Norwegian Institute for Water Research

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SUPPLEMENTARY ASSESSMENTS TO THE HELGELAND INTERMUNICIPAL MASTER PLAN FOR VEGA

Preface.

In connection with the evaluation of location of fish farms at the Vega Archipelago World Heritage area, NIVA and Instead Heritage contracted a deliverable (note) on the following tasks:
Task 1. Identify key natural features and processes of the Vega archipelago for study within a World Heritage impact assessment
Task 2. Contribute to a baseline assessment of the Vega archipelago
Task 3. Identify and predict potential impacts of proposed aquaculture projects
Task 4. Explore alternatives and mitigation

This note includes a short report on the four tasks, based on our background knowledge and relevant information. It also includes a list of relevant background literature and three appendix boxes on the kelp, maerl, and deep trench habitats. These three habitats are evaluated as vulnerable or important habitats that could potentially be affected in the near vicinity of fish farms.

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Note on supplementary assessments to the Helgeland intermunicipal master plan for Vega.

Natural features, distribution and processes of the Vega archipelago seascape.

The Vega archipelago includes about 6500 small or larger islands (a total of 165 km^2) and they have altogether a coastline of 1528 km. These long coastlines cover a marine environment with large differences in diversity, from rocky shores (the dominant shoreline) to sandy shores (soft bottoms), with distinct differences between the outermost wave exposed islands and the more sheltered bays and sounds. The sea water consists of Atlantic and coastal water, which is classified as good (Strøm & Hagen 2015). Due to a tidal range of about 2 meters there are currents between most islands that are affected by the north going coastal current and the east-west tidal currents (inwards and outwards forced by the tidal cycle).

The geomorphological landscape is dominated by a coastal flat, the so-called "strandflat" that creates relatively flat islands surrounded by shallow waters all the way from the inner- (eastern part of the larger Vega and Ylvingen islands) to the outer areas (Bremstein area almost 50 km offshore). However, there are a few deeper parts (deep holes/isolated local basins and short trenches) as well as a few higher mountains standing out from the general flat and shallow landscape. Vega is a coastal flat archipelago that is separated from the mainland by a deep trench area. Along the mainland coast, there are several fjords that reach far inland, which is increasing the water volume that are driving the tidal water transport in and out between the islands in the Vega archipelago. A coastal flat landscape is a rare landscape type that can be found along parts of the Norwegian coast and in particular along the Helgeland coast (south and north of Vega). This landscape is on its most pronounced in the Vega area. Within the archipelago shallows, some deeper trenches can be found, where the underwater landscape forms rare geomorphological habitats that can contribute to increased diversity in the marine life.

In general, the shallow marine landscape is dominated by rocky shores (bedrock or stony bottoms) with flat shallow areas between the rocky shores. Shellsand, coarse sand, and maerl beds (beds of coralline red algae balls, see Figure 3) are typical substrates/habitats on the flat and shallow bottom parts. Seagrass beds are, and have been, very rare in this area and only smaller patches has been observed. None of these seagrass beds are in the vicinity of the suggested sites for fish farms. The rocky shores are dominated by different species of brown Fucacean seaweeds (wracks) in the intertidal zone, and kelp forests in the subtidal zone. Kelp forests are dominated by tangle kelp (*Laminaria hyperborea*) in exposed areas and sugar kelp (*Saccharina latissima*) along the more sheltered coast. This underwater vegetation is found down to approximately 30 meters, however flat sandy bottoms often limit this to shallower depths. In the "Naturbase" at the Norwegian Environment Agency there are maps with different layers of nature types in the sea and on land, but not all nature types have been registered. Among the rich and productive seaweeds only *Laminaria* distribution has previously been mapped. During the last years, some *Laminaria* and most of the *Saccharina* forests have grown back in the area due to decreased sea urchin grazing (see below and Norderhaug & Christie 2009, Christie et al. 2019). The mapped marine nature types, fishing activities and fish farm sites can be found on map layers at the Directorate of Fisheries[1]. Most of the underwater nature and local fish stocks have not been mapped, while numerous observations of kelp reappearance, maerl beds, and other underwater nature data has been recorded during extensive NIVA activities at Vega, not for the purpose of filling in spatial data bases but for scientific ecological studies. Vega has been a focused site to study the relationship between kelp forests and sea urchins for years.

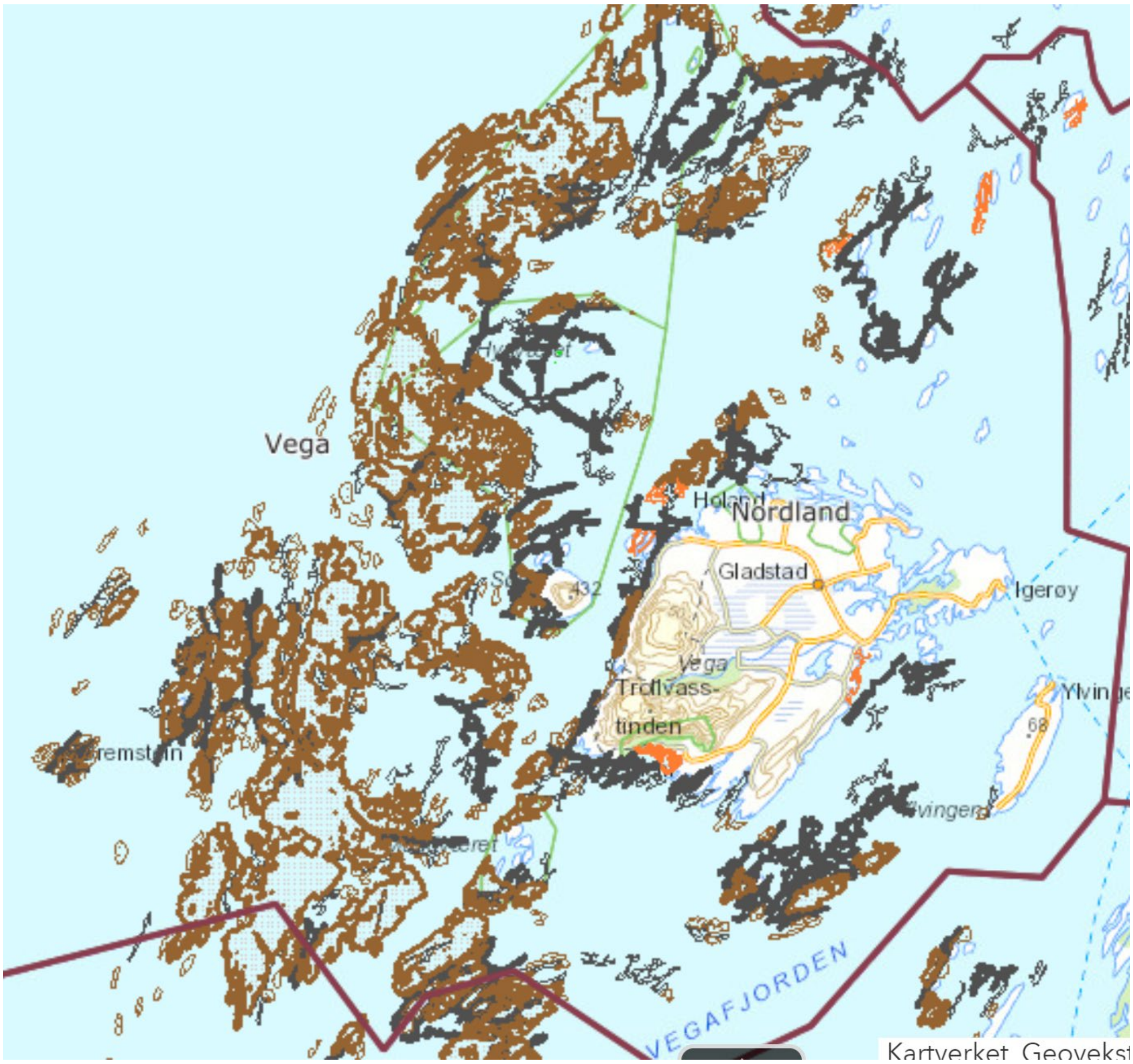

Figure 1. Distribution of kelp, shellsand and shallow soft bottom in the Vega archipelago. Brown is kelp distribution, grey is shellsand and orange is shallow soft bottom[1]. Some shellsand sites may also contain maerl.

[1] https://portal.fiskeridir.no/portal/apps/webappviewer/index.html?id=9aeb8c0425c3478ea021771a22d43476

The marine ecosystems and ecosystem services.

The above mentioned nature types are keystone elements (habitats) in rich ecosystems, particularly the extensive kelp forests (and seaweed associations in general) are rich habitats that produce food and provide shelter for a high number of species and create food chains up to shellfish, fish, seabirds (as eider ducks), and sea mammals. The kelp forests house a high diversity of benthic algae and invertebrates, and densities of small snails, crustaceans and other invertebrates have been found at a level of 100 000 per m^2 (Christie et al. 2003, 2009). Hence, the estimated 487 000 000 m^2 of potential kelp forests modelled for the Vega archipelagos may house a very high number of small animals with high biological production. The kelp forests itself produce at average 10 kg kelp biomass per m^2 per year, more in the shallow and exposed areas and less towards deeper waters. A recent study (Verbeek et al. 2021) estimated the value of kelp to be about 1.2 million Euro per km^2 per year (production of resources + other ecosystem services), making the annual value of kelp forests in Vega to about 584 million Euro. The different species of kelp and other seaweeds, maerl, sand, and deeper muddy bottoms are habitats for a variety of species and contribute to the total biodiversity of macroalgae, macrofauna and fish. Particularly the kelp forests (and to some extent the intertidal seaweeds) are important due to their extensive distribution in the area, high production, high number of associated species, and high value of the ecosystem services (food chains, fisheries, biodiversity, carbon credits, recreational activities, etc.) they provide. All the seaweeds, including kelp, serve as important nutrition to other ecosystems in addition to the kelp system itself. Smaller particles and drifting kelp are transported to the upper shore, but most of the kelp end up in the bottom areas (shallow and deeper waters), feeding the animals and food chains there (80% of the kelp production has been estimated to feed adjacent areas). The animals living on sandy bottoms, deeper soft bottoms, and maerl beds, are depending on supplies of organic material from the kelp forests or the pelagic ecosystem where the primary production take place. The kelp and seaweed systems are important due to their wide distribution in the area, while systems like maerl beds and deep trenches are rare and potentially vulnerable for discharges from fish farms, thus these three systems are described in detail in boxes in the Appendix.

Kelp and sea urchins.

Since the 1970's an estimated number of 3 billon sea urchins have grazed approximately 180 km^2 of kelp forests in the Vega archipelago, leaving the bottom as underwater deserts dominated by persisting sea urchin populations for decades (Norderhaug & Christie 2009, Gundersen et al. 2010, 2011). However, the grazing that occurred along the coast of Mid- and North Norway didn't affect the intertidal seaweeds. The sea urchin grazing entails a large loss of primary production and affects food chains, nursery areas for e.g. cod, fish and shellfish production, carbon credits and other ecosystem services, thus being a loss of value including local inshore fisheries to the Vega community and for the world heritage area. Adult eider ducks have been found to eat sea urchins, even though they are low in energy. Hence, the ongoing reappearance of productive kelp fauna (see below) represent a significant increase in available food for both chicks and adult eider ducks (and more alternative food for the enemies of the eiders). In the outermost parts of the Vega islands, kelp forests have persisted, as this area is too rough for the sea urchins. The suggested locations for two fish farms, Rørskjæran and Hysvær, are both in areas where sea urchin grazing previously occurred and in areas where both kelps species are now recovering, in a transition between exposed and more sheltered coastlines. Both locations are situated above deeper parts such as isolated deep “holes” or short trenches (160-220 m depth), within the more flat and shallow surrounding coastal landscape.

The previous decline, and more current increase, in the eider duck population have not been found to have a strong relationship with fluctuations in the marine habitats, while other factors, such as human activities, were modelled to contribute stronger to eider population dynamics (Skarpås et al. 2014). However, the reappearance of rich kelp forests may nevertheless benefit the eider ducks.

Local fishermen at Vega were among the first to report the loss of kelp forests to sea urchin grazing, and the loss of kelp resulted in termination of the inshore fishery of coastal Atlantic cod (*Gadus morhua*) according to local fishery administration statistics (personnel communication). Vega has been a central area for scientific studies of the relationship between kelps and sea urchins since 1990. During the last 10 years a reappearance of kelp has been recorded around Vega, now covering more than 50% of the former sea urchin barrens (Rinde et al. 2014, Christie et al. 2019). This pattern is expected to increase over time. The recovering kelp forests have reached the location of the two suggested fish farms, and a majority of the remaining sea urchins are now further east and north in the archipelago, however small patches of urchins are still found in the areas close to the proposed farm sites (own observations). Recovery of smaller animals and fish take place in a succession after kelp has returned to an area (own results under preparation show that recovering kelp growth are rapid, and can house juvenile codfish at an early stage, while the associated rich kelp fauna increase more slowly over time). Due to the high production and three-dimensional structure, the returning kelp forests will be beneficial to higher organisms like seabirds (including eider ducks), by increasing potential feeding grounds, which contains a variety of animals from several taxonomic groups. In addition to the positive effect of kelp recovery, future climate change can have both a positive and negative effect on different fish stocks depending on their latitudinal distribution[2]. Even though there are natural fluctuations in fish stocks, coastal cod stocks have declined along most of the Norwegian coast over the last decades.

Besides being an exceptional coastal flat (strandflat) archipelago, the Vega island area has also a value by its important scientific interest for the kelp/sea urchin systems and dynamics during more than 30 years of research. Concerning the marine organisms and nature, the ecosystem structure and function at Vega is similar to what is found along the coast of Mid Norway. Of possible special interest, Vega has two very strong and narrow tidal currents with distinct fauna at the eastern side of the main island. Both the kelp forests and other habitats, as well as the open water masses, are feeding grounds for small animals that again are food for small fish. The many islands and shallow waters with diverse habitats are favorable for numerous animals, ranging from invertebrates to fish, sea birds and sea mammals. The small fish are food for larger fish, several species of sea birds, and sea mammals (otter and two different seal species). In contrast to many fish-eating seabirds, eider ducks feed primarily on benthic invertebrates in kelp forests, between other seaweeds, or on

[2] https://www.hi.no/hi/nyheter/2022/april/hvordan-pavirkes-fiskeriene-av-klimaendringer

other shallow habitats (shellsand, sea urchin barrens etc.). The eider chicks feed on smaller crustaceans (e.g. isopods and amphipods) among the seaweeds. Among the Vega islands, several fish species, such as coastal cod and saith serve as food for different species of sea birds and sea mammals (occasionally feeding in the area of the planned fish farms) while the most vulnerable areas for the two species of seals are further offshore.

Increasing sea temperatures have facilitated a northwards expansion of the edible crab (*Cancer pagurus*) in the last decades, however, this is also depending on the rich feeding possibilities in the kelp forests. The rapidly increasing crab abundance has also raised the opportunity for a sustainable crab fishery in the area, and as the crabs are benefiting from the recovering kelp forests there may be a positive feedback enhancing the crab populations. As the crabs eat sea urchins, they are important in reducing the sea urchin abundance and thus contributing to the ongoing recovery of kelp forests. Several species of crabs are natural inhabitants of kelp forests. Thus, this increasing crab predation on sea urchins can cause a positive trend for the marine life and probably also for the local inshore fish populations, as the kelp beds are important nursery areas for several fish species.

Coastal ecosystems and fish farms.

Aquaculture/fish farms can interact with the coastal environment in different ways (Grefsrud et al. 2021). An aquaculture facility will occupy a certain surface area, but not significantly large areas compared to the wide basins and sounds between the islands of Vega. However, the proposed location of the two fish farms will cover some of the rare deeper parts in the area. Traditional fish farms will release discharges of organic particulate matter; waste feed particles, fecal matter from fish, (Torrisen et al. 2016, Grefsrud et al. 2021), nutrients from fish excretion, copper from the nets, and other chemicals depending on fish health and the method used to combat salmon lice (a small crustacean ectoparasite). Torrisen et al. (2016) give numbers of annual discharges relative to annual production of fish in a farm. Introduction of cleaner fish has been raised as alternatives to chemical or mechanical removal of the salmon lice. Cleaner fish that escape, escaping salmon, and dispersal of their lice, may all affect the wild fish and the fish fauna in the area. The mouth of the Ferset river, which contains wild salmon and trout is on the opposite side of the main island than the planned fish farms and may also be affected by salmon escapees and lice spread from other fish farms in the area. Se map of fish farm permissions in the area (Figure 2), the main water transport direction is northwards along the coast.

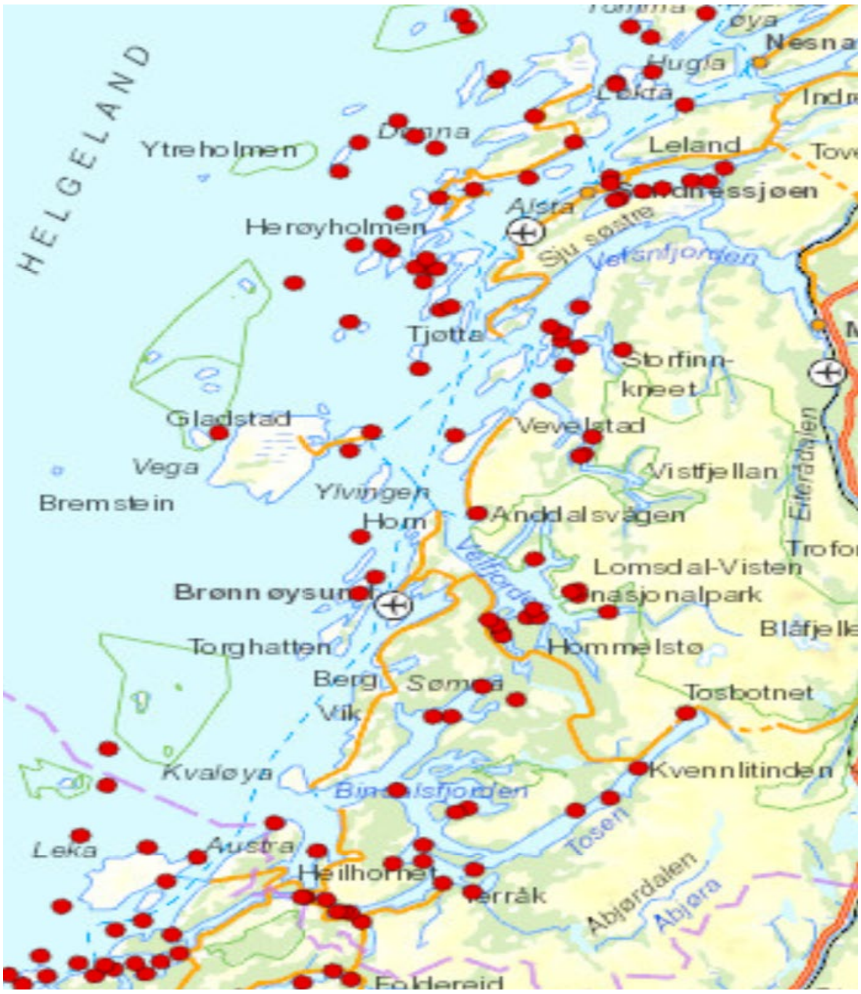

Figure 2. Map of fish farm permissions given in the Helgeland area[3].

The annual emissions of organic matter (fecal matter and feed waste) from each farm will normally be at a level of 1500 tons (most of this is fecal matters according to IMR), and nutrients (mainly nitrogen compounds) at a level of 115 tons (see Torrisen et al. 2016). These emissions may in some cases benefit natural production and food chains if efficiently dispersed by currents, and in other cases lead to negative environmental effects if deposited locally. The impregnation chemicals from the net cages are usually of less effect (information from MOWI), while different ways of lice treatment may cause problems for the nearshore areas (Wilson et al. 2004, Hall spencer et al. 2006, Legrand 2021). There are different methods to combat the challenges with salmon lice and the methods are under continuous development. Hence, it is difficult to predict how the different discharges from the planned fish farms may affect the environment without more detailed information. It is also difficult to evaluate if the combined discharges from all fish farms in the region will cause negative synergies (e.g. nutrients contributing to eutrophication effects).

[3] https://portal.fiskeridir.no/portal/apps/webappviewer/index.html?id=9aeb8c0425c3478ea021771a22d43476

The discharges from aquaculture that is likely to have largest impact on adjacent natural environments are organic matter, nutrients, and potentially chemicals used in salmon lice treatment. The extent of these effects is difficult to quantify, but experience from other studies can be used as guidelines. Deep-bottom areas may act as repositories for organic matter from fish farms, but organic matter will also be dispersed by currents, depending on the release depth from the fish cages. The deepest parts of the deep-water areas are not directly located underneath the proposed fish farms, but the farms are planned above the areas sloping towards these “holes”. Currents have not been monitored in these deeper areas, only at the bottom depths underneath the farm sites, where the MOM studies indicate good oxygen levels and good fauna conditions despite high levels of organic carbon. When these deep bottom “holes” receive additional organic loads, limited water exchange can lead to high local microbial degradation and oxygen depletion in these deeper areas. As the kelp forests have reappeared in these areas recently, increased deposition of dead kelp into these deep areas may contribute to organic load and increase oxygen consumption in the deposit basins. The deep area close to the Hysvær site is a shrimp fishery trench, indicating good conditions at present.

Organic particles are also known to affect shallower bottom habitats, and effects on maerl beds have been observed up to 1 km away from fish farms. Maerl beds are not mapped systematically in the Vega area, but such habitats are observed near the Rørskjæran site; large beds all along the coast of Sundsvoll, and among the small islands on both sides of the Søla sound (See Appendix box on maerl and Rinde et al. 2022). Both organic matter and sea lice chemicals are known to affect the maerl, and recovery time for maerl beds are long.

When only one fish farm is present in an area, the effect from nutrient release to the environment may be diluted, and negative effects are rarely observed in open waters with high coastal and tidal water currents. However, if several fish farms are located within an area, one should pay attention for possible eutrophication effects. There are many fish farms along the coast of Helgeland, and fish farms have become the largest contributor of anthropogenic nutrient discharge along the coast, from Western Norway and northwards, and potential effects may be questioned in certain recipients. Effects may be detected by increasing pelagic algal blooms and increasing growth of filamentous algae covering the kelp (see Baden et al. 2022). In addition to eutrophication, escape and reproduction of wrasse cleaner fish (fish introduced to the cages to eat salmon lice), chemical sea lice control, and pharmaceuticals may have a negative effect on the adjacent feed animals (small isopods and amphipods abundant among the seaweeds) for eider ducks, and in some cases the kelp itself. Eutrophication induced filamentous algae on kelp may reduce fauna abundance, accidentally Introduced wrasses may act as competitors to eider ducks for food, and chemicals that kill lice may also kill crustaceans in the natural habitats close to the farm. However, the effects and their extent are difficult to quantify and predict due to lack of specific information and knowledge.

A baseline assessment of the Vega archipelago marine ecosystems.

After sea urchin reduction, the health status of the Vega coast has improved because one of the most productive and rich nature types, the kelp forests, are recovering. Although the kelp beds have reappeared in the areas close to the planned fish farm sites, the ecosystems have not fully recovered yet. Studies comparing kelp beds and sea urchin barrens shows that kelp beds house far more of juvenile codfish and edible crabs, that the kelp forest systems under development house substantially more small animals than non-kelp areas, and the abundance and diversity of these animals are increasing (own results under preparation). One can expect further positive development in terms of biological production and species richness around the mid and inner parts of the archipelago, as well as more fish, crabs and food for organisms higher up in the food chain, since a major part of the kelp areas have recovered recently. Further development may be followed by monitoring but can be time consuming due to the diversity and abundance of the invertebrates.

Within the area, there are some data available on animals living in kelp, other seaweed, and maerl beds, while data on soft bottom fauna in shallow and deeper waters are scarce. However, sand and shellsand are known to house diverse fauna (infauna and epifauna), and the MOM investigations showed good faunal conditions at the soft bottom at different depth levels. The spatial and ecological extent of the kelp recovery is a large-scale positive event for Vega and the Heritage area.

Since the edible crab has moved northwards with increasing temperature and have become highly abundant around Vega and further north, it is likely that also other temperate species can expand northwards into the area. Mid Norway is an important border between temperate and northernly distributed organisms. The use of wrasses as cleaner fish in fish farms has led to introduction of these species (or strains of these species) to new areas further north (Jansson et al. 2017). During the last years we have observed wrasses and other species, e.g. the small sea urchin *Psamechinus miliaris*, to be more common at Vega (this sea urchin is not reckoned as a threat). The sea urchin *Echinus acutus* (*Gracilechinus acutus*) densities have increased dramatically further south, with negative consequences for marine benthic life in Western Norwegian fjords, a phenomenon probably related to increased organic debris from fish farms[4]. With increasing temperatures, areas close to fish farms further north should be monitored for similar outbreaks. Also, the extremely high densities of the brittle star *Ophicomina nigra* close to areas with high organic load should be given attention as well as other organisms known to increase in numbers with organic enrichment[5]. There are observations of *O. nigra* at high densities close to the existing fish farm at Igerøy (own observations), but a clear relationship cannot be documented without further investigations.

Rich maerl beds have been observed in the area near the Rørskjæran locality (Rinde et al. 2022). This nature type is known to be negatively affected by organic load from fish farms in both Scotland and The Mediterranean, almost 1 km away from the fish farms (Hall Spencer et al. 2006, Legrand 2021). Similar studies are now performed in Norway, and a guideline for monitoring such habitats are being prepared from the Institute of Marine Research (Vivian Husa, pers. com.).

[4] https://www.fishfarmingexpert.com/article/salmon-farm-nutrients-increase-numbers-of-damaging-sea-urchins/

[5] https://findresearcher.sdu.dk:8443/ws/files/170501740/1_s2.0_S0048969719342640_main.pdf

Even though the current research focus has been on the effect of organic load to deeper deposition areas, and sea lice chemicals on shrimps, there is an emerging literature and research on effects from fish farms on other organisms and habitats. As such effects are poorly understood or documented, establishment of new fish farms in pristine areas may initiate new monitoring programs adapted to the environment, where discharges are both planned and controlled.

Recent investigations show that ropes and other permanent structures at kelp farms, but also harbors and fish farms, may act as steppingstones for introduced species (own data under preparation). Hence, there should be a general awareness for new species moving northwards into the Vega area.

Potential impacts and monitoring of proposed aquaculture projects.

The effects of discharges from fish farms will depend on the amount of organic materials spread to the environment and on how the particles will be dispersed. Discharge is either dispersed by surface currents over large distances (potentially to shellsand and kelp beds but also to maerl beds as mentioned above), or to a greater extent deposited down to the deep basins from the bottom of deep fish cages. Based on the production size, provided by the fish farm companies, it is possible to estimate emission of organic materials and nutrients, but models for dispersal of the emissions are currently missing. The investigations from 2014 indicate good water flow in the shallow areas. However, the large amount of organic materials from the fish farms, combined with lower water flow in deeper layers, indicate that parts of the organic particles may end up in the deeper areas where reduced water exchange, followed by oxygen depletion, can potentially reduce bottom conditions. Hence, increased organic load from fish farms may have a limited effect on the shallow areas that are important for eider ducks or other organisms living in shallow areas, as well as the strandflat habitats, but could influence biodiversity in the rare deep bottom areas of the WHA. Consequently, currents and bottom conditions in the deepest areas (the holes) near the suggested fish farm sites should be investigated.

Maerl beds and shellsand, with their associated fauna diversity and abundance in areas close to the proposed fish farms should be monitored and thoroughly evaluated with respect to expected dispersal of materials from the farms. Even if surface currents and shallow water exchange are good, the three-dimensional structure of maerl beds may accumulate organic materials (Hall Spencer et al. 2006), and the distribution of maerl beds and their location in relation to dispersal of organic materials are not currently investigated. The abundant and diverse fauna of kelp forests have been investigated along the Norwegian coast, and it will be a very time-consuming process to monitor the kelp forest associated fauna in this context.

Another question is the preferred solution for salmon lice combat in the area; different chemical treatment, mechanical removal or by using cleaner fish. This choice will have an influence on the potential impact of the fish farms to the nearshore environment. The use of hydrogen peroxide has a negative effect on kelp and some chemicals are also known to kill shrimps and other crustaceans. However, this effect has not been studied for all “non-target” crustaceans in the adjacent habitats (that could be expected). Another concern is the potential for introduction of non-native strains of cleaner fish. There are currently several examples of translocated wrasses (used as cleaner fish) that has escaped and colonized new areas. These concerns are mentioned as question marks for further considerations.

The health situation of kelp forests near farm sites could be monitored. If nutrients and particles from the farms have an influence on fouling on the kelp, comparisons to a baseline and relevant areas further away, can be made. If fouling occurs, it is likely to be stronger close to the farms, but the proposed impact may be compensated by the extensive (ongoing) reappearance of kelp forests within the large areas in the WHA.

In cases where activities from the fish farms affect the marine environment, a stop in the salmon production is likely to lead to a restoration towards natural conditions for most of the habitats. E.g. the kelp forest is based on a key species (kelp) with a limited lifespan and the kelp and associated species is adapted to regular exchanges. On the other hand, habitats as maerl beds and shellsand take much longer to establish, and restoration of affected habitats will be a slow process. The recovery of any deep bottom "holes" will depend on water exchange and is expected to be vulnerable for organic load.

As already mentioned, several of the potential impacts from fish farms may only be of local scale. However, there is a scaling effects of emissions from an increasing number of fish farms in a region, where each farm will contribute to unwanted effects. Increasing temperature and eutrophication further south have resulted in increasing turf algal growth, changing sugar kelp communities to degraded systems. Possible shifts due to climate change and northwards expansions of environmental and biological processes (mentioned earlier) may interact with effects from fish farms, but these are not clear knowledge-based predictions. Other disturbances, such as increased boat traffic, tourist fishing, recreation activities, kelp trawling (currently occurring south of Vega), intertidal seaweed harvest (not occurring at Vega at present), may affect eider ducks or marine life, but not interact directly with fish farms. However, many small "piece-by-piece disturbances" should be considered, as the combined effects may become significant.

Explore alternatives and mitigation.

As fish farms need deep-water sites, there are few alternative farm sites within the shallow strandflat areas in the Vega WHA. Thus, the sites are vulnerable for further biological production if serious environmental effects emerge. It is likely that expansion of established fish farms or alternative fish farm locations around Vega have been explored. Alternatives may be to reduced production in the proposed farms or to choose only one of the farms for production. If only one farm turns out to be the preferred option, a thorough evaluation should include several factors and solid fact-based evaluations should be performed before conclusions are drawn.

As mentioned, the emissions from a fish farm are either affecting the habitats in a negative way or could potentially have a positive effect by increasing the production of plankton as well as elements in the food chains. If the fish cages are of a shallow type, most of the emissions may be dispersed in the upper water layers. Emission to these upper layers where the currents are stronger, can result in relatively rapid dilution of nutrients, and dispersal of organic matter to the deeper deposition areas can potentially be reduced.

The use of lumpsucker (*Cyclopterus lupus*) of local origin as cleaner fish (instead of wrasses), as an alternative to chemical use should be considered, as lumpsucker is a native species to the kelp forests in the area.

There may also be alternative activities/industries in the area. Cultivation of seaweed stands out as an environmental-friendly and green industry, with potential for future development in terms of both volume and further processing of various products. Other "open-water farm" initiatives such as growing mussels or tunicates could be other alternatives. Such activities represent sustainable, low trophic aquaculture industries, that alongside with kelp farming can contribute to removing excess nutrients and particles from the water masses and even enhance food organisms for e.g. eider ducks. Other suggestions are marine "kitchen gardens", including sampling of marine species for niche food restaurants or smaller enterprises. Harvesting of sea urchins have also been suggested as an industry, but as they are declining around Vega the future for this is not promising.

For a general evaluation and management of fish farms in protected areas, this evaluation is mainly based on the special conditions at the suggested sites, the threats related to the area, and the specific factors important for this WHA. However, certain points of evaluation may be general, and an evaluation of synergistic or cumulative factors on local and more regional scale may be of general importance. A changing world by both climatic, environmental, and technological development may alter the evaluations and predictions. Many of the reports and evaluations for the Vega fish farms are more than five years old, and it is advisable that this information is updated.

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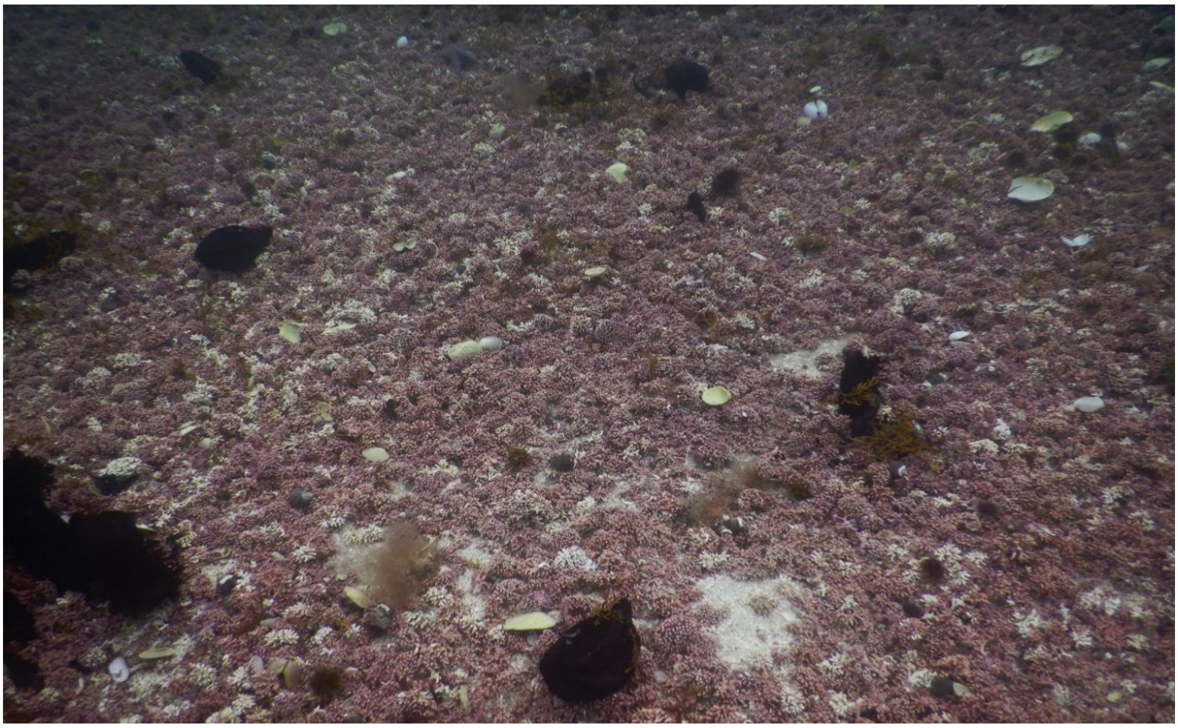


Figure 3. Maerl bed. Photo: NIVA.

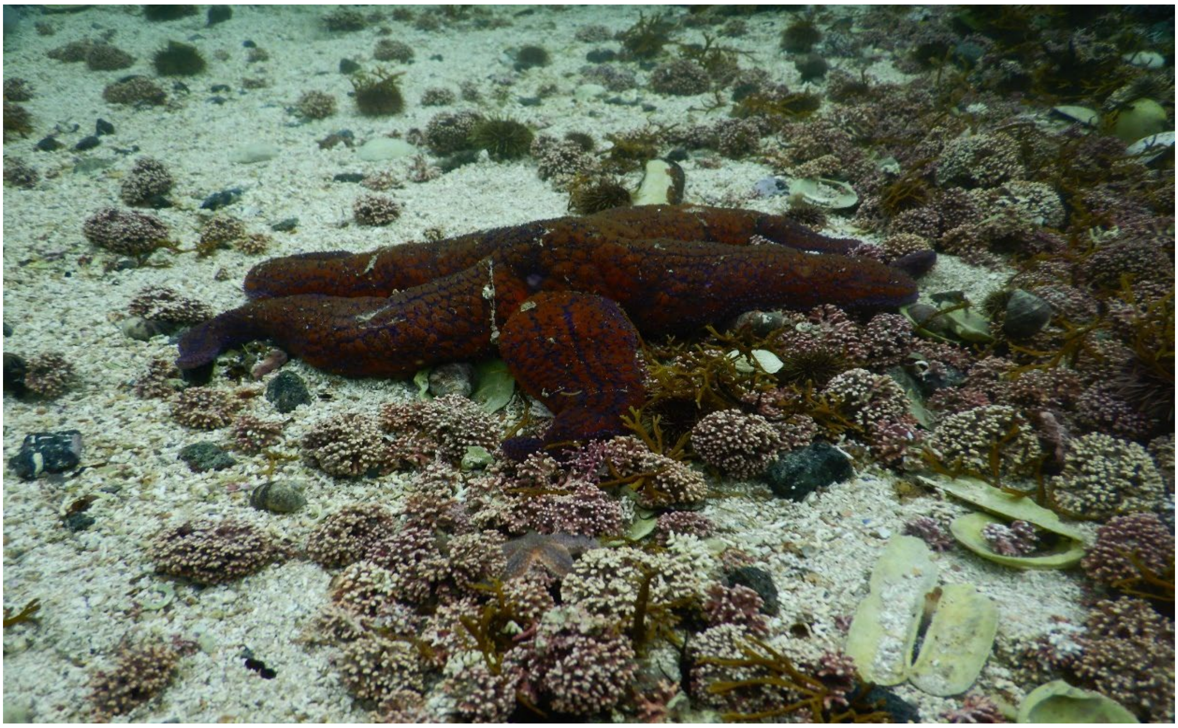
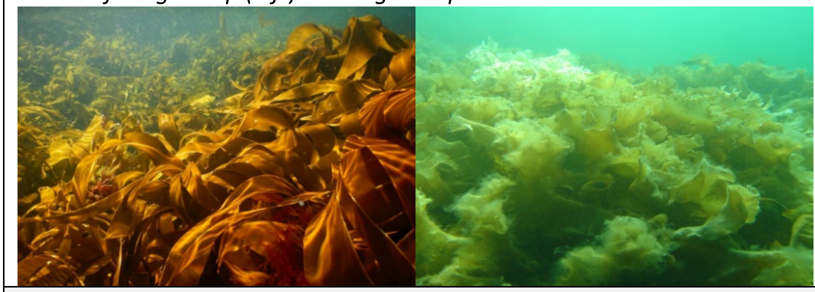
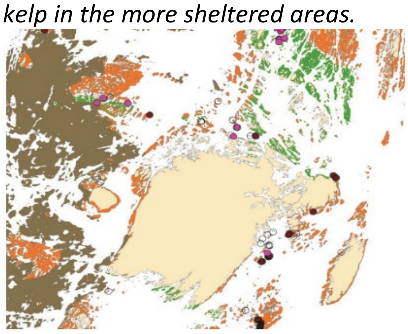


Figure 4. Shellsand and maerl. Photo: NIVA.

Figure 5. Kelp bed. Photo: NIVA.

Figure 6. Sea urchins grazing leave little left of other organisms. Photo: NIVA.

APPENDIX (Boxes with characterisation of three important and potentially vulnerable habitats; kelp forest, maerl bed and deep trench).

GENERAL OVERVIEW:
Habitat category:
Marine ecosystem, subtidal from surface to about 30 m depth.
Habitat type:
Kelp forest.
Habitat representativity / distinctiveness:
Common habitat on rocky shores all along the Norwegian coast. Mainly two kelp species are important for building this highly productive and diverse ecosystem. The kelp forests are increasing at Vega due to reduction of grazing sea urchins. Important habitat for production and shelter for fish and other animals.
Habitat status:
☐ Critically Endangered ☐ Endangered ☒ Vulnerable ☐ Near Threatened ☒ Least Concern *Even if the habitat is abundant and in good condition at the Vega islands, the kelp and its associated animals are vulnerable for local and regional disturbances.*
Image:
Forest of tangle kelp (left) and sugar kelp. Photo: NIVA. 
Locations:
Only tangle kelp has been mapped in the Vega area (brown shading on map), see: (https://portal.fiskeridir.no/portal/apps/webappviewer/index.html?id=9aeb8c0425c3478ea021771a22d43476). *Kelp forests are now common all around the Vega islands, tangle kelp at exposed sites and sugar kelp in the more sheltered areas.* 

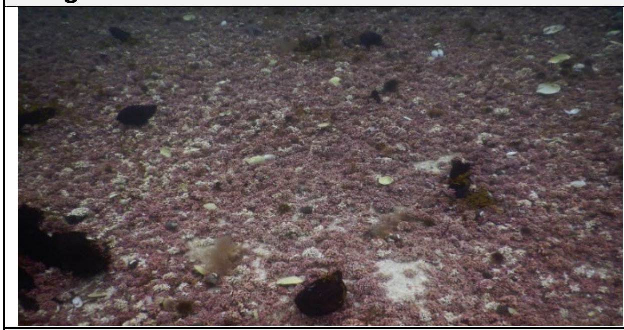
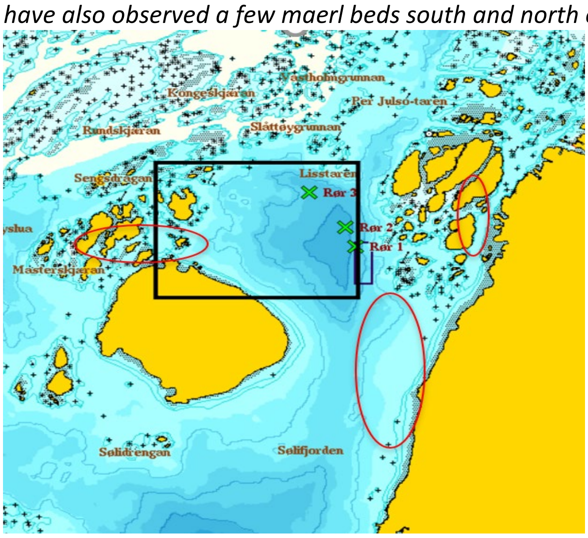
PHYSICAL CHARACTERISTICS:
Depth / height asl:
Tangle kelp may create up to 2 m high upright forests, while sugar kelp has long leaves closer to the bottom. Kelp are plants that liv in the upper 20-30 m zone depending on light conditions.
Bathymetry / topography:
Kelp is living on most bottom topography except for vertical walls.

Substrate / soil characteristics:
Kelp is fastened with their holdfasts to hard substrate as bedrock, stones, and also to artificial surfaces.
Currents / climate:
The tangle kelp is dominating where wind/waves and currents are strong, and sugar kelp is taking over at more sheltered sites among the islands. Potential temperature increase (climate change) will not be a threat to kelp at the Vega latitude.

BIOLOGICAL CHARACTERISTICS:
Dominant and keystone plant species:
Laminaria hyperborea (tangle kelp) and Saccharina latissima (sugar kelp) are the two keystone kelp species. Other seaweeds, such as the intertidal brown seaweeds, may give similar ecosystem services.
Dominant and keystone animal species:
Thousands of small crustaceans, snails, mussels and worms are key species in transfer of energy from the kelp production up the food chain, to fish and crabs. Different species of fish belonging to e.g. the cod family are key fish species in this system.
Threatened or protected species:
The kelp forests and its inhabitants are common along the Norwegian coast. Kelp in general, and thus the whole ecosystem, have been threatened by sea urchin grazing, and sugar kelp has been threatened by eutrophication further south. The urchins are disappearing at the Vega area, and severe eutrophication problems have so far not been observed in the area.
Biological processes related to dominant and keystone species:
The very high production in kelp forests are important for food chains up to fish, crabs, sea mammals and sea birds. The three-dimensional structure of kelp provide shelter and serve as important nursery grounds for juvenile fish species such as cod. The high numbers of benthic animals living in the kelp forests are important food for e.g. eider ducks.

FACTORS AFFECTING THE HABITAT:
Environmental trends:
The trend seems positive for the kelp forests as the sea urchins are declining in the area. While the kelp themselves are increasing, the pattern of recovery of the entire ecosystem is unknown.
Human interactions:
There are at present no human activities affecting the kelp activity in the Vega WHA. There are planned kelp trawling south of Vega, of the tangle kelp resources in the sectors allowed for such harvest. Discharges from fish farms, particularly the salmon lice chemicals may harm both kelp and local animals, depending on the lice treatment method. There are no known analyses of direct interactions between the activities related to kelp forests, but multiple activities affecting the kelp forest may have additional effects.

RESEARCH:
Key publications and data:
See reference list on kelp forest, kelp and sea urchins. There are numerous publications on kelp related topics available.
Knowledge gaps:
We know that kelp recovers quickly after disappearance of sea urchins, but we do not know the succession of the recovery of the whole diverse ecosystem. Laboratory experiments have shown the salmon lice chemicals to affect natural non-target animals, but there have not been direct studies of the effects on kelp fauna. As the intertidal seaweeds have similar ecological characteristics as the kelps, these systems should be further studied.

GENERAL OVERVIEW:
Habitat category:
Marine ecosystem, subtidal from surface to more than 30 m depth.
Habitat type:
maerl bed.
Habitat representativity / distinctiveness:
This habitat is not recognised or mapped, but is found commonly along the Norwegian west coast, particularly in mid- and northern Norway.
Habitat status:
☐ Critically Endangered ☐ Endangered ☒ Vulnerable ☐ Near Threatened ☐ Least Concern *The status is unknown because it is poorly mapped and not easy to discover.*
Image:
 *Photo: NIVA.*
Locations:
Maerl beds are found in the same areas as shellsand, on flat bottoms. We have observed maerl beds south (Sundsvoll), west (north side of Søla) and east (between islands) of the Rørskjæran locality. We have also observed a few maerl beds south and north of Vega.  *Maerl beds are found in the areas marked by red circles but are not more detailed mapped or bounded.*

PHYSICAL CHARACTERISTICS:
Depth / height asl:
Mearl are characterised as beds where more than 25% of the bottom are covered by live (pink) maerl balls (preliminary suggestion). Live maerl is coralline red algal balls of variable forms, depending on light and can live down to 30 m depth and sometimes further down. The maerl "balls" create a three-dimensional substrate 5-10 cm deep.

Bathymetry / topography:
Maerl beds are found on flat bottoms.
Substrate / soil characteristics:
Maerl beds are found on flat bottoms mainly on shellsand substrate.
Currents / climate:
Maerl beds are mainly found on sites with currents; sites with good water exchange, but not where wave action is too strong.

BIOLOGICAL CHARACTERISTICS:
Dominant and keystone plant species:
Lithothamnion sp. and *Phymatolithon sp. More species have been determined by genetic methods.*
Dominant and keystone animal species:
It is a wide diversity of animals (invertebrates such as worms, small crustaceans, snails and mussels) living among the three-dimensional structures of maerl balls. So far this is poorly investigated at the Norwegian coast. Juvenile sea urchins are often abundant in these habitats.
Threatened or protected species:
The maerl species may be threatened by physical and chemical disturbances and should probably be protected. If the maerl becomes affected and die, the animals using maerl beds as habitat will be affected.
Biological processes related to dominant and keystone species:
The slow growing maerl is probably of low value as food or energy supporting any food chain, and the animals living in the maerl bed are likely to depend on organic materials from elsewhere. The animals in maerl beds are potential food organisms for e.g. eider ducks.

FACTORS AFFECTING THE HABITAT:
Environmental trends:
There are no indication of environmental trends affecting the maerl beds, but reservations may be taken as these habitats are poorly understood.
Human interactions:
Maerl beds have been affected by organic materials from fish farms, at least in the areas adjacent to the farms (magnitude of 1 km). Also, chemicals used to combat salmon lice have been found to affect maerl. Eutrophication leading to filamentous algal growth may cover and kill maerl. Dredging is detrimental.

RESEARCH:
Key publications and data:
Hall-Spencer J, White N, Gillespie E, Gillham K, Foggo A. 2006. Impact of fish farms on maerl beds in strongly tidal areas. Marine Ecology Progress Series, 326: 1-9. *Hall-Spencer JM. 1998. Conservation issues relating to maerl beds as habitats for molluscs. Journal of Conchology Special Publication, 2: 271-286.* *Legrand E, Kutti T, Gonzalez Casal EV, Rastrick SPS, Andersen S, Husa V. 2021. Reduced physiological performance in a free-living coralline alga induced by salmon feces deposition. Aquaculture Environment Interactions 13: 225-236.* *Legrand E. 2021. Effect of sea lice chemotherapeutant hydrogen peroxide on the photosynthetic characteristics and bleaching of the coralline alga Lithothamnion soriferum. Abstract to NHF årsmøte 2021.*
Knowledge gaps:
There is a need for more mapping and knowledge to make predictions of where to find maerl. The ecological role of maerl beds should be investigated, as well as vulnerability and recovery speed.

GENERAL OVERVIEW:

Habitat category:

Marine habitat, subtidal.

Habitat type:

Deep trench bottoms (also named deep holes as they are restricted deep sites surrounded by shallow areas).

Habitat representativity / distinctiveness:

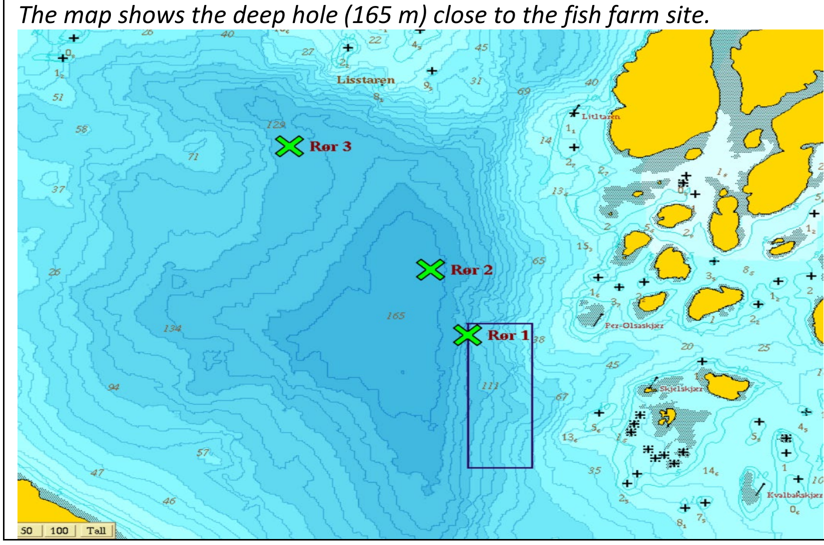
These habitats could be distinct for regions with extensive shallow coastal flats. They are not particularly focussed along the coast, but they will probably be focussed as carbon sequestration hot spots.

Habitat status:

☐ Critically Endangered ☐ Endangered ☒ Vulnerable ☐ Near Threatened ☐ Least Concern

Locations:

The map shows the deep hole (165 m) close to the fish farm site.



PHYSICAL CHARACTERISTICS:

Depth / height asl:

The deep hole bottom is at 165 m depth.

Bathymetry / topography:

The bottom of the hole is expected to be flat.

Substrate / soil characteristics:

Soft bottom of mud/clay.

Currents / climate:

Such deep holes are expected to have limited water movements. The MOM C investigation revealed good water quality in this particular deep hole, but the high organic content in the sediments indicate a deposition area.

BIOLOGICAL CHARACTERISTICS:

Dominant and keystone plant species:

No plants live at such depths.

Dominant and keystone animal species:

A diversity of infauna and epifauna occur rather than some dominant species. By increasing organic deposition some tolerant species will dominate.

Threatened or protected species:
All species living in the sediment in the deep hole will be threatened by organic depositions that lead to oxygen depletion. Mobile epifauna and fish may abandon the area.
Biological processes related to dominant and keystone species:
Not known, but the deep holes are more rare than important for biological processes in the coastal ecosystem.

FACTORS AFFECTING THE HABITAT:
Environmental trends:
Probably not affected under normal conditions.
Human interactions:
The marine life in deep holes may be severely affected by increasing organic load, e.g. depositions from fish farms. Due to limited water exchange the degradation of organic material will lead to reductions of oxygen levels and even dead bottoms.

RESEARCH:
Key publications and data:
Strøm V, Hagen L. 2015. MOM C-undersøkelse ved oppdrettslokalitet Rørskjæran i Vega kommune, Nordland, juli 2015. Aqua Kompetanse AS rapport.
Knowledge gaps:
Possible amount of deposition from the fish farm to the deepest part and the effect on oxygen conditions and fauna.