of nutrients (Farr, 2021; Alawady, 2024). Little is known about these effects, but they are most likely relatively minor, especially compared to fixed wind parks in shallow waters.

The level of scientific evidence for the ecosystem impact is depicted in Table 2. Overall, the level of scientific evidence for ecosystem impacts floating offshore wind parks is low, since this is still an emerging field. Table 2 also indicates the likelihood or potential for severity for each ecosystem impact.

Table 2 – The potential ecological impacts of offshore floating wind parks. The level of scientific knowledge of each effect is depicted in three categories: red = little to no knowledge available, orange = some studies available, green = well studied. The likelihood (or in some cases: potential severity) of the effect is indicated in three reversed categories: red = highly likely, orange = moderately likely, green = unlikely. These assessments are supported by a number of review studies (Farr, 2021; Maxwell et al., 2022b; Alawady, 2024; Danovaro, 2024).

Potential impact	Example	Scientific knowledge	Likelihood
Primary entanglement	Entanglement in cables or mooring lines	Orange	Green
Secondary entanglement	Entanglement in fishing gear/debris caught on cables or mooring lines	Red	Orange
Habitat displacement	Displacement from feeding/breeding sites (including barrier effects)	Red	Orange
Artificial reef effect	Cables and floating elements form artificial habitat	Orange	Red
Habitat destruction	Bottom disruption from cable movement	Orange	Red
Vessel collision	Collision of large animals with maintenance vessels	Orange	Green
Turbine collision	Collision of seabirds with blades	Orange	Green

Electromagnetic field effects	Altered behaviour due to EMF		
Noise effects	Altered behaviour due to noise *	*	
Light effects	Altered behaviour due to light		
Water quality	Chemical emission from corrosion protection measures		
Atmospheric effects	Reduction in downstream wind speed		
Oceanic effects	Changes in water movement and stratification		

* The effects of noise are studied in more detail for marine mammals than for other species groups. Therefore, it is marked as “little to no knowledge available” for most species, but marked as “some studies available” for marine mammals.

Table 3 indicates the estimated relevance of each ecological impact on different trophic levels. Overall, the local ecological effects of offshore floating wind parks are most likely relatively minor, especially in relation to floating wind parks in coastal waters, or wind parks with fixed foundations (Farr, 2021; Maxwell, 2022a). However, long term ecological impact studies are currently lacking.

Table 3 – The potential impacts of offshore floating wind parks, and how they may affect trophic levels of the marine ecosystem. Green = minor impact, orange = moderately severe impact, no colour means that there is no indication a potential impact is relevant for a group of species. These assessments are supported by a number of review studies (Farr, 2021; Maxwell, 2022b; Alawady, 2024; Danovaro, 2024).

Potential impact	Marine mammals	Seabirds	Fish	Benthic organisms	Plankton
Primary entanglement					
Secondary entanglement					
Habitat displacement					
Artificial reef effect					
Habitat destruction					
Vessel collision					
Turbine collision					
Electromagnetic field effects					
Noise effects					
Light effects					
Water quality					
Atmospheric effects					
Oceanic effects					

Shading effects of large floating structures

One potential impact that is not often discussed in literature is the potential ecological impact of introducing large floating structures to the marine environment. With the exception of floating ice sheets in the Arctic and Antarctic regions, there are no natural floating structures (Follestad, 2022). The effects of shading are not well known and should be investigated further. Compared to other floating infrastructure, such as floating solar wind facilities, floating wind turbines represent relatively small shading areas, and any potential effects are most likely relatively minor. Due to the lack of scientific literature on this topic, and the relatively small shading areas of Hywind Tampen, this potential impact is not further investigated in this report.

4.2 Potential mitigation measures for offshore floating wind parks

Here, a number of mitigation measures are discussed for each of the six ecological impact classes. The primary focus is on avoidance and reduction measures, following the mitigation hierarchy (Tucker, 2020).

Entanglement

To avoid and reduce the risk of primary entanglement (entanglement in the lines or cables) it is important to regularly monitor cable and line tension. Lines that have slack will have greater potential to entangle whales or other large organisms. In addition, the materials used to produce the lines and cables should be evaluated to ensure a smooth surface, so that lost or discarded fishing gear and debris is less likely to become caught (Maxwell, 2022a). It is possible that the colour of lines and cables makes it easier for marine mammals to see and avoid them, but this should be further investigated. An additional mitigation measure, that is perhaps more relevant for Hywind Tampen could be to regularly search for (and remove) entangled fishing gear and other debris.

Habitat disruption

The disturbance of bottom habitats by cables and lines dragging through the bottom sediment is perhaps one of the most dramatic ecological impacts of offshore floating wind parks. The total combined length of cables, chains and lines should be considered during the design phase. Burying cables might have a lower long-term impact on bottom communities than continuous disturbance by moving cables, lines and chains (Danovaro, 2024). It is unclear what potential mitigation measures might be relevant at Hywind Tampen, but any measure to reduce the potential for movement of cables and chains will help to reduce the impact on bottom habitats. Such measures may include the burying of cables and the regular monitoring of cable tension.

Collision (vessel, rotating blades)

The risk for bird collisions with rotating blades can be mitigated in several ways. First, the visibility or distinguishability of the rotating blades to birds should be maximised (Maxwell, 2022a). For example, painting patches of ultraviolet reflecting colours on the blades or the tower can help to make them more visible for birds (Danovaro, 2024). In addition, operations can be restricted during seasonal migration patterns of species of concern. Perhaps most promising is the development of automated detection technology to detect the presence of birds near the turbines. Automated detection could trigger either a bird-deterrent signal, or a pause in operations. Some of these mitigation measures are already being tested at Hywind Tampen.

The risk of vessel collision at Hywind Tampen is most likely relatively low. A potential measure to further reduce the risk of collision can be by adjusting periodic maintenance activities to overlap with known seasonal migrations of whales.

Noise, light and electromagnetic field effects

Noise produced during the construction of floating wind parks is drastically lower compared to the construction phase of wind parks with fixed foundations, as there is no need for piledriving. Very few studies have evaluated the effects of operational noise, but it is generally believed that environmental impacts of operational noise are relatively minor (Maxwell, 2022a). It is therefore not recommended to implement the use of acoustic animal deterrents and similar devices to deter marine mammals from the wind park. During certain construction or maintenance activities, the use of noise quieting technology (e.g. bubble curtains) can be considered.

The effects of light pollution on birds can be reduced by switching from white and red lights to blue and green lights (Farr, 2021). The effects of light pollution on other species are not well understood. Furthermore, lighting on offshore floating wind parks is subject to strict regulation, which may limit the opportunity to switch to other light colours.

The ecological effects of electromagnetic fields remain poorly understood (Alawady, 2024). One important reduction measure is to regularly monitor the condition of electricity cables, as wear and tear can increase the effects of electromagnetic fields. It is possible that effects from electromagnetic fields could be reduced by burying cables as much as possible, however, this needs to be investigated further (Maxwell, 2022a).

Water quality

The risk of chemical pollution from coating materials to reduce corrosion and biofouling has been much reduced with the implementation of new regulations. It is therefore thought to be a minor impact of offshore floating wind parks. However, frequent monitoring of water quality is highly recommended. Most mitigation measures related to this ecological impact are specifically relevant during the planning phase of a new floating wind park, for example in the selection of materials.

Atmospheric and oceanic effects

The atmospheric and oceanic effects of offshore floating wind parks are thought to be less severe than effects from floating wind parks in shallow waters, or than effects from fixed-foundation wind farms (Farr, 2021). Therefore, placing floating wind farms in deeper waters is an important reduction or avoidance measure. Similar to the previous ecological impact, this mitigation measure is only relevant during the planning phase of a new offshore floating wind park.

Other potential mitigation measures

In addition to these mitigation measures, there are potential compensation measures that can be applied to offshore floating wind parks. Two compensation measures that are particularly interesting could be: 1) environmental cleaning, and 2) nature inclusive design (Sella *et al.*, 2022; Pardo *et al.*, 2023; Danovaro, 2024). Environmental cleaning includes the removal of marine litter, ghost fishing gear, and abandoned infrastructures in the area near the wind park. In particular the removal of marine litter and lost or discarded fishing gear, as these likely get caught on cables, chains, lines etc. Removing these not only increases the lifespan of the cables and lines, but it also reduces the risk of animal entanglement, both at the wind park and elsewhere (in case litter is removed that was not stuck, or partly stuck). Nature inclusive design involves the deliberate deployment of artificial hard substrate to create shelters for fish and invertebrates, as well as habitat for benthic organisms (Pardo, 2023; Danovaro, 2024). With careful planning, this could have a double function, as it can also protect cables, help stabilize anchoring systems or form a protective layer between the natural bottom habitat and moving lines or chains. Natural hard substrate is rare in the North Sea, especially since the destruction of shellfish banks through bottom trawling in the 20th century in some parts of the North Sea. However, this compensation method should be investigated thoroughly, to avoid adverse effects of non-native colonising organisms. An interesting variation to this concept could be the implementation of artificial habitat in the form of resting platforms for seals (Steins *et al.*, 2021).

Finally additional measures to reduce the impact of anthropogenic activities in marine systems is the combined use of marine space through coexistence (Steins, 2021; Danovaro, 2024). Combining offshore wind with other activities, such as offshore aquaculture, seaweed- or mussel farming, reduces the total area that is affected by these activities.

4.3 Biodiversity near Hywind Tampen

Hywind Tampen is a floating offshore wind park, approximately 140 km off the coast of Norway, between Vestland County (Norway) and the Shetland Islands in Scotland. The 11 turbines are located between the oil fields Snorre and Gullfaks, at a depth of 260-300 meters on the edge of the Norwegian Trench (Equinor, 2024).

The sediment on the seafloor near Hywind Tampen consists of silty sand on the west side, and sandy mud on the east side (Vasquez *et al.*, 2023). No hard structures are reported in the vicinity of Hywind Tampen. At a depth of 260-300 meters, it is too deep for bottom vegetation (macroalgae), as sunlight does not reach the bottom. According to data from the Environmental

Monitoring Database of DNV (<https://mod.dnv.com/>), a total of 550 benthic organisms have been identified within a 20km radius of Hywind Tampen (see also Johansen *et al.*, 2022). The role of primary producers in the area is fulfilled by free-floating microalgae, or phytoplankton. The concentration of phytoplankton is relatively low (< 1,000,000 cells per litre) and dominated by small (<10µm) unidentified flagellates (Franzè *et al.*, 2021). The main group of microplankton in the area was heterotrophic/mixotrophic microzooplankton (30-200µm). Zooplankton biomass was relatively low in the area and dominated by Copepoda (Franzè, 2021). Zooplankton plays a central role in marine ecosystems, because they form an important link between phytoplankton (primary production) and species from higher levels in the food chain (Albretsen *et al.*, 2023). A total of 74 fish species have been recorded within 25 km from Hywind Tampen over the last 20 years, based on the ICES North Sea International Bottom Trawl Survey (NS-IBTS) database DATRAS (ICES, 2024). The area around Hywind Tampen overlaps with the spawning areas of four fish species: Atlantic cod (*Gadus morhua* – Norwegian: *torsk*), saithe (*Pollachius virens* – Norwegian: *sei*), haddock (*Melanogrammus aeglefinus* – Norwegian: *hyse*), and Norway pout (*Trisopterus esmarkii* – Norwegian: *øyepål*) (Sundby *et al.*, 2017). According to seabird tracking studies, 39 species of seabirds have either a seasonal or an annual distribution that overlaps with the Hywind Tampen area (Fauchald *et al.*, 2023). In addition, 8 species of cetaceans have been observed in the area during the SCANS surveys (Hammond *et al.*, 2021), and both harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) can be found in the area, based on satellite tracking studies (Russell and Mcconnell, 2014).

4.4 Ecosystem types relevant to Hywind Tampen

The EUNIS habitat classification currently describes four groups of coastal and marine habitats; M: Marine benthic habitats (MA-MG), MH: Pelagic water column, MJ: Ice-associated marine habitats and N: Coastal habitats (European Environment Agency, 2023). Of these, only Marine benthic habitats and the Pelagic water column are relevant for the Hywind Tampen area. No further subdivisions are specified for either of these groups.

The IUCN's Global Ecosystem Typology describes 24 functional groups within the marine realm, divided into 4 marine biomes; M1: Marine shelf, M2: Pelagic ocean waters, M3: Deep sea floors, and M4: Anthropogenic marine (Keith, 2022). The marine shelf biome (M1) refers to ecosystems where light still penetrates. Since the bottom at Hywind Tampen is 260-300 meters below the surface, the third biome (M3: Deep sea floors) is more appropriate. Within the Deep sea floors biome (M3), the functional groups M3.1: Continental and island slopes and M3.2 Submarine canyons are relevant. Within the pelagic ocean waters (M2), two functional groups are relevant to the Hywind Tampen area: M2.1 Epipelagic ocean waters and M2.2 Mesopelagic ocean waters. The anchoring systems of Hywind Tampen may represent the functional group M4.1: Submerged artificial structures within the biome M4: Anthropogenic marine biome. There is no functional group specified within this biome that is relevant for floating artificial structures.

The EU Ecosystem Typology (EUROSTAT, 2023) classifies ecosystems into different levels. At the first level, all marine ecosystems (coastal waters, shelf and open ocean) are grouped together. At the second level, 12 ecosystem types are recognised; 12.1 Marine macrophyte habitats, 12.2 Coral reefs, 12.3 Worm reefs, 12.4 Shellfish beds and reefs, 12.5 Subtidal sand beds and mud plains, 12.6 subtidal rocky substrates, 12.7 Continental and island slopes, 12.8 Deep-water benthic and pelagic ecosystems, 12.9 Deepwater coastal inlets (fjords) and 12.10 Sea ice. Ecosystem type 12.1 is further divided at the third level into: 12.1.1 Kelp forests, 12.1.2 Coastal macrophyte beds and 12.1.3 Seagrass meadows. However, only 12.7 (Continental and island slopes) and 12.8 (Deepwater benthic and pelagic ecosystems) are relevant for Hywind Tampen. Although the sediment around Hywind Tampen consists mainly of sand and mud, ecosystem type 12.5 (Subtidal sand beds and mud plains) is not applicable, since the subtidal zone refers to a water layer in shallow coastal areas, where sunlight (easily) reaches the seafloor (which is not the case for Hywind Tampen).

In Norway, a national classification called Natur i Norge (NIN, Nature in Norway) was developed by Artsdatabanken (Halvorsen, 2023). NiN recognises two main groups for marine ecosystems;

NA-M: Sea bottom systems (Marine bunnsystemer) and NA-S: Marine water systems (marine vannmassesystemer). NA-M and NA-S contain 23 subgroups and 11 subgroups, respectively. Relevant for Hywind Tampen are: Aphotic saltwater sediment bottom (*Afotisk saltvanns-sedimentbunn*, NA-M06), Heavily modified or new marine bottom (*Sterkt endret eller ny marin bunn*, NA-MM01), Aphotic marine water systems (*Afotiske havvannmasser*, NA-SC01) and Euphotic marine water systems (*Eufotiske havvannmasser*, NA-SA01).

The four typologies that are compared in table 4 describe similar classifications for the Hywind Tampen area. The main differences can be found in the level of detail, and in the definition of depth layers. The IUCN GET typology and the NiN typology also include a habitat for artificial structures. For the Hywind Tampen area, these two typologies are the most detailed, and they are interchangeable. In this report, the selection of ecosystem condition indicators within this report will be based on NiN. The NiN classification only describes one bottom habitat, which is suitable for the Hywind Tampen area. However, the term “aphotic” can be confusing as in some areas of the world (e.g. clear tropical waters), the euphotic zone may be extended to depths up to 1000 m. However, in the Hywind Tampen area, it is assumed that no light can penetrate > 200 meters, which means that here, the aphotic zone begins at approximately 200 meters depth. The term “mesopelagic” that is used in the IUCN is the top layer of the aphotic zone. This term may be more appropriate for deeper areas where a distinction can be made between different layers of the aphotic zone (e.g. mesopelagic and the deeper layer bathypelagic). In this report, the water surface is considered to be a part of the euphotic marine water system. The NiN category NA-NM06 is referred to as “Heavily modified or new marine bottom”, which may be confusing as it is not restricted to the bottom of the sea. In this report, the word “bottom” is replaced by “structures”, so that it also includes artificial hard structures that are higher up in the water column or even at the surface.

Table 4 – Ecosystem types that are considered relevant for Hywind Tampen, according to four commonly used typologies.

	EUNIS Habitats	IUCN Global Ecosystem Typology	EU Ecosystem Typology	Natur i Norge
<i>Seafloor (benthic)</i>	Marine benthic habitats (M)	Continental and island slopes (M3.1)	Continental and island slopes (12.7) & Deepwater benthic and pelagic ecosystems (12.8)	Aphotic* saltwater sediment bottom (NA-M06)
		Submarine canyons (M3.2)		
<i>Water column (pelagic)</i>	Pelagic water column (MH)	Epipelagic ocean waters (M2.1)		Euphotic marine water systems (NA-SA01)
		Mesopelagic ocean waters (M2.2)		Aphotic* marine water systems (NA-SC01)
<i>Artificial structures</i>	-	Submerged artificial structures (M4.1)	-	Heavily modified or new marine structures (NA-NM06)**

* Technically, the aphotic zone is not synonymous with the mesopelagic zone, but with the bathypelagic zone, where no sunlight is present at all (>1000m depth). In the mesopelagic zone (200-1000, depth) sunlight can still penetrate, but not sufficiently for photosynthesis. The NiN typology does not distinguish between the dysphotic (twilight) zone and the aphotic zone. Therefore, NiN ecosystem type NA-SC01 is thought to start just below the euphotic zone, which is referred to by the IUCN GET as the mesopelagic zone.

** The original name of this ecosystem type is: “Heavily modified or new marine bottom”, but it is changed here to “structures” as it also includes structures at the surface.

4.5 Ecosystem condition indicators relevant to Hywind Tampen

The selection of indicators is a major challenge in any ecosystem condition assessment (Czúcz, 2021; Niner, 2021; Luisetti, 2023). In national ecosystem accounts, the overall health of ecosystems within the jurisdiction of a nation is assessed. This requires a large and detailed set of ecosystem indicators, such as the lists used in the ecosystem condition assessments of the Norwegian marine habitats, listed in Annex I (Arneberg, 2023, 2023; Siwertsson, 2023). In a project-based account however, it may be more relevant to focus on indicators that can potentially be influenced by the intervention. For example, it is unlikely that variables such as primary production, temperature, pH and light attenuation will be affected by Hywind Tampen.

Combining the four NiN subgroups that apply to the Hywind Tampen area with the most relevant ecosystem effects resulted in a list of 20 ecosystem condition indicators (Table 5). These indicators are loosely based on the ecosystem condition assessments of the Norwegian marine habitats and consists of both biotic and abiotic indicators. Note that phytoplankton is also listed in the aphotic zone, despite the absence of sunlight. This is because phytoplankton can have a diurnal vertical migration pattern. Sampling phytoplankton only in the euphotic zone may therefore underrepresent the primary production. An indicator for macroalgae (seaweed that is attached to the bottom) is listed for the new hard substrate. This would be an example of a taxonomic group that is not found in this area without artificial substrate.

Table 5 – The suggested indicators for ecosystem condition, for each of the four relevant ecosystem types near Hywind Tampen.

Ecosystem type	Ecosystem Condition Indicator
<i>Aphotic saltwater sediment bottom (NA-M06)</i>	Benthic invertebrates Bottom fish Water quality Area unimpacted by cable movement
<i>Aphotic marine water systems (NA-SC01)</i>	Fish Phytoplankton Copepods Water quality Stratification Water movement
<i>Euphotic marine water systems (NA-SA01)</i>	Fish Phytoplankton Copepods Marine mammals Seabirds Water quality Stratification Water movement
<i>Heavily modified or new marine structures (NA-NM06)</i>	Benthic invertebrates Macroalgae *

* The ecosystem type “heavily modified or new marine structures” includes the floating foundations of the wind turbines, which can be colonised by macroalgae, since they are in the photic zone.

5 Suggestions for ecosystem accounting at Hywind Tampen

This chapter illustrates how ecosystem extent and condition accounts can be created for Hywind Tampen. Potential scoring criteria for the ecosystem condition indicators are suggested, and the findings of this report that are relevant specifically for Hywind Tampen are summarized in table 7.

5.1 Ecosystem extent account

Hywind Tampen consists of 11 turbines that are placed approximately 1.5 km apart. The wind park itself covers an area of approximately 9 km². The floating turbines have a concrete part under water of ~100 m and with a diameter of 18 meters. While there is no standardized method for determining the ecosystem account area in offshore projects, one approach is to base the ecosystem account area on the impact area. In this case, the largest impact range is likely to be the (potential) impact on seabirds. In a 2018 study on the impacts of Hywind Tampen on seabirds, the area that was deemed relevant for potential impacts on seabirds was defined as a 600 km² (60 km x 20 km) rectangular area (Moe, 2018), as depicted in Figure 3. The rationale for this area is a 10 km radius to account for potential impact, adjusted to align with the grid-cell structure that is used to estimate seabird density in Norwegian waters (Moe, 2018).

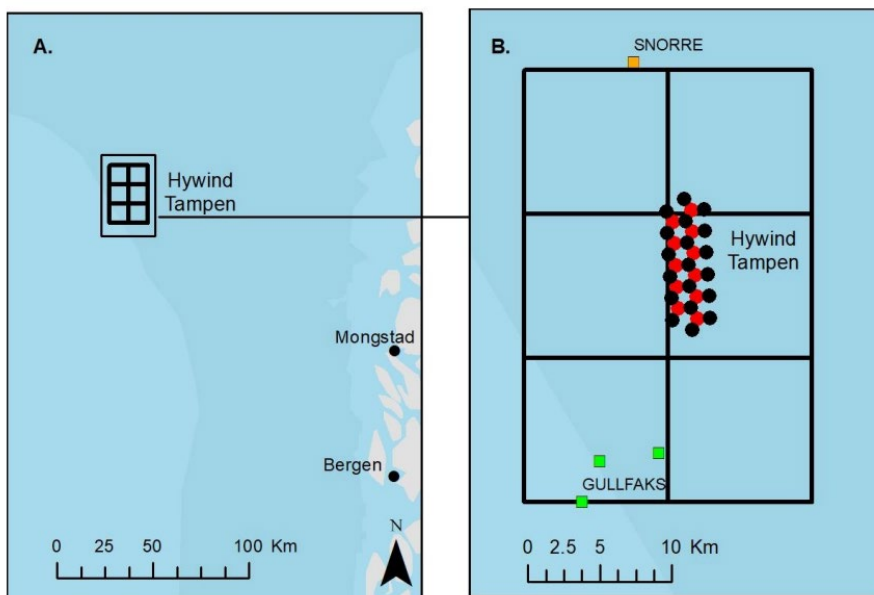


Figure 3 – The location of Hywind Tampen, with the proposed Ecosystem Accounting Area, adopted from an impact assessment for seabirds near Hywind Tampen. Figure: Moe et al. (2018)

In contrast to many terrestrial ecosystem account areas, the ecosystem account area around Hywind Tampen does not consist of a mosaic of adjacent ecosystem types. Instead, the three natural ecosystem types found in the area (based on the NiN typology) cover the full account area, each at their own depth layer; Aphotic saltwater sediment bottom (NA-M06), Aphotic marine water systems (NA-SC01) and Euphotic marine water systems (NA-SA01). From a spatial perspective (2-dimensional) these ecosystem types overlap. The absolute changes in the extent for these three ecosystem types is small, since habitat loss is not a major ecological impact of floating wind. The only true habitat loss is the area that is disturbed or damaged by cables, lines and chains that drag over the bottom, or arguably by the floating turbines and their rotating blades at the surface. Perhaps the most significant change in ecosystem extent is the addition of artificial structures, both at the bottom and at the surface, which can be represented by NiN subgroup NA-NM06 (Heavily modified or new marine bottom). The term "bottom" is replaced by "structures" in this report, since the structure of the floating wind turbines functions as an artificial substrate for sessile (benthic) organisms, even though it is not at the bottom of the sea.

A suggestion for an ecosystem extent account is presented in Table 6. The suggested total ecosystem account area is $20 \times 30 \text{ km}$ (600 km^2). As the three natural ecosystem types each encompass the entire ecosystem account area, their “original size” is also 600 km^2 . Habitat loss is not a major consequence of offshore floating wind parks, except for the area of the bottom habitat that is disturbed by anchoring systems, cables and mooring lines. The total area of lost habitat at the bottom is estimated at 22.5 km^2 (Equinor, 2019), which is the estimated area on the bottom that is affected directly or indirectly by anchoring systems, cables and mooring lines (including any movement of cables and lines). It could be argued that the total area of the wind park above the surface represents lost habitat for seabirds. This area is approximately 9 km^2 . However, this does not apply for other species in the Euphotic marine water system ecosystem type. For this reason, the air above the water surface could represent a fifth ecosystem type, only inhabited by birds. This ecosystem type is not suggested in any of the typologies mentioned in this report, as it is not listed in any classification system. The ecosystem type “Heavily modified or new marine structures” is introduced by the installation of the offshore floating wind park. For Hywind Tampen, the surface area of the submerged floating towers is calculated as $62\,150 \text{ m}^2$ (or 0.06215 km^2), based on 11 towers with a diameter of 18 meters and 100m deep.

Table 6 – Suggestion for ecosystem extent account for Hywind Tampen, based on the four ecosystem types that are relevant to this area, and the ecosystem account area, as adopted from Moe *et al.* (2018).

Ecosystem type	Original size	Change due to Hywind Tampen
Aphotic saltwater sediment bottom	600 km^2	↓ $\sim 22.5 \text{ km}^2$ (anchors and cables)
Euphotic marine water systems	600 km^2	↓ $\sim 9 \text{ km}^2$ (habitat lost to seabirds)
Aphotic marine water systems	600 km^2	No substantial change
Heavily modified or new marine structures	0 km^2	↑ 0.06215 km^2 (submerged surface areas)

5.2 Ecosystem condition account

A list of scoring criteria is listed for each of the 20 indicators for ecosystem condition. These scoring criteria are based on the ecosystem condition assessments for the Norwegian marine habitats (Arneberg, 2023, 2023; Siwertsson, 2023). It is recommended that these indicators are scored at regular time intervals, so that changes in the ecosystem condition can become apparent. A baseline should be scored before the start of the construction of new infrastructure, which can be used as a reference account. Comparing the reference account with condition accounts during the construction and during operation indicates changes in ecosystem health as a result of the wind park. Information on these indicators can be obtained through several methods. Benthic communities, both on the bottom and on hard substrate, can be studied using video systems (e.g. with remotely operated underwater vehicles) or bottom sampling. Fish in all three ecosystem types can be sampled through sampling trawls at various depths, by using video systems, by using echosounders, or through eDNA analysis (Hestetun *et al.*, 2023). Phytoplankton and copepods can be studied using eDNA analysis or net sampling. Phytoplankton concentrations at the surface can also be assessed via chlorophyll concentrations which can be assessed from satellite images (Dalpadado *et al.*, 2020). Marine mammals can be observed from dedicated surveys or with the use of hydrophone systems. Alternative detection methods for marine mammals are being investigated (e.g. fixed-wing drone surveys, eDNA metabarcoding, automatic video detection). Seabirds can be studied through ship-based surveys or with video systems. Biotelemetry studies (e.g. satellite tracking) to track seabirds, marine mammals and potentially certain fish species could also provide information about the occurrence of these species groups. Potentially, these type of studies could be used to create vulnerability maps, based on habitat suitability and sensitivity to certain stressors (Fauchald, 2024). Water quality can be assessed by analysing the content of pollutants in water, while stratification and water movement can be assessed using CTD surveys (conductivity, temperature and depth). The suggested scoring criteria for each indicator are listed below.

Aphotic saltwater sediment bottom**Indicator**

Benthic invertebrates
 Bottom fish
 Water quality
 Area unimpacted by cable movement

Scoring criteria

Species composition
 Species composition / body length
 Concentration of pollutants
 Relative benthic status (Pitcher *et al.*, 2022)

Aphotic marine water systems**Indicator**

Fish
 Phytoplankton
 Copepods
 Water quality
 Stratification
 Water movement

Scoring criteria

Species composition / body length
 Concentration / species composition
 Concentration / body length
 Concentration of pollutants
 Difference in water density at different depths
 Current direction and velocity

Euphotic marine water systems**Indicator**

Fish
 Phytoplankton/primary production
 Copepods
 Marine mammals
 Seabirds
 Water quality
 Stratification
 Water movement

Scoring criteria

Species composition / body length
 Chlorophyll concentration / species composition
 Concentration / body length
 Counts of marine mammals
 Counts of seabirds
 Concentration of pollutants
 Difference in water density at different depths
 Current direction and velocity

Heavily modified or new marine structures**Indicator**

Benthic invertebrates
 Macroalgae

Scoring criteria

Species composition / percentage coverage
 Species composition / percentage coverage

The findings of this report are summarised in Table 7, which lists the potential impacts Hywind Tampen may have on each indicator. The impacts are described as “increase”, “decrease”, “both increase and decrease”, and “unknown”. This table also describes the main impact mechanisms for each indicator, which are explained in more detail in chapter 4.1, and potential mitigation measures, which are explained in more detail in chapter 4.2. Furthermore, estimates are given for the magnitude of the potential impact, as well as for the level of existing scientific knowledge.

Table 7 – Potential impacts of Hywind Tampen, listed for each of the ecosystem indicators. The potential impact can be “increase”, “decrease”, and “unknown”. In some cases, the potential impact is marked as “both increase and decrease”, which is the case when the ecosystem indicator is impacted via two impact mechanisms with an opposing effect. The magnitude of the potential impact, and the level of scientific knowledge are estimated, based on the findings of this report. Finally, potential mitigation measures are listed. Note that these mitigation measures are relevant for offshore floating wind in general, and may or may not be applicable for Hywind Tampen.

Ecosystem type	Indicator	Potential impact	Main impact mechanisms	Magnitude of effect	Knowledge level	Possible mitigation measures
Aphotic salt-water sediment bottom	Benthic invertebrates	Both increase and decrease	Artificial reef effect & habitat destruction	High	Moderate	Ensure cable tension and/or bury cables to prevent cable movement
	Bottom fish	Both increase and decrease	Habitat displacement & electromagnetic fields	Moderate	Moderate	Monitor cable condition and/or bury cables to reduce electric field effects
	Water quality	Decrease	Chemical pollution	Low	Moderate	Monitor chemical composition of the water
	Area unimpacted by cable movement	Decrease	Habitat destruction	High	High	Ensure cable tension and/or bury cables to prevent cable movement
Aphotic marine water systems	Fish	Both increase and decrease	Artificial reef effect & secondary entanglement	Moderate	Moderate	Monitor cable condition and regularly search for/remove stuck fishing gear
	Phytoplankton	Unknown	Oceanic effects	Low	Poor	None found
	Copepods	Unknown	Oceanic effects & light effects	Low	Poor	None found
	Water quality	Decrease	Chemical pollution	Low	Moderate	Monitor chemical composition of the water
	Stratification	Decrease	Oceanic effects	Low	Poor	None found
	Water movement	Increase	Oceanic effects	Low	Poor	None found

Table is continued on the next page.

Table 7 – continued...

Ecosystem type	Indicator	Potential impact	Main impact mechanisms	Magnitude of effect	Knowledge level	Possible mitigation measures
Euphotic marine water systems	Fish	Both increase and decrease	Habitat displacement & secondary entanglement	Moderate	Moderate	Regularly search for/remove stuck fishing gear
	Phytoplankton/primary production	Unknown	Oceanic effects	Low	Poor	None found
	Copepods	Unknown	Oceanic effects & light effects	Low	Poor	None found
	Marine mammals	Both increase and decrease	Secondary entanglement, barrier effect & noise effects	Moderate	Moderate	Regularly search for/remove stuck fishing gear and monitor sound levels
	Seabirds	Decrease	Secondary entanglement, barrier effect & Turbine collision	Moderate	High	Regularly search for/remove stuck fishing gear and automated bird detection technology
	Water quality	Decrease	Chemical pollution	Low	Moderate	Monitor chemical composition of the water
	Stratification	Decrease	Oceanic effects	Low	Poor	None found
	Water movement	Increase	Oceanic effects	Low	Poor	None found
Heavily modified or new marine structures	Benthic invertebrates	Increase	Artificial reef effect	High	Moderate	Monitoring of species distribution and foodweb consequences is recommended
	Macroalgae	Increase	Artificial reef effect	High	Poor	Monitoring of species distribution and foodweb consequences is recommended

6 Further recommendations

Marine ecosystem accounting and biodiversity change assessments (e.g. no net loss) in marine ecosystems have received much less attention in literature than their terrestrial counterparts. This is largely due to the complex, 3-dimensional structure of marine ecosystems, which poses great challenges in identifying spatial explicit marine ecosystem types, measuring marine ecosystem conditions and poor data availability and quality, compared to terrestrial systems. The key factor in mitigating these challenges in ecosystem accounts is the development of common statistical frameworks for reporting ecosystem status, robust typologies that properly delineate the different marine ecosystem types, and standardized approaches for identifying, measuring and reporting ecosystem condition indicators. Accounting for biodiversity is one of the greatest challenges in achieving no net loss or biodiversity gain, especially in marine ecosystems (Luisetti, 2023). There is currently no standardized statistical framework to aid in this challenge. As a result, only a few case studies that focus on no net loss or biodiversity gain in marine systems can be found. Two consistent issues in these case studies are the overall lack of transparency in the assessments and lacking accountability for levels of uncertainty. In addition, the comparability between offsetting measures and impacted habitat is difficult to assess, which leads to concerns regarding the equality of these offsetting measures. Ecosystem accounting frameworks are statistically sound methods to report ecosystem condition, including biodiversity, which incorporate the reporting of uncertainty levels. This means that implementing an ecosystem accounting framework should improve both the transparency and comparability of biodiversity assessments.

No-net-loss assessments generally aim to counter the loss of biodiversity by offsetting measures. At a project level, this requires the estimation of the overall change in biodiversity as a result of the intervention (loss), and a similar estimation for the change in biodiversity as a result of the offsetting measures (gain). However, given the complexity of estimating biodiversity status and biodiversity change, it is highly recommended to compare offsetting measures with interventions separately for each species group. In addition, biodiversity loss is only one indicator of ecosystem condition. In marine systems ecological impact of interventions (such as floating wind parks) is not well represented by habitat loss or biodiversity loss alone.

The mechanisms through which offshore floating wind parks, such as Hywind Tampen, will affect the marine ecosystem are different from the mechanisms that are associated with terrestrial infrastructure. Specifically, it is difficult to express these impacts by describing the loss of habitat, as is often proposed in no-net-loss studies in terrestrial systems. Instead, the environmental impacts will most likely be more subtle and therefore more difficult to quantify in a spatial context. For example, a change in behaviour or a small change in the distribution of certain species might have an effect on the population, but there is no clear way to quantify this on a relatively small scale. One notable exception is the potential to map the vulnerability of seabirds, which can be used to evaluate the relative vulnerability of seabirds in prospected areas for the development of offshore wind (Fauchald, 2024). It should be noted however, that such maps have not (yet) been developed for other marine species, and, given the large quantities of required empirical data to construct these maps, it is not likely that similar maps will become available in the near future. Instead, the best available approach for estimating changes in ecosystem condition, related to offshore floating wind parks, is through Panel-Based Assessment of the Ecosystem (PAEC).

Since habitat loss is a less important driver in marine systems, changes in habitat loss or biodiversity loss alone are not representative for the full ecological impact of an intervention (such as a floating wind park). Assessing the change in ecosystem condition, via a range of indicators (including biodiversity) is therefore a much more appropriate method for marine ecosystems. A recommended approach for this is the use of ecosystem accounting frameworks, and in particular ecosystem condition accounts, which typically includes a range of different condition indicators. Comparing the same set of ecosystem indicators of interventions with those of offsets ensures a much higher level of equality between ecosystem changes from offset measures and from interventions. It also increases the level of transparency and the level of repeatability (either

by other researchers, or at a later stage). However, this means that the change in ecosystem condition is represented by an account, or a set of values, rather than a single value for change in biodiversity.

Finally, an important opportunity for offshore floating wind may be found in the form of coexistence with other industries (Nordic Energy Research, 2023; Edwards-Jones, 2024). Floating offshore wind parks have great potential for coexistence with other anthropogenic activities, such as aquaculture or fisheries, or with other initiatives for energy production, such as offshore floating solar energy facilities. Combining these interventions could reduce the sum of the ecological impact, compared to the sum of ecological impacts of two separate interventions. Coexistence may also reduce the area extent that is impacted, compared to separate interventions. Furthermore, it may be worthwhile to explore coexistence with nature based solutions, such as seaweed cultivation, which helps to reduce the buildup of greenhouse gasses, by capturing and storing large quantities of atmospheric CO₂ (Ross *et al.*, 2025).

7 References

- Addamo, A.M. and La Notte, A. (2023) *Towards an ecosystem-based approach in marine ecosystem accounting. Seagrass ecosystems in the Mediterranean Sea: from diversity to restoration*. Luxembourg: European Commission. doi:10.2760/612075.
- Alawady, A. *et al.* (2024) 'Environmental Impact Assessment of Offshore Wind Farms in Deep Waters', *E3S Web of Conferences*, 540. doi:10.1051/e3sconf/202454003004.
- Alden Hull, R. *et al.* (2022) 'Unlocking environmental accounting for healthy future landscapes', *People and Nature*, 4(5), pp. 1113–1125. doi:10.1002/pan3.10378.
- Arneberg, P. *et al.* (2023) 'Panel-based Assessment of Ecosystem Condition of the North Sea Shelf Ecosystem', 166 [Preprint]. Available at: <https://imr.brage.unit.no/imr-xmlui/handle/11250/3063093> (Accessed: 30 January 2025).
- Arneberg, P. *et al.* (2023) *Panel-based Assessment of Ecosystem Condition of the Norwegian Sea Pelagic Ecosystem*. Bergen.
- Baldachini, M. *et al.* (2025) 'Assessing the potential acoustic impact of floating offshore wind farms in the Central Mediterranean Sea', *Marine Pollution Bulletin*, 212, p. 117615. doi:10.1016/j.marpolbul.2025.117615.
- Bartolini, A. *et al.* (2024) 'Ecosystem Accounting for Marine-Based Tourism provided by *Posidonia oceanica* in Italy', *One Ecosystem*, 9. doi:10.3897/oneeco.9.e129751.
- Benjamin, S. *et al.* (2014) 'Understanding the potential for marine megafauna entanglement risk from marine renewable energy developments', *Scottish Natural Heritage Commissioned Report No. 791*, (7), p. 95. Available at: <http://www.snh.gov.uk/publications-data-and-research/publications/search-the-catalogue/publication-detail/?id=2174> (Accessed: 31 January 2025).
- Bogaart, P. *et al.* (2023) *SEEA Ocean Ecosystem Accounting for the Dutch North Sea: towards a first full implementation*. Available at: www.cbs.nl (Accessed: 15 January 2025).
- Brodie, J. *et al.* (2018) 'A comparison of multispectral aerial and satellite imagery for mapping intertidal seaweed communities', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 28(4), pp. 872–881. doi:10.1002/aqc.2905.
- C.E.Q. (2005) *Regulations For Implementing The Procedural Provisions Of The National Environmental Policy Act*.
- Carnell, P. *et al.* (2022) 'Prioritising the restoration of marine and coastal ecosystems using ecosystem accounting', *PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-1617940/v1]*, pp. 1–31. doi:10.21203/rs.3.rs-1617940/v1.
- Carr, M.H. *et al.* (2003) 'Comparing marine and terrestrial ecosystems: Implications for the design of coastal marine reserves', *Ecological Applications*, 13(1 SUPPL.), pp. 90–107. doi:10.1890/1051-0761(2003)013[0090:cmatei]2.0.co;2.
- Chen, W. *et al.* (2020) 'Ecosystem accounting's potential to support coastal and marine governance', *Marine Policy*, 112, p. 103758. doi:10.1016/j.marpol.2019.103758.
- Cummins, G.H. *et al.* (2023) 'A global review of ocean ecosystem accounts and their data: Lessons learned and implications for marine policy', *Marine Policy*, 153, p. 105636. doi:10.1016/j.marpol.2023.105636.
- Czúcz, B. *et al.* (2021) 'A common typology for ecosystem characteristics and ecosystem condition variables', *One Ecosystem*, 6, pp. 1–16. doi:10.3897/oneeco.6.e58218.
- Dalpadado, P. *et al.* (2020) 'Climate effects on temporal and spatial dynamics of phytoplankton and zooplankton in the Barents Sea', *Progress in Oceanography*, 185(April), p. 102320. doi:10.1016/j.pocean.2020.102320.
- Danovaro, R. *et al.* (2024) 'Making eco-sustainable floating offshore wind farms: Siting, mitigations, and compensations', *Renewable and Sustainable Energy Reviews*. Pergamon, p. 114386. doi:10.1016/j.rser.2024.114386.

Department for Environment Food & Rural Affairs (2024) *The Statutory Biodiversity Metric User Guide*. Available at: www.gov.uk/defra (Accessed: 28 January 2025).

Dvorskas, A. (2019) 'Experimental ecosystem accounting for coastal and marine areas: A pilot application of the SEEA-EEA in Long Island coastal bays', *Marine Policy*, 100(November 2018), pp. 141–151. doi:10.1016/j.marpol.2018.11.017.

Edwards-Jones, A. *et al.* (2024) 'Stakeholder insights into embedding marine net gain for offshore wind farm planning and delivery', *Environmental Challenges*, 14, p. 100814. doi:10.1016/j.envc.2023.100814.

Engledew, M. (2021) 'Marine accounts , natural capital , UK : 2021', pp. 1–25.

Equinor (2019) *Hywind Tampen PUD del II – Konsekvensutredning*. Available at: www.equinor.com/en/how-and-why/impact-assessments/hywind-tampen.html.

Equinor (2024) *Hywind Tampen - Equinor*. Available at: <https://www.equinor.com/energy/hywind-tampen> (Accessed: 27 January 2025).

European Environment Agency (2023) *EUNIS -EUNIS habitat types hierarchical view - revised groups*. Available at: <https://eunis.eea.europa.eu/habitats-code-browser-revised.jsp> (Accessed: 26 January 2025).

EUROSTAT (2023) 'Guidance note on ecosystem extent accounts', pp. 1–99. Available at: https://ec.europa.eu/eurostat/documents/1798247/12357920/Guidance-note-on-ecosystem-extent-accounts_2023.pdf/9d17c2ae-623f-9b4d-5c57-b1ea8c455f94?t=1702894975706 (Accessed: 22 January 2025).

Faglig Forum for Norske Havområder (2024) *Pilot marint naturregnskap - forprosjekt M-2767*.

Farr, H. *et al.* (2021) 'Potential environmental effects of deepwater floating offshore wind energy facilities', *Ocean and Coastal Management*, 207(March), p. 105611. doi:10.1016/j.ocecoaman.2021.105611.

Fauchald, P. *et al.* (2023) *Verdisetting av sjøfuglers sensitivitet for havvind i norske kyst- og havområder - NINA rapport 2184*. Trondheim. Available at: <https://hdl.handle.net/11250/3094728>.

Fauchald, P. *et al.* (2024) 'Mapping seabird vulnerability to offshore wind farms in Norwegian waters', *Frontiers in Marine Science*, 11, p. 1335224. doi:10.3389/fmars.2024.1335224.

Findlay, K. *et al.* (2022) *Exploring basic spatial units for the ocean: identifying challenges and potential solutions*. Available at: url: https://seea.un.org/sites/seea.un.org/files/lg28_1_s2_1_findlay.pdf (2022) (Accessed: 29 January 2025).

Follestad, A. *et al.* (2022) *Environmental impacts of floating bridges - NINA Report 2057*. Available at: <https://brage.nina.no/nina-xmlui/handle/11250/2837003>.

Franzè, G. *et al.* (2021) *North Sea Ecosystem Cruise. Havforskningsinstitutt cruise report Nr. 20-2021*.

Franzese, P.P. *et al.* (2017) 'Natural capital accounting in marine protected areas: The case of the Islands of Ventotene and S. Stefano (Central Italy)', *Ecological Modelling*, 360, pp. 290–299. doi:10.1016/j.ecolmodel.2017.07.015.

Gacutan, J., Pınarbaşı, K., *et al.* (2022) 'The emerging intersection between marine spatial planning and ocean accounting: A global review and case studies', *Marine Policy*, 140(September 2021). doi:10.1016/j.marpol.2022.105055.

Gacutan, J. *et al.* (2022) 'Using Ocean Accounting towards an integrated assessment of ecosystem services and benefits within a coastal lake', *One Ecosystem*, 7. doi:10.3897/oneeco.7.e81855.

GOAP (2021) *Technical Guidance on Ocean Accounting for Sustainable Development - V1, Global Ocean Accounts Partnership*.

Halpern, B.S. *et al.* (2008) 'A Global Map of Human Impact on Marine Ecosystems', *Science*, 319(5865), pp. 948–952. doi:10.1126/science.1149345.

Halpern, B.S. *et al.* (2015) 'Spatial and temporal changes in cumulative human impacts on the world's ocean', *Nature Communications*, 6(1), p. 7615. doi:10.1038/ncomms8615.

- Halvorsen, R. *et al.* (2023) *NiN 3 Systemdokumentasjon 1 (NiN3SD1)*.
- Hammond, P.S. *et al.* (2021) *Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys*.
- Harnois, V. *et al.* (2015) 'Assessment of entanglement risk to marine megafauna due to offshore renewable energy mooring systems', *International Journal of Marine Energy*, 11, pp. 27–49. doi:10.1016/J.IJOME.2015.04.001.
- Hestetun, J.T. *et al.* (2023) 'Environmental DNA reveals spatial patterns of fish and plankton diversity at a floating offshore wind farm', *Environmental DNA*, 5(6), pp. 1289–1306. doi:10.1002/edn3.450.
- ICES (2024) *Datras: Survey descriptions. NS-IBTS*. Available at: <https://datras.ices.dk/home/descriptions.aspx> (Accessed: 27 January 2025).
- Jakobsson, S. *et al.* (2021) 'Introducing the index-based ecological condition assessment framework (IBECA)', *Ecological Indicators*, 124, p. 107252. doi:10.1016/j.ecolind.2020.107252.
- Jaureguiberry, P. *et al.* (2022) 'The direct drivers of recent global anthropogenic biodiversity loss', *Science Advances*, 8(45), pp. 1–11. doi:10.1126/sciadv.abm9982.
- Jepsen, J.U. *et al.* (2020) 'Panel-based Assessment of Ecosystem Condition (PAEC). Technical protocol version 2', 40 [Preprint]. Available at: <https://brage.nina.no/nina-xmlui/handle/11250/2720073> (Accessed: 30 January 2025).
- Jepsen, J.U. *et al.* (2024) 'Panel-based assessment of ecosystem condition as a platform for adaptive and knowledge driven management', *Environmental Management*, 74(5), pp. 1020–1036. doi:10.1007/S00267-024-02042-9/FIGURES/5.
- Johansen, P.O. *et al.* (2022) *Miljøovervåking av olje- og gassfelt i Region IV, 2020*.
- Juanes, J.A. *et al.* (2008) 'Macroalgae, a suitable indicator of the ecological status of coastal rocky communities in the NE Atlantic', *Ecological Indicators*, 8(4), pp. 351–359. doi:10.1016/j.ecolind.2007.04.005.
- Keith, D.A. *et al.* (2020) *IUCN Global Ecosystem Typology 2.0: descriptive profiles for biomes and ecosystem functional groups*, *IUCN Global Ecosystem Typology 2.0: descriptive profiles for biomes and ecosystem functional groups*. doi:10.2305/iucn.ch.2020.13.en.
- Keith, D.A. *et al.* (2022) 'A function-based typology for Earth's ecosystems', *Nature*, 610(7932), pp. 513–518. doi:10.1038/s41586-022-05318-4.
- Lange, S. *et al.* (2022) 'Progress on ecosystem accounting in Europe', *Ecosystem Services*, 57(August), p. 101473. doi:10.1016/j.ecoser.2022.101473.
- Larkin, P.A. (1996) 'Concepts and issues in marine ecosystem management', *Reviews in Fish Biology and Fisheries*, 6(2), pp. 139–164. doi:10.1007/BF00182341.
- Liebel, H. and Haukland, A.K. (2024) *Pilotstudie (fase 1/2) - naturmangfoldregnskap for Equinors prosjektområde på Wergelandbasen, Sløvåg*.
- Loureiro, T.G. *et al.* (2023) 'Ocean accounts as an approach to foster, monitor, and report progress towards sustainable development in a changing ocean – The Systems and Flows Model', *Marine Policy*, 154(May). doi:10.1016/j.marpol.2023.105668.
- Luisetti, T. and Schratzberger, M. (2023) 'Including biological diversity in natural capital accounts for marine biodiversity conservation and human well-being', *Biodiversity and Conservation*, 32(1), pp. 405–413. doi:10.1007/s10531-021-02342-0.
- Madsen, P.T. *et al.* (2006) 'Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs', *Marine Ecology Progress Series*, 309(Tyack 1998), pp. 279–295. doi:10.3354/meps309279.
- Maes, J. *et al.* (2013) *An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020*, *Publications office of the European Union, Luxembourg*. doi:10.2779/12398.
- Maes, J. *et al.* (2020) 'A review of ecosystem condition accounts: Lessons learned and options for further development', *One Ecosystem*, 5, pp. 1–19. doi:10.3897/oneeco.5.e53485.

- Maxwell, S.M. *et al.* (2022a) 'Potential impacts of floating wind turbine technology for marine species and habitats', *Journal of Environmental Management*, 307(June 2021), p. 114577. doi:10.1016/j.jenvman.2022.114577.
- Maxwell, S.M. *et al.* (2022b) 'Potential impacts of floating wind turbine technology for marine species and habitats', *Journal of Environmental Management*, 307. doi:10.1016/j.jenvman.2022.114577.
- Mengo, E. *et al.* (2022) 'Marine and coastal accounts for Small Island Developing States: A case study and application in Grenada', *One Ecosystem*, 7. doi:10.3897/ONEECO.7.E84865.
- Moe, B. *et al.* (2018) 'Hywind Tampen vindpark. Vurdering av konsekvenser for sjøfugl.', 1521(1521).
- Mul, E. *et al.* (2024) *Miljøverdiregnskap for flytende vindpark Hywind Tampen. NINA prosjektnotat 540*. Tromsø.
- Navarro, M.L. *et al.* (2024) 'Embracing uncertainty in ocean accounts', *Marine Policy*, 162, p. 106040. doi:10.1016/j.marpol.2024.106040.
- Niner, H.J. *et al.* (2021) 'Exploring the practical implementation of marine biodiversity offsetting in Australia', *Journal of Environmental Management*, 295(September 2020), p. 113062. doi:10.1016/j.jenvman.2021.113062.
- Nordic Energy Research (2023) *Coexistence and nature-inclusive design in Nordic offshore wind farms*. Available at: <https://pub.norden.org/nordicenergyresearch2023-01/>.
- Nybo, S. and Evju, M. (2017) *A technical system for assessing good ecological condition. Recommendations from an expert committee*.
- Pardo, J.C.F. *et al.* (2023) 'A synthesis review of nature positive approaches and coexistence in the offshore wind industry', *ICES Journal of Marine Science*, 0(0), pp. 1–17. doi:10.1093/icesjms/fsad191.
- Perkiss, S. *et al.* (2024) 'Exploring Accounting for the Ocean: Utilisation of the Sociology of Worth to Assess Current Practice and Develop Propositions for Holistic Accounting', *Social and Environmental Accountability Journal* [Preprint]. doi:10.1080/0969160X.2024.2419913.
- Perrow, M. (2017) *Wildlife and Wind Farms-Conflicts and Solutions: Onshore: Potential Effects*. Pelagic Publishing Ltd.
- Petersen, J.E., Mancosu, E. and King, S. (2022) 'Ecosystem extent accounts for Europe', *Ecosystem Services*, 57(May), p. 101457. doi:10.1016/j.ecoser.2022.101457.
- Pitcher, C.R. *et al.* (2022) 'Trawl impacts on the relative status of biotic communities of seabed sedimentary habitats in 24 regions worldwide', *Proceedings of the National Academy of Sciences of the United States of America*, 119(2), p. e2109449119. doi:10.1073/pnas.2109449119.
- Robinson, L.A. *et al.* (2014) *Towards delivering ecosystem-based marine management: The ODEMM approach, Deliverable EC FP7 Project (244273) 'Options for Delivering Ecosystem-based Marine Management'*. University of Liverpool.
- Rockwood, R.C., Calambokidis, J. and Jahncke, J. (2017) 'High mortality of blue, humpback and fin whales from modeling of vessel collisions on the U.S. West Coast suggests population impacts and insufficient protection', *PLOS ONE*. Edited by S. Li, 12(8), p. e0183052. doi:10.1371/journal.pone.0183052.
- Ross, F.W.R., Malerba, M.E. and Macreadie, P.I. (2025) 'Global potential for seaweed aquaculture on existing offshore infrastructure', *Heliyon*, 11(1), p. e41248. doi:10.1016/J.HELIYON.2024.E41248/ASSET/5723EDC1-7DE2-4908-A27D-54AF64F1C4D4/MAIN.ASSETS/GR3.JPG.
- Russell, D.J.F. and McConnell, B. (2014) 'Seal at-sea distribution, movements and behaviour Report to DECC 14D/085', 2014(March), pp. 1–26.
- Schenau, S., Rietveld, H. and Bosch, D. (2019) 'Natural capital accounts for the North Sea: The physical SEEA EEA accounts Final report', p. 51. Available at: www.cbs.nl.
- Sella, I. *et al.* (2022) 'Design, production, and validation of the biological and structural performance of an ecologically engineered concrete block mattress: A Nature-Inclusive Design for shoreline and offshore construction', *Integrated Environmental Assessment and Management*, 18(1), pp. 148–162.

doi:10.1002/ieam.4523.

Siwertsson, A. *et al.* (2023) 'Panel-based Assessment of Ecosystem Condition of Norwegian Barents Sea Shelf Ecosystems', p. 275. Available at: <https://imr.brage.unit.no/imr-xmlui/handle/11250/3063093> (Accessed: 30 January 2025).

Souza, B.A. *et al.* (2023) 'Evaluating the potential of biodiversity offsets to achieve net gain', *Conservation Biology*, 37(4), pp. 1–14. doi:10.1111/cobi.14094.

Steele, J.H., Brink, K.H. and Scott, B.E. (2019) 'Comparison of marine and terrestrial ecosystems: Suggestions of an evolutionary perspective influenced by environmental variation', *ICES Journal of Marine Science*, 76(1), pp. 50–59. doi:10.1093/icesjms/fsy149.

Steins, N.A. *et al.* (2021) 'Combining offshore wind farms, nature conservation and seafood: Lessons from a Dutch community of practice', *Marine Policy*, 126, p. 104371. doi:10.1016/j.marpol.2020.104371.

Stöber, U. and Thomsen, F. (2021) 'How could operational underwater sound from future offshore wind turbines impact marine life?', *The Journal of the Acoustical Society of America*, 149(3), pp. 1791–1795. doi:10.1121/10.0003760.

Sundby, S. *et al.* (2017) 'Dynamic Mapping of North Sea Spawning: Report of the "KINO" Project. Fisken og Havet no. 2-2017', *Institute of Marine Research, Bergen* [Preprint], (2).

Tadesse, S.A. (2018) 'Why are marine ecosystems biologically more diversified than their equivalent terrestrial ecosystems?', *International International Journal of Avian & Wildlife Biology*, 3(4). doi:10.15406/ijawb.2018.03.00105.

Tucker, G., Quétier, F. and Wende, W. (2020) 'Guidance on achieving no net loss or net gain of biodiversity and ecosystem services', (July), p. 101. Available at: https://ec.europa.eu/environment/nature/biodiversity/nnl/index_en.htm.

UN Statistical Commission (2021) *Report of the Commission on its fifty-second session*.

United Nations (2015) *THE 17 GOALS | Sustainable Development, Department of Economic and Social Affairs | Sustainable Development*. Available at: <https://sdgs.un.org/goals> (Accessed: 27 January 2025).

United Nations (2019) *Technical Recommendations Environmental-Economic*.

United Nations (2024) *System of Environmental Economic Accounting*. Available at: <https://seea.un.org/ecosystem-accounting> (Accessed: 20 January 2024).

Vasquez, M. *et al.* (2023) 'EUSeaMap 2023, A European broad-scale seabed habitat map, Technical Report', (November). doi:10.13155/97116.

Virtanen, E.A. *et al.* (2024) 'Marine ecosystem extent and condition pilot accounts for Finland', *One Ecosystem*, 9. doi:10.3897/oneeco.9.e138839.

Yuan, M.H. *et al.* (2024) 'Exploring coral reef benefits: A systematic SEEA-driven review', *Science of the Total Environment*. Elsevier, p. 175237. doi:10.1016/j.scitotenv.2024.175237.

zu Ermgassen, S.O.S.E. *et al.* (2021) 'Exploring the ecological outcomes of mandatory biodiversity net gain using evidence from early-adopter jurisdictions in England', *Conservation Letters*, 14(6). doi:10.1111/conl.12820.

8 Annex

Ecosystem indicators for pelagic ecosystems used to evaluate the condition of the Norwegian Pelagic ecosystem and the shelf ecosystems of the Barents Sea and the North Sea (Arneberg, 2023, 2023; Siwertsson, 2023), in relation to the ecosystem characteristics as presented in (Nybo, 2017).

Table Annex 1 – Ecosystem indicators for pelagic ecosystems for Norwegian marine ecosystems (Arneberg, 2023, 2023; Siwertsson, 2023)

Ecosystem characteristic	Indicator shelf ecosystem	Indicator pelagic ecosystem
Primary productivity productivity	Annual primary productivity	Annual primary productivity
	Timing of the spring bloom	Timing of the spring bloom
Biomass distribution among trophic levels	Annual primary productivity	Annual primary productivity
	Herbivorous copepods	Mesozooplankton biomass relative to pelagic fish biomass
	Carnivorous zooplankton	
	Low trophic level fish	
	High trophic level fish	
	High trophic level seabirds	High trophic level seabirds
Functional groups within trophic levels	Holoplankton vs meroplankton	
	Copepod body size	Copepod body size
	Gelatinous zooplankton	
	Fish body size	
	Fish life history	
Functionally important species and biophysical structures	Calanus species	Calanus species
	Pseudocalanus/Paracalanus species	Pseudocalanus/Paracalanus species
	Cod stock size	
	Cod recruitment	
	Haddock stock size	
	Haddock recruitment	
	Saithe stock size	
	Saithe recruitment	
	Lesser sandeel stock size	
	Lesser sandeel recruitment	
	Norway pout stock size	
	Norway pout recruitment	
	Whiting stock size	Blue Whiting stock size
	Whiting recruitment	Blue Whiting recruitment
	Herring stock size	Herring stock size
	Herring recruitment	Herring recruitment
	Mackerel stock size	Mackerel stock size
	Mackerel recruitment	Mackerel recruitment
Northern shrimp stock size	Calanus finmarchicus production	
Northern shrimp recruitment		

Landscape-ecological patterns	Area unimpacted by bottom trawling	
Biological diversity	Fish species vulnerable to higher temperature	
	Fish species benefiting from higher temperature	
	Copepod species vulnerable to higher temperature	Copepod species vulnerable to higher temperature
	Copepod species benefiting from higher temperature	Copepod species benefiting from higher temperature
	Fish species vulnerable to fisheries	
Abiotic factors	Temperature	Heat content
		Freshwater content
		Inflow of Arctic water
	Stratification	Stratification
	Flow conditions	Inflow of Atlantic water
	Nutrients	Nutrients
	Light attenuation	
	pH	pH
	Aragonite saturation	Aragonite saturation

Norsk institutt for naturforskning, NINA, er en uavhengig stiftelse som forsker på natur og samspillet natur–samfunn.

NINA ble etablert i 1988. Hovedkontoret er i Trondheim, med avdelingskontorer i Tromsø, Lillehammer, Bergen og Oslo. I tillegg driver NINA Sæterfjellet avlsstasjon for fjellrev på Oppdal, og forskningsstasjonen for vill laksefisk på lms i Rogaland.

NINAs virksomhet omfatter både forskning og utredning, miljøovervåking, rådgivning og evaluering. NINA har stor bredde i kompetanse og erfaring med både naturvitere og samfunnsvitere i staben. Vi har kunnskap om artene, naturtypene, samfunnets bruk av naturen og sammenhenger med de store drivkreftene i naturen.

ISSN:1504-3312
ISBN: 978-82-426-5415-1

Norsk institutt for naturforskning

NINA Hovedkontor

Postadresse: Postboks 5685 Torgarden, 7485 Trondheim

Besøks-/leveringsadresse: Høgskoleringen 9, 7034 Trondheim

Telefon: 73 80 14 00, Telefaks: 73 80 14 01

E-post: firmapost@nina.no

Organisasjonsnummer 9500 37 687

<http://www.nina.no>



Samarbeid og kunnskap for framtidens miljøløsninger