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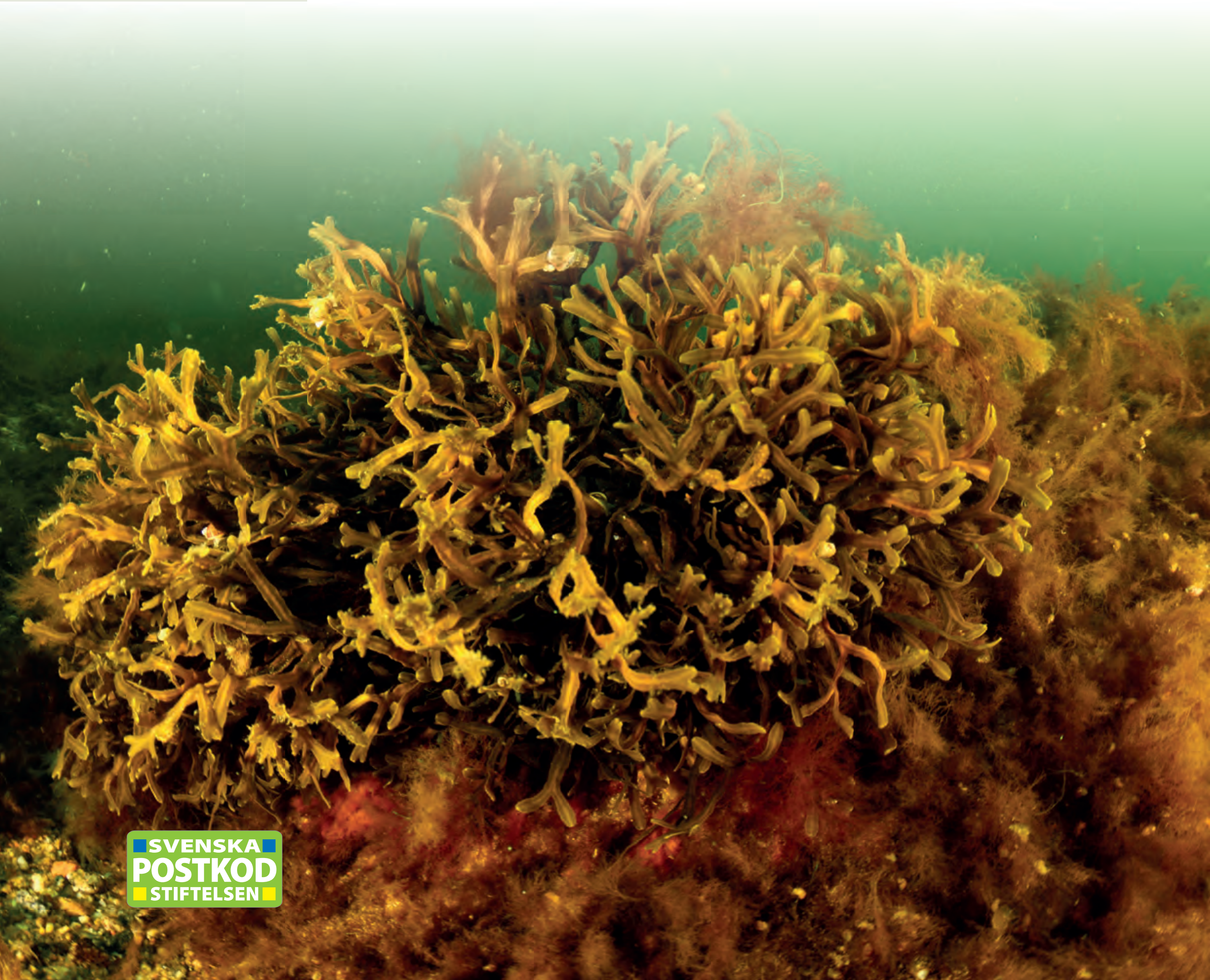
Protection beyond borders: An opportunity for the Quark



SVENSKA POSTKOD STIFTELSEN

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Acknowledgements:
Oceana is grateful to the County Administrative Board of Västerbotten, especially Johnny Berglund and Carlos Paz von Friesen, for their help and insights regarding the habitats and species of the Quark, and for aiding in identifying data gaps. We also thank Parks & Wildlife Finland, particularly Roosa Mikkola, for assistance and sharing knowledge about the habitats, species, and features of the Quark, before, during and after the expedition. Further thanks are due to the Centre for Economic Development, Transport and the Environment in South Ostrobothnia, especially Hans-Göran Lax and Vincent Westberg, for their assistance regarding the habitats and species of the Quark, and for helping to identify data gaps. The Finnish Environment Institute also kindly provided support with permits and clarifying data needs.

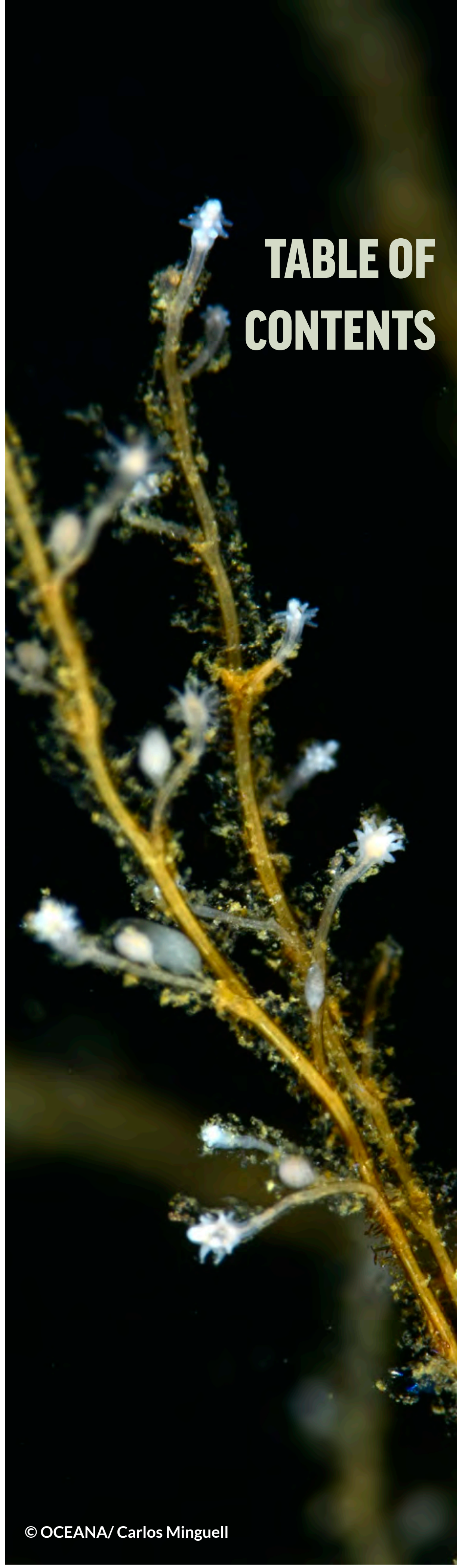
Oceana warmly thanks the captains, crew, and divers from the expedition for their hard work and assistance.

This project was made possible thanks to the generous support of the Svenska Postkod Stiftelsen.

Recommended citation: Hamberg, A., Perry, A.L., Blanco, J., Aguilar, R., Álvarez, H., Stavenow, J. and H. Paulomäki. 2019. Protection beyond borders: An opportunity for the Quark. Oceana, Madrid. 64 pp.

Cover: © OCEANA/ Carlos Minguell

Design: Neo Estudio Gráfico, S.L.



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EXECUTIVE SUMMARY

Shared between Finland and Sweden, the Quark is a shallow, narrow sub-basin in the northern Baltic Sea that separates the nearly-freshwater Bothnian Bay from the more saline Bothnian Sea. The marked variation in salinity across the waters of the Quark is reflected in its flora and fauna; the area hosts a unique mix of marine, brackish, and freshwater species. It represents an important area for breeding or migration of various fish and bird species, and is home to an array of threatened species and habitats. The importance of the Quark has been internationally recognised, through the identification of the entire area as an Ecologically and Biologically Significant Area under the United Nations Convention on Biological Diversity, and the designation of one area (the *Kvarken Archipelago*) as part of a UNESCO World Heritage Site, on the basis of its geological value.

Despite the known ecological importance of the Quark, protection of marine life in the area is relatively limited. A patchwork of assorted types of marine protected areas (MPAs) covers nearly one-third of the waters of the Quark – but many of these sites do not entail any specific measures to conserve natural marine features. Overlapping designations, fragmented information about sites, and gaps in knowledge about the distributions of species and marine habitats further complicate the situation, making it difficult to assess real levels of marine protection in the area and to ensure that marine life is effectively safeguarded.

To help advance the protection of the Quark, Oceana carried out a research expedition in 2018 that aimed to fill identified data gaps and to document the biodiversity value of the area's marine life and unique features. Surveys were carried out on both the Finnish and Swedish sides of the Quark, primarily via SCUBA divers, a drop video camera, and infaunal grab sampling. In total, the research documented one-third of all known macrospecies described from the Quark and ten habitat types, including habitats that had previously been well-surveyed (such as fladas) as well lesser-known ecosystems (such as offshore reefs).

On the basis of its biodiversity importance and the range of threats facing marine life in the area, Oceana proposes that Finland and Sweden establish a transboundary MPA in the Quark sub-basin. Critically, this MPA should be underpinned by a joint management plan addressing the key habitats and species and the threats they face – which are very similar on both sides of the border. Such an area would be the most appropriate means of protecting marine biodiversity in the Quark, and would build on the strong foundation of cross-border collaboration between the two countries that has already been developed in the region.

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INTRODUCTION

The Quark (also called *Kvarken* in English and Swedish, and *Merenkurkku* in Finnish) is a sub-basin in the northern Baltic Sea (Figure 1) that is shared between Finland and Sweden, and dotted with roughly 7,000 islands and islets.[1,2] The area is relatively shallow, with an average depth of 22 metres, and reaches its deepest point (133 m) in the open sea.[3] The Quark is also a narrow marine area; the coasts of Sweden and Finland are only 80 km apart, while the distance between the closest islands of the two countries is around 25 km.[1,2]

Approximately 750,000 people live in the Quark region,[4] with the largest concentrations found in the coastal cities of Vaasa in Finland and Umeå in Sweden. The countries are not only close to one another geographically, but also culturally. Furthermore, the region has a long history of cross-border cooperation that lives on in the present time, for example through the *Kvarkenrådet/Merenkurkun neuvosto* (in English the *Kvarken Council*). The *Kvarkenrådet/Merenkurkun neuvosto* was established in 1972 and works with supporting transboundary cooperation and projects in the Quark region.[4]

In the north, the Quark borders the very low salinity Bothnian Bay (the northernmost part of the Baltic Sea), and in the south, the more saline waters of the Bothnian Sea. All three areas together constitute the Gulf of Bothnia, and the shallow, northern part of the Quark acts as a threshold that separates the two basins from one another. Because of its location, the Quark has the greatest relative latitudinal difference in salinity of any area in the Baltic Sea.[2,3] The flora and fauna of the Quark reflect this variation from the south to the north, and the Quark thus acts a transformation zone and sill between the more marine characteristics of the Bothnian Sea and the nearly freshwater Bothnian Bay.

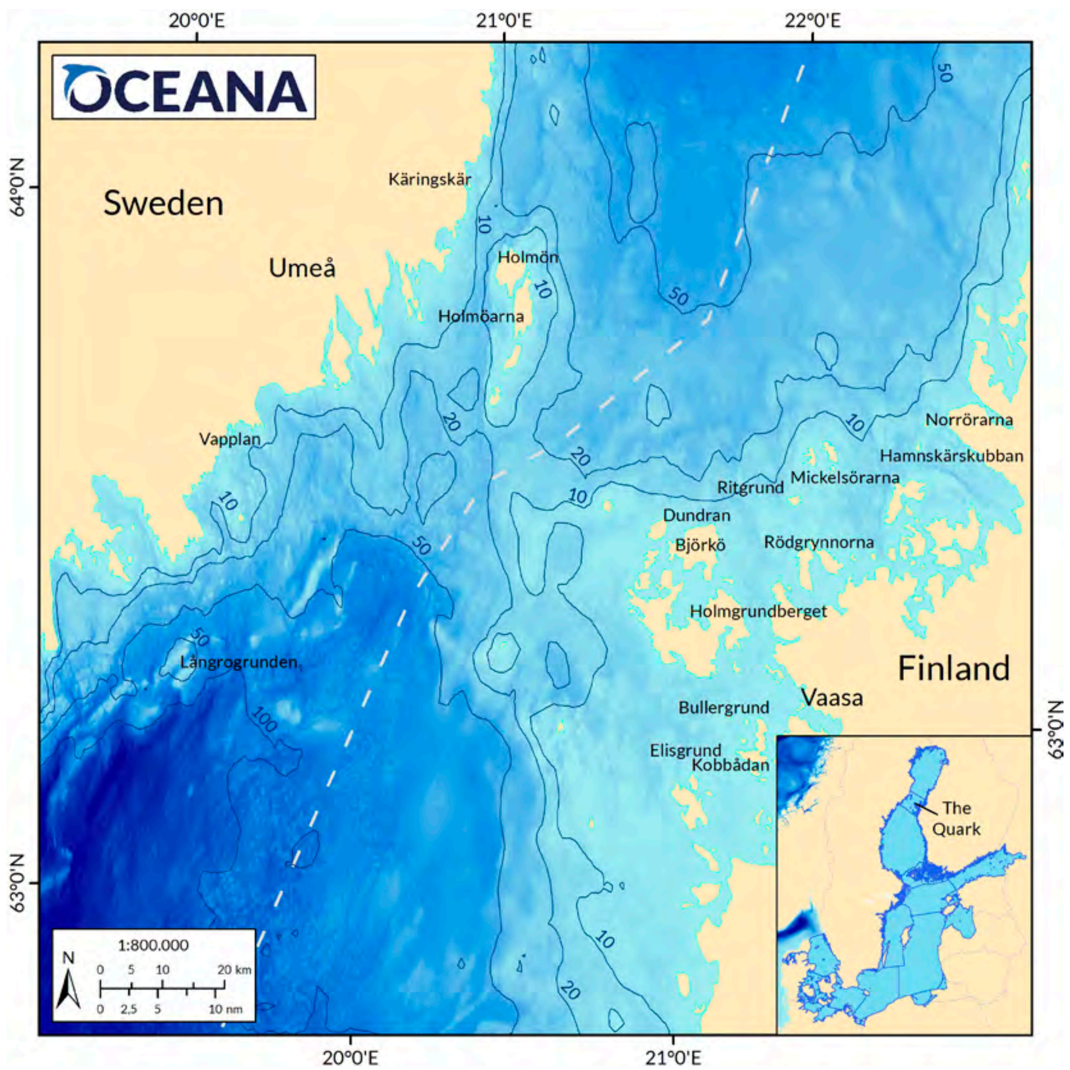


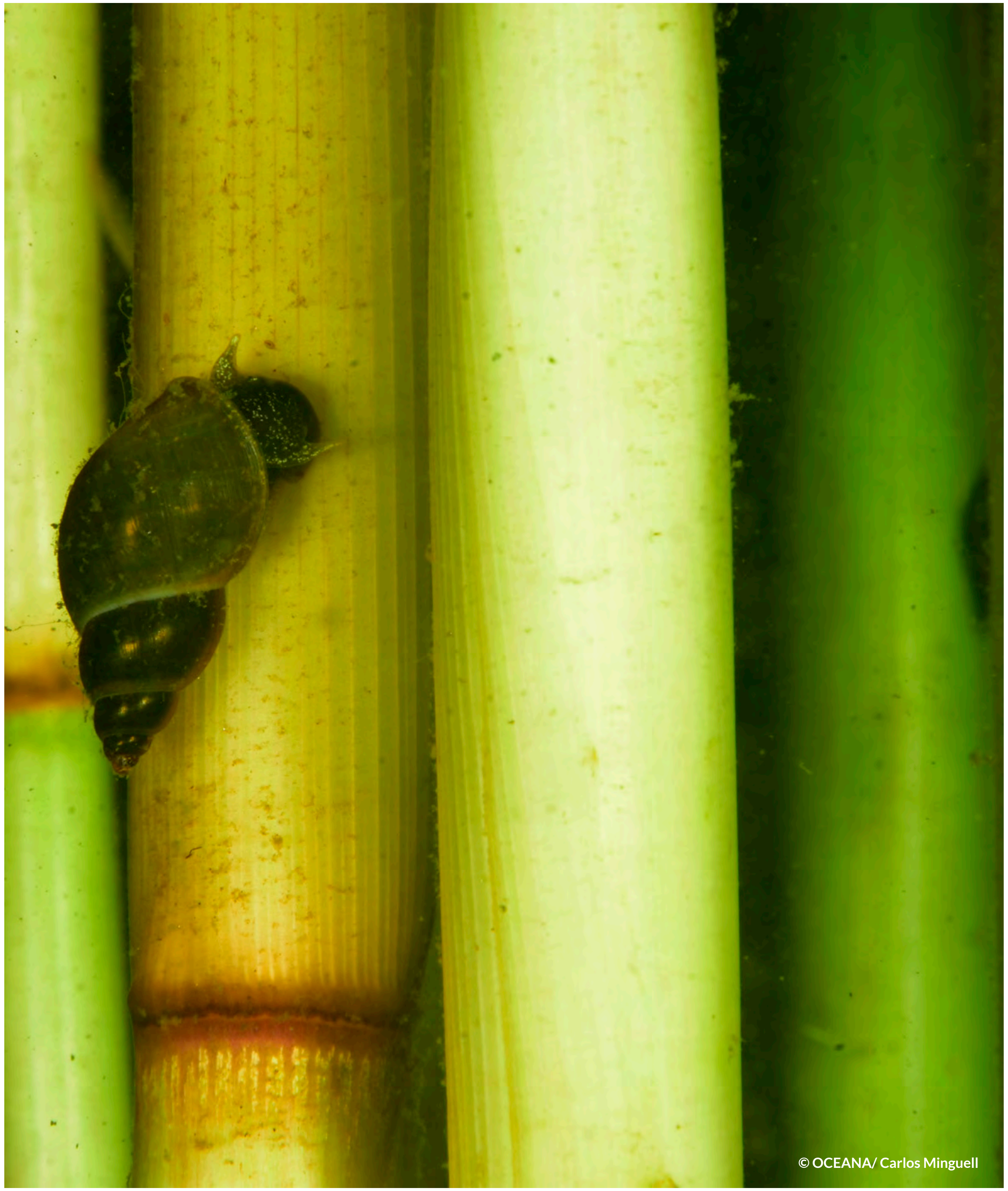
Figure 1. The bathymetry of the Quark, and the main locations referred to in this report. Sources: EMODnet, European Environment Agency and HELCOM.

Various characteristics make the Quark a unique area with features not commonly found elsewhere, which has in turn resulted in part of the area being designated as a UNESCO World Heritage Site (Box 1) and the entire Quark being recognised as an Ecologically and Biologically Significant Area (EBSA; Box 2) under the United Nations Convention on Biological Diversity. Life below and above water in the Quark is greatly shaped by some of these special characteristics, such as the ongoing phenomenon of land upheaval (see *The unique characteristics of the Quark*). The Quark is also a productive sea area, due to its shifting topography, which creates a mosaic of different habitats on a small spatial scale, and the approximately 20 hours of sunlight per day that the area experiences in summer.[2,3]

With changing salinity, depth, and exposure level, the substrates, flora, and fauna of the Quark also vary. In more sheltered places, the dominant substrate is often soft (i.e., silt and sand), and these habitats are typically densely vegetated by different tracheophytes and charophytes (see *Typical and valuable habitats*). In contrast, macroalgal communities dominate in more exposed locations, especially in the southern, more saline part of the Quark.[5] In coastal habitats, vegetation is commonly found at depths of less than 10 m, whereas this depth limit doubles in more exposed locations where the water is clearer, such as on offshore banks.[5]

The Quark is also a very important area for various fish and bird species, whether for spawning, nesting, or migration. Many commercially important fish species, such as perch (*Perca fluviatilis*), pike (*Esox lucius*), zander (*Sander lucioperca*) and Baltic herring (*Clupea harengus membras*) spawn in the warm and densely vegetated waters of the shallow marine bays that are abundant in the Quark.[6] The area also represents an important thoroughfare for the anadromous European whitefish (*Coregonus lavaretus*), salmon (*Salmo salar*) and sea trout (*Salmo trutta*).[7,8,9] The Quark is furthermore one of the most important breeding and migration areas for birds in the Baltic[3,10,11] and several Natura 2000 Special Protection Areas (SPAs) for birds and Ramsar Sites have been designated in the area (see *Current protection and management*).

In addition to its importance for birds and fishes, the Quark is also home to the apex mammalian predators grey seal (*Halichoerus grypus*) and ringed seal (*Pusa hispida*).[12] One of Finland's seven national



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seal reserves is located in the Quark (see *Current protection and management*). These reserves aim to protect both seals and their habitats, and were established because of the drastic decline of seals in the Baltic Sea during the 20th Century. The seal reserves provide, among other things, areas where seals can rest and socialise undisturbed.[13]

The unique characteristics of the Quark

The Quark is a fascinating area in many ways, one of which is the fact that due to its location in the Baltic Sea and resulting pronounced salinity gradient, it is home to a unique mixture of freshwater, brackish, and marine species. This mixture creates a melting pot of sorts in the Quark, and results in it having a slightly higher species richness than its northern adjacent sub-basin as well as several other sub-basins in the Baltic Sea (Figure 2). Many species, both freshwater and marine, reach their distribution limits in the Quark (Figure 2). For examples, marine species with northern distribution limits in the Quark include bladder wrack (*Fucus vesiculosus*), which is a keystone species in the Baltic Sea, and blue mussel (*Mytilus edulis x trossulus*) (Figure 2).[14,15]

Those individuals living at the edges of their distributions and at their tolerance limits constitute so-called 'fringe populations'; these populations often have high biological value and significance, since individuals of these populations can differ genetically from those of species' core populations, and may therefore be more likely to lead to the evolution of new species.[16] Two species that are endemic to the Baltic Sea and that are believed to have evolved in response to low salinity conditions are the brown macroalga known as narrow wrack (*Fucus radicans*) and Baltic flounder (*Platichthys solemdali*).[17,18]

One of the main factors affecting species distributions throughout the Baltic Sea is salinity, which averages approximately 4-5‰ in the Quark.[19] This low level can be compared to the salinity of around 30‰ in the Skagerrak,[20] just outside of the Baltic Sea, and the average salinity of roughly 35‰ found in the world's oceans.[21] Salinity varies within the Quark, increasing from north to south and from coastal areas to the open sea, resulting in corresponding and noticeable changes in the flora and fauna.[22] Close to the coast and the rivers that discharge into the Quark (e.g., Umeälven, Kalgrundsfaret and Toby å/Laihianjoki), salinity can drop close to zero.[3]

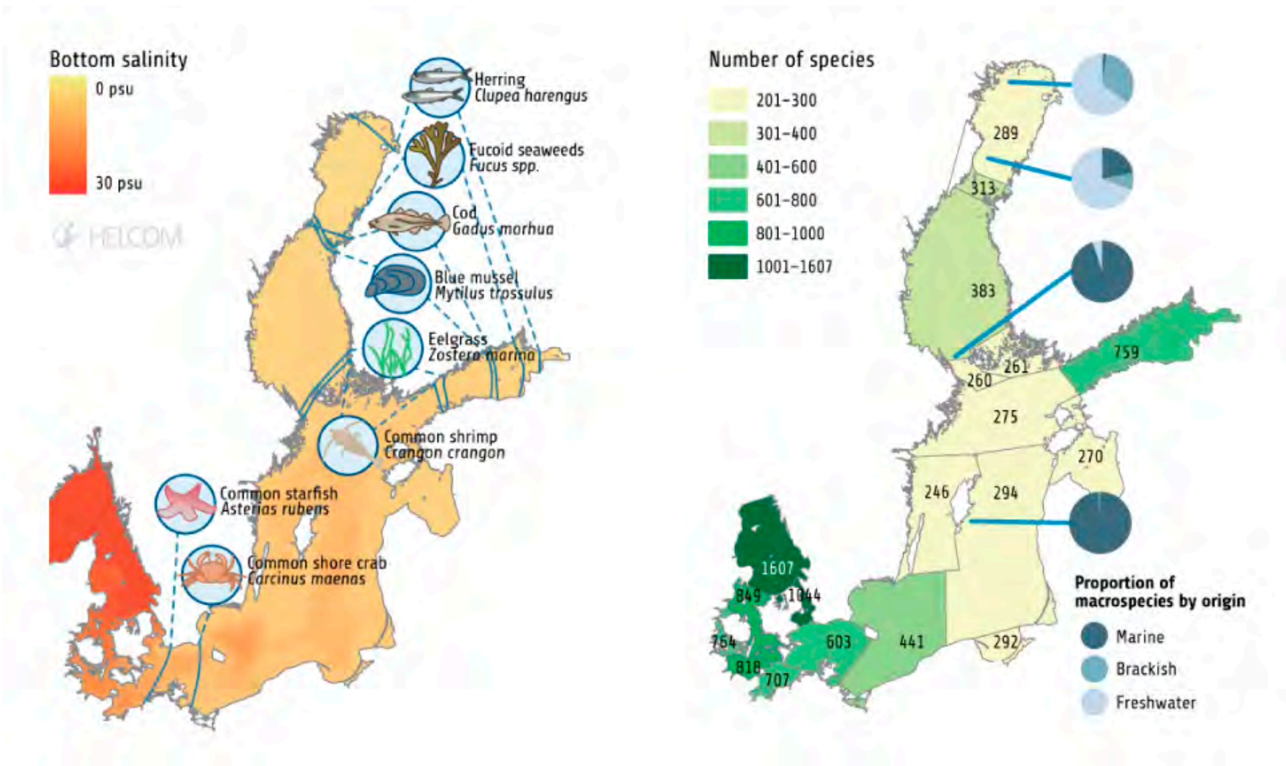

Figure 2. The map on the left shows the distribution of keystone and/or typical Baltic Sea species of marine origin and how the salinity gradient in the Baltic Sea limits their occurrence. Salinity decreases from around 25 ‰ in Kattegat, the most marine part of the Baltic Sea, to close to zero in the Bothnian Bay, the northernmost part of the Baltic Sea. The map on the right shows species richness per sub-basin in the Baltic Sea; for some areas the proportions of macrospecies of marine, brackish and freshwater origin are also shown. Source: HELCOM (2018).[23]

Another characteristic that significantly contributes to the uniqueness of the Quark, and the biodiversity that it supports, is the geological phenomenon of land upheaval. Through this process, land that was weighed down by ice sheets during the last Ice Age is 'rebounding', rising at a rate of roughly 9 mm per year.[2] This rate of uplift is one of the fastest in the world, and results in the addition of 1 km^2 of land to the Quark archipelago each year.[19] This process, combined with the low average depth of the area, creates an ever-evolving mosaic of marine bays that subsequently become gloe lakes and, eventually, land upheaval forest. This type of forest has been classified by the EU as a priority habitat type for conservation under the Habitats Directive[24] and by Finland as an endangered habitat type.[25] In addition to new land, the land upheaval process creates so-called fladas, which are highly productive shallow marine lagoons that are typical in the Quark area and represent Baltic Sea hotspots of marine biodiversity (see *Typical and valuable habitats*). The Quark is also characterised by the presence of spectacular geological formations known as De Geer moraines, another feature created by the last Ice Age.

Further contributing to shaping the Quark and its flora and fauna is the lengthy ice season, which lasts from around 120 days from January to April in the outer coastal parts of the Quark, to around 150 days in inshore areas.[1,26] Some species, such as ringed seal (*Pusa hispida*) depend on the sea ice to successfully reproduce.[27] The moving sea ice also shapes the Quark by annually shifting rocks and boulders, and by favouring annual vegetation, since the scraping of ice on the seafloor makes it difficult for perennial vegetation to thrive in many shallow areas of the Quark.[5]

The Quark is home to 71 species that are nationally threatened or included in the EU Habitats or Birds Directives.[28] Among these species, a key marine species of conservation interest is the Critically Endangered sea-spawning grayling (*Thymallus thymallus*), which has only ever been found in the Quark and in the adjacent Bothnian Bay.[29,30] The Quark archipelago is also the main distribution area of narrow wrack (*Fucus radicans*), a brown macroalga that is endemic to the Baltic Sea and was recently assessed as Near Threatened in Finland.[3,31]

Other noteworthy species include the threatened aquatic flowering plant fourleaf mare's tail (*Hippuris tetraphylla*) (classified as Critically Endangered in Sweden and Vulnerable in Finland[31,32] and white-tailed sea eagle (*Haliaeetus albicilla*), an apex predator that is protected under Finnish and Swedish national law.[33,34] The Quark area is currently home to the largest population of white-tailed sea eagles in Europe.[3]

Typical and valuable habitats

In the Quark, the unique and changing geological landscape results in a variety of habitats found on a relatively small spatial scale.[2,3] The level of exposure to wave motion, depth and salinity largely shape the distribution of habitats in the Quark.[35] In the Quark, typical habitats include fladas and other soft-substrate habitats dominated by tracheophytes such as *Zannichellia* spp. and *Ruppia* spp., or the alga *Vaucheria* spp., or habitats with mostly hard substrates that are dominated by blue mussel (*Mytilus edulis x trossulus*) or red algae. Also common are shell-gravel bottoms, where the empty shells or shell fragments of blue mussel, softshell clam (*Mya arenaria*), Baltic tellin (*Limecola balthica*) and/or lagoon cockle (*Cerastoderma glaucum*) form a layer on top of the substrate. Dense aggregations of polychaetes and their tubes also form habitat in the Quark area, although much remains unknown about their distribution, how common they are in the Quark, and which polychaete species is the most prevalent in constructing these habitats.[31] In offshore areas, reefs and sand banks also occur, and they are both defined as being topographically distinct from the surrounding seafloor. In addition, they are separated from each other by, for example, sediment type; for sandbanks the dominant sediment type is sand, whereas for reefs the substrate is coarser (e.g., boulders).[31,36,37]

Various habitat types found in the Quark are of special conservation interest, because they are recognised as biodiversity hotspots and/or are considered to be at risk. For example, of the fourteen marine habitat types that the Finnish national Red List assessment identified as being threatened or near-threatened, thirteen are found in the Quark (Table 1).[25] Furthermore, 25 of 91 Swedish and Finnish Natura 2,000 habitat types can be found in the Quark area.[28] Below, some of the most valuable and typical marine habitats found in the Quark are presented in greater detail.

Table 1. Marine habitat types that have been Red Listed as threatened (Endangered or Vulnerable) or Near Threatened on the Finnish national Red List of threatened habitat types.[25] All but one of the threatened habitat types occurs in the Quark.

Habitat Type	Red List status	Present in the Quark
Zannichellia spp. dominated bottoms	Endangered	✓
Red algae dominated bottoms	Endangered	✓
Unionidae-dominated bottoms	Endangered	✓
Monoporeia affinis/Pontoporeia femorata dominated bottoms	Endangered	✓
Coastal estuaries	Endangered	✓
Sheltered Charales-dominated bottoms	Vulnerable	✓
Zostera marina bottoms	Vulnerable	
Sea ice	Vulnerable	✓
Fladas	Vulnerable	✓
Gloe lakes	Vulnerable	✓
Ranunculus spp. dominated bottoms	Near Threatened	✓
Zannichellia and/or *Ruppia* spp. dominated bottoms	Near Threatened	✓
Open/exposed Charales-dominated bottoms	Near Threatened	✓
Najas marina habitat	Near Threatened	✓

The single most iconic type of habitat found in the Quark are fladas, a type of shallow marine lagoon, as well as their subsequent stages (i.e., gloefladas, gloe lakes) that emerge when fladas become increasingly detached from the sea through land upheaval (Figure 3). Depending on their stage of development, fladas may have either continuous water exchange with the open sea, or a more restricted influx of seawater, causing a resultant decrease in salinity. This type of habitat is common in the Quark, where approximately 2,500 fladas have been identified; in contrast, for example, with the Stockholm area and archipelago, where the corresponding number is only around 400.[38]

Fladas are biodiversity hotspots that are very productive and are considered key habitats in the Baltic Sea.[39] They fall within the priority natural habitat type 'coastal lagoon' under the EU Habitats Directive (habitat code: 1,150)[40] and are important for a wide array of species. Fladas are characterised by dense vegetation of typically different tracheophytes and charophytes, which can form meadows. Generally, fladas have very fine, muddy substrate,[41,42,43] which permits tracheophytes and charophytes to be able to grow their roots. The vegetation-rich habitat and calm waters attract different types of invertebrates, such as crustaceans, snails and insects. Many fishes also depend on the fladas, since their shallow waters warm up relatively early in the year, and the dense vegetation and invertebrate populations they host provide both shelter and nutrition for spawning and juvenile fish. These juvenile fishes, in turn, attract larger fishes that prey upon them. Fish species that utilise fladas for reproduction and foraging include, for example, perch (Perca fluviatilis), common roach (Rutilus rutilus), and the top predator, pike (Esox lucius).[3,43] Fladas also represent important habitat for migratory birds, which use them as breeding sites, and as resting and feeding sites during their annual migrations.[44,45]

Another typical and valuable habitat for many species in the Quark is that of offshore reefs, which are found in several locations in the area. These reefs serve as hotspots for vegetation in an otherwise fairly barren seascape, because they rise from aphotic depths to the photic zone, thus enabling different types of algal communities to thrive there, as well as blue mussels and other fauna.[37,46] The offshore reefs are characterised by relatively clear waters, due to their location far from the coast and from most anthropogenic influences. Typical species associated with offshore reefs in the Quark area include viviparous eelpout (*Zoarces viviparus*), the brown macroalga *Battersia arctica*, and green algae of the genus *Cladophora*. The different algae do not exhibit the zonation typically found in other parts of the Baltic Sea, in which green algae occur closest to the surface, brown algae are deeper, and red algae are found in the deepest zones, because the algae have evolved to maximise their photosynthesis to different wavelengths of sunlight, which penetrate the water column to differing depths. In the Quark area, this sharp photic zonation is lacking; brown, red and green macroalgae are found throughout the photic zone, and are only diffusely zonated.[5,46]

Figure 3. Stages of flada succession in the Quark. © Jaakko Haapamäki, Parks and Wildlife Finland.

Current protection and management

Various marine sites in the Quark (totalling 31.6% of the marine area of the sub-basin) are considered to be protected under different national, EU, and international frameworks (see Annex 1). These areas include Natura 2000 sites, a UNESCO World Heritage Site (see Box 1), HELCOM MPAs, Ramsar Sites, and national protected areas.[47,48] However, the different types of designations vary widely in what they mean in practice for sites. For example, while Natura 2000 areas have legally binding requirements for protection of listed features, designations such as HELCOM MPAs do not carry any such legal obligations. The situation is further complicated by the fact that many of these designations overlap within areas, resulting in disparate levels of protection among individual sites.

Although this patchwork of designated areas in the Quark covers a relatively significant area in total, the resulting protection that they provide to marine life is fairly limited. In many cases, designations do not include any specific measures to protect natural marine features. For example, the largest designated area in the Quark, the *Kvarken Archipelago* World Heritage Site, aims solely to conserve the geological and geomorphological features of the Quark; its status as a World Heritage Site does not in itself entail any protection or specific measures for marine life (Box 1).

Another example of limited marine protection within designated areas is the case of two privately-owned protected areas (YSA MPAs) in Finland (YSA 107282 and YSA 107244), for which the official legal designations include no description of marine characteristics, species, or habitats. Similarly, management measures for the areas also do not protect marine values, aside from a blanket ban on measures that could negatively impact the areas' characteristics or natural vegetation, fauna or landscape.[49,50] Both of these areas are, however, included within the Natura 2000 site *Merenkurkun saaristo*. The information for this site provides an overview of which marine Natura 2000 habitats can be found there, as well as a relatively brief description of the private sites' marine characteristics.[51] While the management plans for the Natura 2000 site include some measures to protect specific marine parts of the site (e.g., fladas), these plans are not legally binding for the privately-owned protected areas.[52,53]

However, not all MPAs in the Quark area lack marine data, management plans, or conservation measures. One example of an MPA where marine biological surveys were carried out before designation, and where biological features are considered within a comprehensive conservation and management plan is *Örefjärden-Snöanskärgården*, in Sweden. This nationally-designated MPA was established in 2012, and encompasses three Natura 2000 sites. Its conservation and management plan includes management measures such as prohibitions on dredging, construction, and aquaculture.[54]

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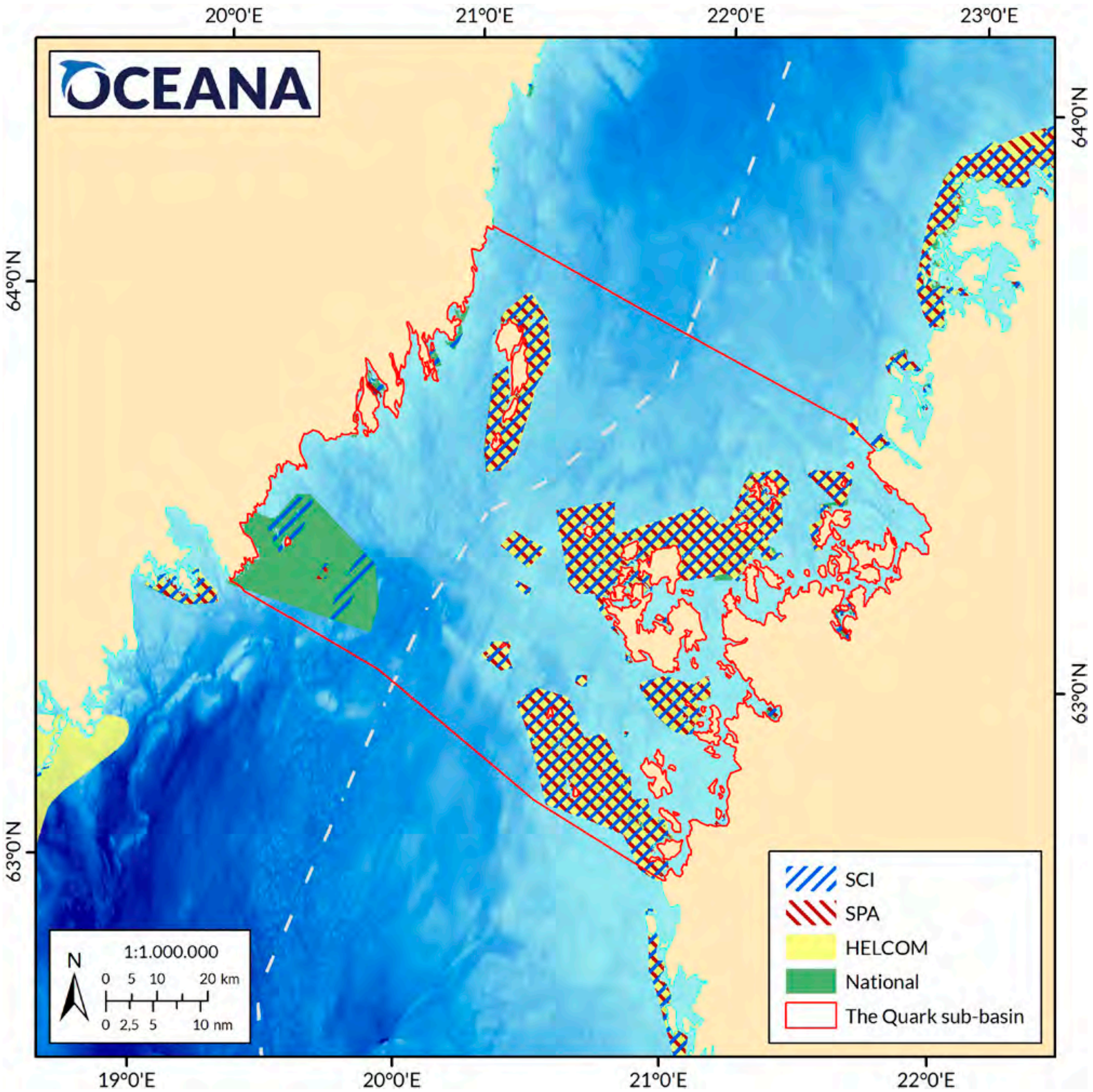

Figure 4. Marine protected areas in the Quark that are focused on nature conservation. Some areas have multiple designations and therefore the levels of management and protection also differ. SCI: Sites of Community Importance (designated under the EU Habitats Directive); SPA: Special Protection Areas (designated under the EU Birds Directive); HELCOM: HELCOM MPAs; and National: nationally-designated MPAs. Sources: EMODnet, European Environment Agency, and HELCOM.

Figure 4 shows those MPAs in the Quark that are focused on nature conservation. It is apparent that although MPAs cover both coastal and offshore waters, as well as deeper and more shallow sites, they are generally concentrated within the coastal and/or shallow areas of the Quark. Overall, Finland has more MPAs in the Quark than Sweden, and a higher percentage of its waters in the area designated as MPAs (24.1%) than does Sweden (21.7%) (Figure 4). Beyond this simple summary, however, the current situation, with fragmented information about many different types of MPAs with varying levels of protection and management, makes it difficult to obtain a clear overview of real levels of protection, let alone ensure that the unique marine values of the Quark are adequately protected and conserved.

Threats

The Baltic Sea – including the Quark – faces a plethora of different threats and pressures. At the same time, it is not as resilient as other seas, due to it being a semi-enclosed, relatively shallow body of water with a large drainage area in comparison to its surface area. Saline and oxygen-rich water can only enter the Baltic Sea via the Danish straits, which usually occurs mainly during winter storms.[23] Therefore, any pollutants or nutrients accumulate, and their impacts persist in the Baltic Sea system for many years.[23,55]

In the Quark, specifically, the main threats and human pressures include:

- climate change
- eutrophication
- shipping
- fisheries
- recreation
- dredging
- invasive and non-native species
- underwater noise
- marine litter

The most significant of these threats are discussed in more detail below.

One of the foremost threats to the marine environment in the Quark is climate change, the impacts of which are predicted to have different consequences in the Quark than in other some parts of the world. Projections by the Intergovernmental Panel on Climate Change show that sea level rise is expected to cancel out the evident effects of ongoing land upheaval.[3,56] In other words, the geological phenomenon will not cease, but the processes through which new land emerges and marine bays are slowly cut off from the surrounding sea would no longer occur.[57,58] Other predicted effects of climate change in the Baltic Sea as a whole include changing species composition and shifting species distributions, thus impacting the entire sea area, and its ecosystems and food webs. Salinity in the Baltic Sea is projected to diminish even further in the future, due to increased freshwater runoff, which will further limit the distributions of marine species.[59,60] Many marine species in the Quark are already living at their edges of tolerance, and therefore are unlikely to persist under conditions of lowered salinity. Three such keystone species in the Quark that are projected to completely vanish from the area by the end of this century are blue mussel (*Mytilus edulis x trossulus*) and the brown macrophytic algae *Fucus radicans* and *F. vesiculosus*. The absence of these species would severely impact the entire Quark area and its species.[1,61]

One already notable effect of ongoing climate change is the shrinking of ice cover, both in extent and duration[23] (Figure 5). Recent studies show that the Quark will become increasingly important for species that rely on annual sea ice, such as ringed seal (*Pusa hispida*), since it is one of only two areas in the EU (together with the northernmost part of the Bothnian Bay) where models show that sea ice will form reliably for the next hundred years.[3,27,62]

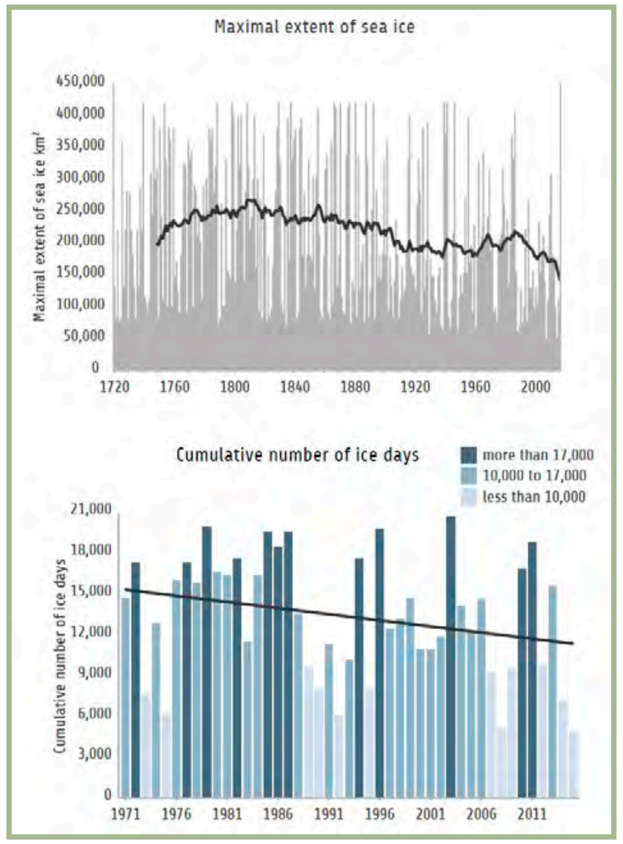

Figure 5. Temporal trends in ice cover for the Baltic Sea region. The upper panel shows the maximum areal extent of sea ice (km²) during winter over time, and the black line indicates the 30-year moving average. The lower panel shows the decreasing trend in the cumulative number of ice days per winter since 1971. Source: HELCOM (2018)[23]

The Baltic Sea – and the Quark – are highly eutrophied, largely due to substantial increases in nutrient inputs during the second half of the last century.[23] Although the situation has improved, and the amounts of phosphorus and nitrogen being added to the marine environment have been decreasing since the 1980s, 97% of the Baltic Sea is still estimated to be eutrophied.[23] In its report from 2019, the Swedish Agency for Marine and Water Management also concluded that all of the sub-basins of the Baltic Sea adjacent to Sweden, including the Quark, are eutrophied.[62]

In the Quark, open-sea areas are not as heavily impacted by eutrophication as the southern parts of the Baltic Sea, due to the continuous flow of water from large rivers that discharge and thus move the water masses, and also because the level of nutrients from anthropogenic sources is lower than in the southern Baltic Sea. However, noticeable eutrophication does occur locally, usually stemming from point sources, especially in coastal and sheltered areas.[1,3,63,64]

One habitat type that is particularly threatened by local eutrophication in the Quark are fladas, because their limited water exchange and shallowness make them especially vulnerable to excess nutrient input. Fladas furthermore often experience high levels of nutrient input due to their coastal location,[43,65] leading to associated changes in vegetation, such as the growth of filamentous algae.[25] The effects of eutrophication add to other direct human impacts on fladas, in the form of shoreline construction, building of piers, and dredging channels to facilitate boat traffic. The latest Finnish Red List assessment of threatened habitat types suggested that over 50% of potential fladas in Finland have been subjected to construction (on the shore or in the form of piers) and/or dredging (see below).[25] The combination of these threats – construction, dredging, and eutrophication – facing this valuable habitat type is cause for concern.

Eutrophication also manifests itself in the form of cyanobacterial blooms, which quite commonly occur in the Baltic Sea during the summer and/or autumn; the extent of these blooms largely depends on water temperature and wind conditions. Although cyanobacterial blooms are usually absent in the Quark, substantial blooms occurred in many locations throughout the area during the summer and early autumn of 2018.[66,67] These unusually prolific blooms were partly caused by an exceptionally warm summer,[68,68,69] and also in large part by the generally highly eutrophied state of the Baltic Sea.[67]

Invasive and/or non-native species constitute another threat to marine life in the Baltic Sea and the Quark. HELCOM estimates that roughly 140 species have been introduced to the Baltic Sea to date, with the main entryway for being via ship traffic.[23] Several non-native species have also established themselves in the Quark area, such as polychaetes (*Marenzelleria* spp.), New Zealand mudsnail (*Potamopyrgus antipodarum*), fishhook waterflea (*Cercopagis pengoi*), and waterweeds (*Elodea* spp.).[32,70] The western waterweed (*Elodea nuttallii*) is included on the EU list of Invasive Alien Species of Union concern,[71] but in general, most of the non-native species in the Quark have not yet been classified as invasive. However, some of these species do occur in very high densities, such as polychaetes of the genus *Marenzelleria*,[5] and *Elodea* spp., which can locally outcompete native vegetation and form very dense growths.[72] Furthermore, the invasive fish species round goby (*Neogobius melanostomus*) was spotted in Bothnian Bay in 2019.[73] Although no observations have been recorded yet for the Quark,[74] its distribution both north and south of the Quark suggests that the species will be found in the Quark as well. Overall, the introduction and establishment of a non-native species can have complex effects on food webs and ecosystem structure, which are difficult to foresee and therefore constitute a serious potential threat to the marine environment of the Quark.[23,71]

In the Quark, the shallowness of the area means that maritime traffic is concentrated to a quite narrow zone (Figure 6), which in turn means that disturbances from shipping are fairly localised. Shipping traffic is concentrated, besides the main thoroughfare visible in Figure 6, to the two largest ports in the Quark: Umeå and Vaasa.[3,23] The port in Umeå is one of the largest in northern Scandinavia and handles a freight volume of 2.3 million tons per year, whereas the port of Vaasa handles 1.5 million tons annually.[75]

> **"**
> ***Invasive and/or non-native species constitute another threat to marine life in the Quark.***

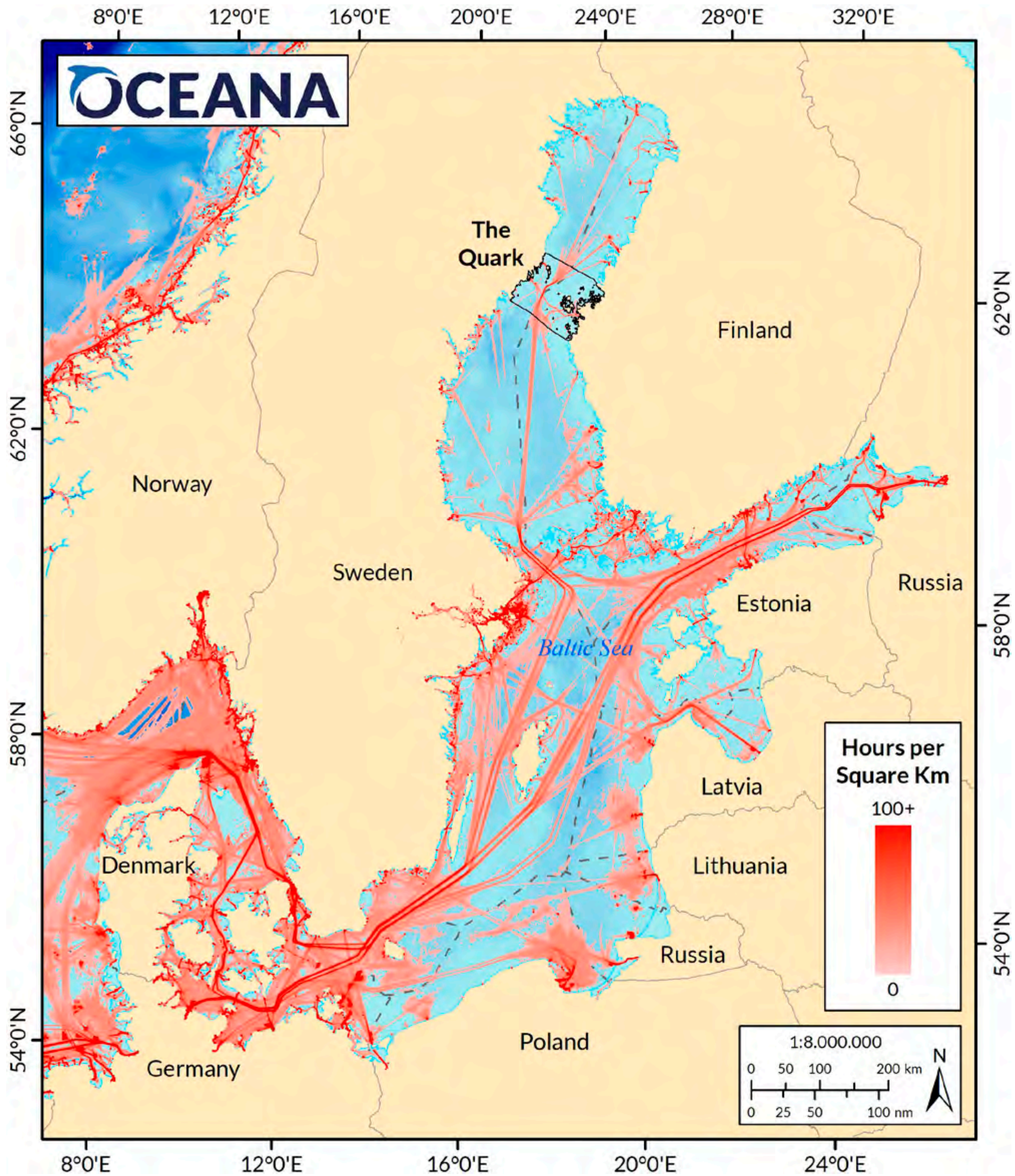

Figure 6. Density of shipping traffic in the Baltic Sea. Maritime traffic in the Quark is concentrated in the main thoroughfare situated roughly in the middle of the Quark, between the area's main ports of Umeå (Sweden) and Vaasa (Finland). Source: EMODnet and European Environment Agency.

Due to the narrow concentration of shipping traffic in the Quark, related disturbances are therefore likely to be relatively localised. Nevertheless, a maritime disaster, such as an oil or chemical spill, is considered one of the most serious threats towards the Quark ecosystem, since the particulars of the Quark (e.g., its shallowness and the extensive archipelago) would make it very difficult to minimise the effects of a spill.[1,58]

Smaller ships and recreational vessels can also have a cumulatively significant local impact on the Quark by disturbing the seabed, creating turbulence, and resuspension and movements of sediments. All of these effects can lead to murkier waters and re-entry of nutrients to the water column, thus possibly contributing to eutrophication and shoreline erosion, caused by the waves created by the vessels.[25,58] Species that are sensitive to high nutrient levels and environmental toxins are affected, as well as, for example, visual predators and suspension-feeding animals that live on the bottom, such as mussels. Light conditions in the water can be lowered up to 10 km from the source of the disturbance, and environmental toxins can be spread up to 100 km from the source.[76] Recreational boats can also directly disturb the seabed and vegetation, by cutting or uprooting vegetation and creating holes in the seabed as a result of anchoring and/or impacts from propellers. This type of serious damage is most likely to occur in the shallowest and most protected habitats, which are often densely vegetated with perennial, slow-growing vegetation (so-called 'underwater meadows') which can take years or in some cases even decades to regrow.[22,77]

Underwater noise is another problem for marine ecosystems related to boating, especially during summer months, when the greatest proportion of recreational boating occurs and many marine organisms experience important life history events, such as migration, spawning, or parenting their offspring. Sound travels quickly in water (approximately four times faster than in air). This fact, in combination with the large number of recreational boats equipped with engines (producing far-travelling, low-frequency sounds) and echolocation (producing loud, high-frequency sounds), can have a negative impact on organisms in large areas, both because sound waves cover long distances, and because the sounds produced cover a broad sound spectrum, targeting species with different hearing abilities.[79]

> **"Dredging impacts can be far-reaching, locally altering the entire ecosystem by changing the vegetation and thus negatively impacting benthic fauna and associated fishes.**

One reason for boat traffic and anchoring inside fladas and shallow, protected marine bays is recreational fishing, usually targeting primarily larger top predators such as pike (*Esox lucius*), perch (*Perca fluviatilis*) and zander (*Sander lucioperca*). These fish arrive en masse to or via the fladas and shallow bays to reproduce during spring, and recreational fishing can have negative ecosystem-level effects by depleting their stocks, in addition to harming the seafloor and vegetation, as described previously. Removing too many of these vital apex predators has been shown to lead to increased growth of filamentous algae and eutrophication via trophic cascades.[78,79] Depleted stocks of pike, in particular, have been documented to affect the ecosystem as whole in other parts of Sweden, such as the counties of Blekinge and Östergötland.[80,81] These counties have taken steps to restrict fishing during the pike mating season. Previous studies show that these types of fishing restrictions have had significantly positive results on pike populations.[82] Although there are currently no indications that recreational fisheries significantly affect the stocks of top predator fishes in the Quark, it could become an issue in the future.

Another threat that is particularly relevant in fladas and other shallow areas of the Quark is dredging of the seabed. In the Quark, dredging mostly occurs in shallow areas to enable boat traffic. Its impacts can be far-reaching, locally altering the entire ecosystem by changing the vegetation and thus negatively impacting the benthic fauna and associated fish community.[43,66,83] For example, preliminary analyses by Finnish authorities assessing the current state of the Finnish MPA network, under the *Merisuojelu-hanke* (*Tila2*) project, have revealed extensive dredging within the *Kvarken Archipelago* UNESCO World Heritage Site (Figure 7).[84]

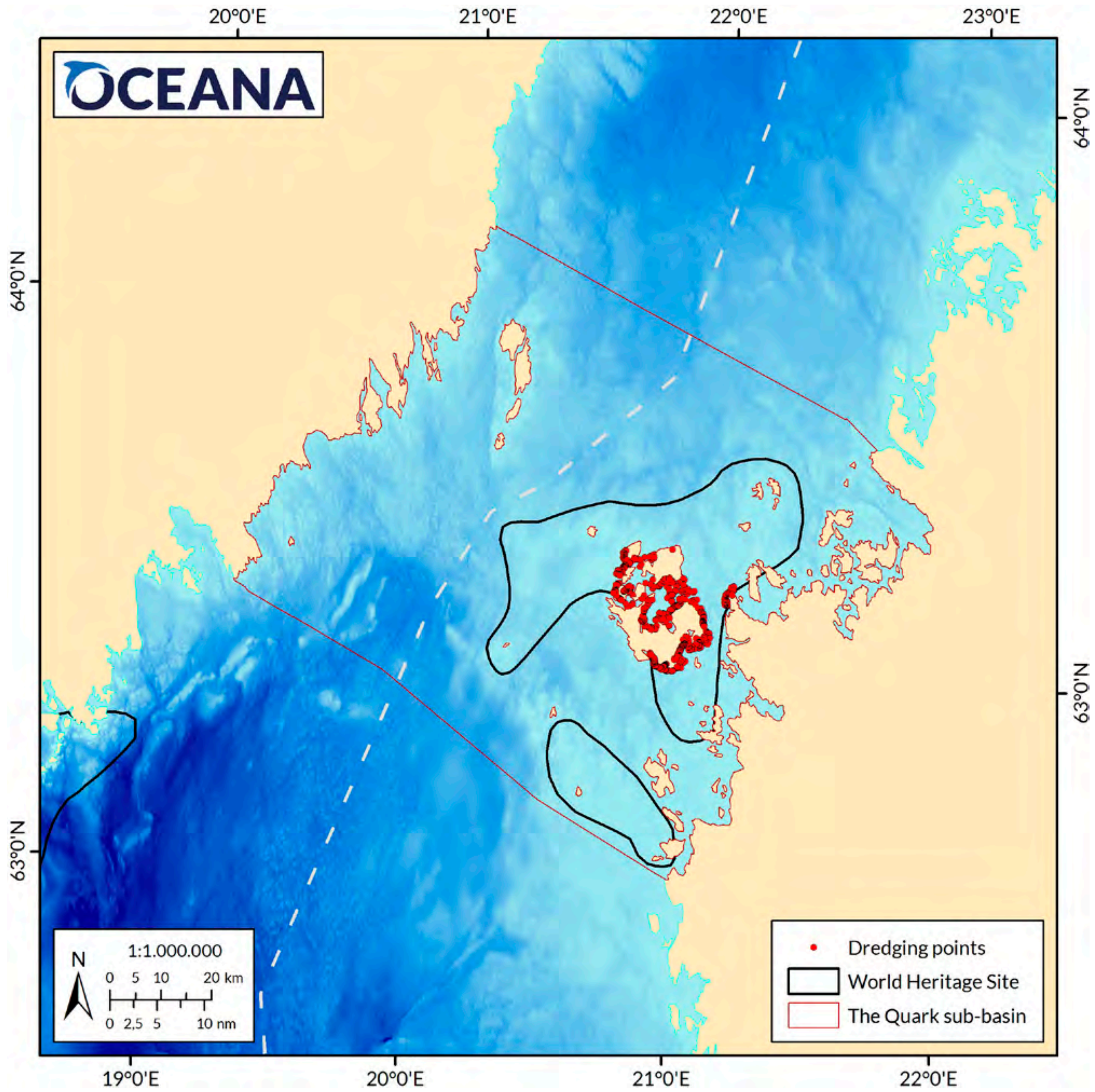

Figure 7. Location of dredging sites within the Kvarken Archipelago UNESCO World Heritage Site, based on preliminary analyses under the Merisuojelu-hanke (Tila2) project, which is assessing the current state of marine protection in Finland. Sites are shown only for the World Heritage Site because it is one of the few areas mapped to date; analyses will cover the entire Quark area by the end of the project. Source: EMODnet, European Environment Agency, and Parks and Wildlife Finland.

Oceana expeditions in the Quark

In 2014, Oceana proposed the protection of the Quark as a transboundary MPA, based partly on our findings from two at-sea Baltic Sea expeditions carried out in 2011 and 2013.[85] The proposed transboundary MPA tied together several protected areas, including Natura 2000 sites and the *Kvarken Archipelago* UNESCO World Heritage site. The proposal recommended a transnational MPA as the best solution both for protecting the unique values of the area, and ensuring adequate and proper management of the site.

The Quark region has a long-standing tradition of transboundary cooperation (e.g., Destination Kvarken),[86] and with specific regard to marine management and biological inventories, interest in cross-border efforts has been steadily rising in both countries during the last decade. This has resulted in transboundary projects that aim to collect more data and knowledge about marine life in the Quark region, such as SeaGIS 2.0[87] and Kvarken Flada[88]. These projects, in combination with the culture of transboundary cooperation in the region, lay a strong foundation that would make a transboundary MPA in the Quark a fitting and natural form of protection for this unique area. There are, however, still gaps in knowledge about the Quark and its habitats and species, especially from certain areas such as offshore reefs. Without sufficient data it is not possible to establish functional and effective protection and management.

In light of the identified gaps in knowledge about the marine ecosystems of the Quark, and the area's known high and unique nature values, Oceana decided to embark on a third expedition in the area, focused solely on the Quark. This expedition was carried out in September 2018 and the methodology used and results are detailed in the following chapters. The goals of the 2018 expedition were to fill in the aforementioned gaps in knowledge, and to survey and record the documented high biodiversity value of the Quark as well as the area's unique features, to provide a stronger basis for advancing the protection of the Quark.

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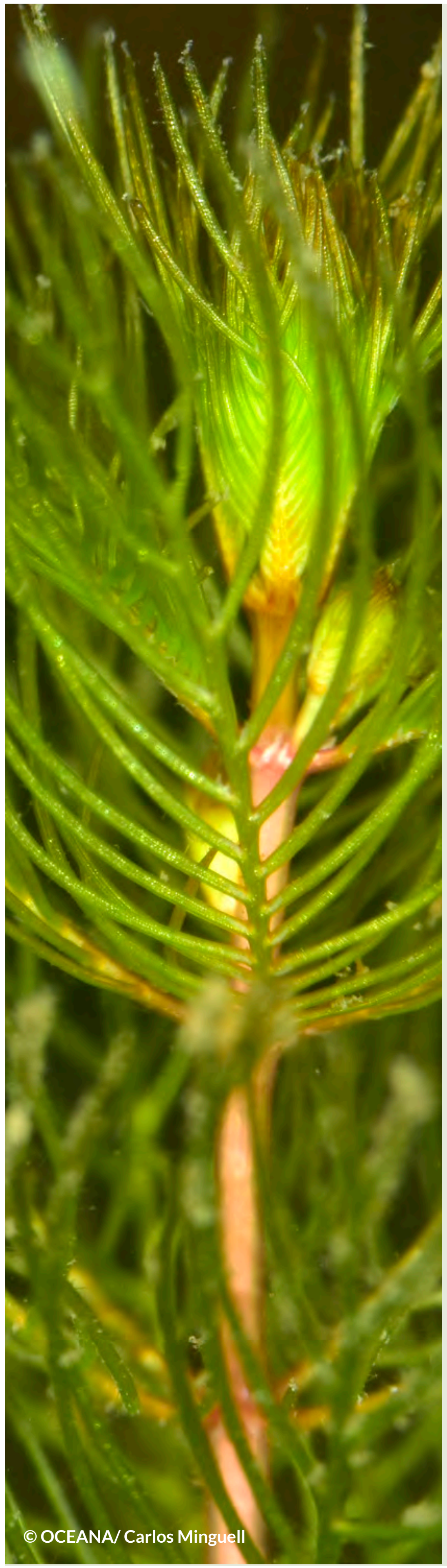

BOX 1 | The *High Coast/Kvarken Archipelago* World Heritage Site

In 2006, part of the Finnish side of the Quark – the *Kvarken Archipelago* – was designated as part of a UNESCO World Heritage Natural Site,[58] together with the *High Coast* (in Sweden), which was designated in 2000 (Figure 8). It is the only such site in Finland and, furthermore, is a transboundary World Heritage Site. The designation of World Heritage Sites began in 1972, when the World Heritage Convention was created. As of today, there are 209 Natural Sites globally, 16 of which are transboundary.

The selection of World Heritage Sites is based on ten criteria (four natural and six cultural criteria), of which a site must fulfil at least one. The *High Coast/Kvarken Archipelago* site meets criterion (viii): to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.[89]

The *Kvarken Archipelago* is the most representative site in the world for studying the process of isostatic land uplift in flat and shallow moraine archipelagos. Within the archipelago, the most spectacular geomorphological features are the glacial formations known as De Geer moraines, which are clusters of low, narrow ridges. Although such moraines also occur elsewhere, the De Geer moraines located in the Quark are considered to be the most distinctive globally.[1]

The *Kvarken Archipelago* part of the site is managed at a regional level in Finland, and parts of the site are protected under other designations, such as Natura 2000 protected areas. However, protection mostly focuses on the geological formations, and the designation of the area as a World Heritage Site has not led to any additional legislative or protective measures being taken. Potential threats towards the World Heritage Site include large-scale development such as building projects, excessive visitor numbers, and the occurrence of an oil or chemical spill.[58] Another recognised threat is climate change (see *Threats*).[3,57]

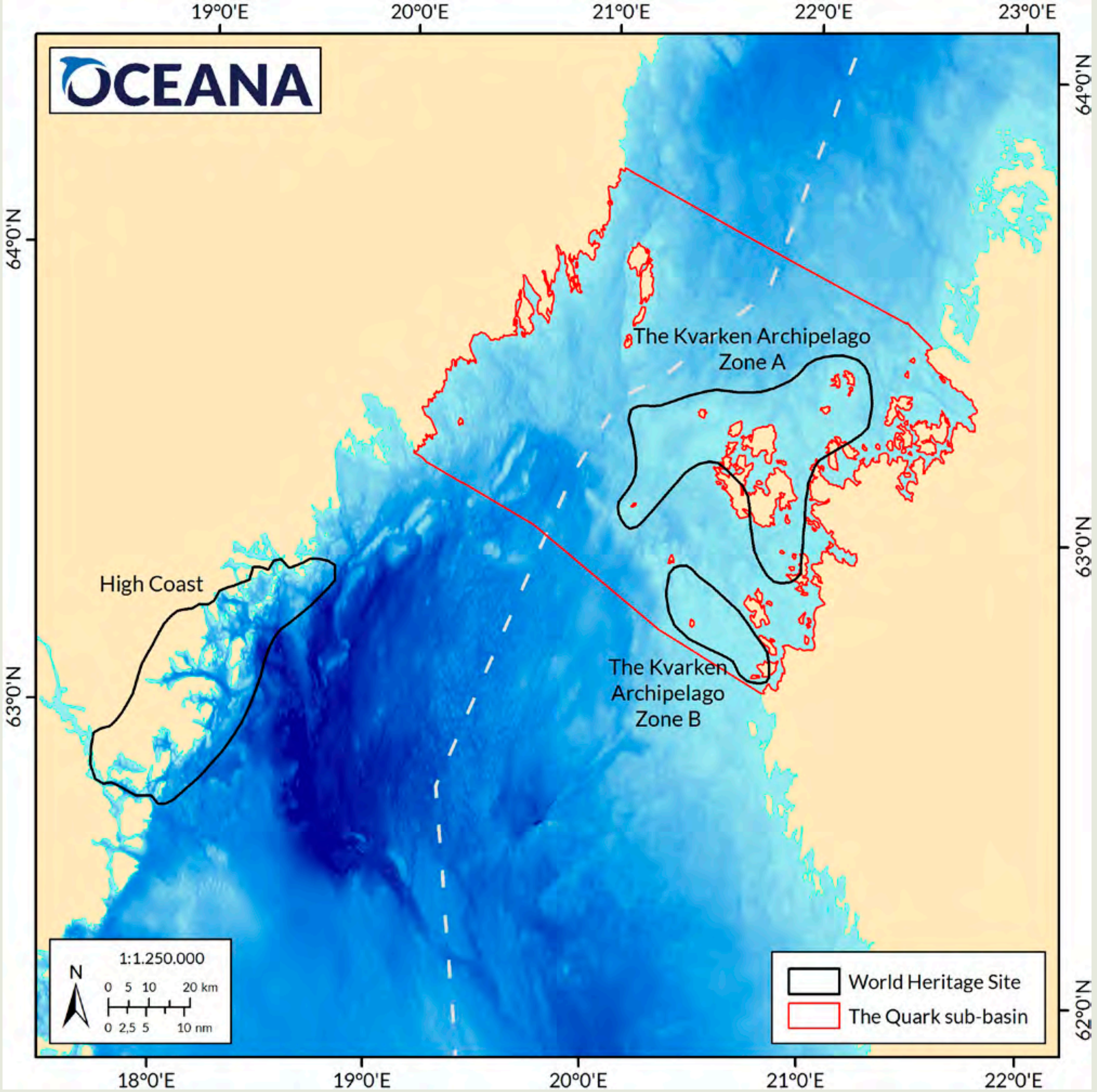

Figure 8. In total, the Kvarken Archipelago part of the World Heritage Natural Site encompasses 194,400 ha, of which 165,000 ha are marine. Sources: EMODnet, European Environment Agency, and HELCOM.

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BOX 2 | What does the EBSA status of the Quark entail?

Ecologically and Biologically Significant Areas (EBSAs) have been defined by the Convention on Biological Diversity as “special areas in the ocean that serve important purposes, in one way or another, to support the healthy functioning of oceans and the many services that it provides”.[90] An EBSA usually has unique biological characteristics and the following seven scientific criteria are used when identifying EBSAs:

1. Uniqueness or rarity
2. Special importance for life history stages of species
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, fragility, sensitivity, or slow recovery
5. Biological productivity
6. Biological diversity
7. Naturalness

EBSAs are identified through regional workshops in which scientific experts evaluate the data available from specific areas against the EBSA criteria. Since 2011, 13 such regional workshops have been held; together these workshops have assessed more than 74% of the total surface of the world’s oceans. In early 2018, a workshop was held to identify potential EBSAs in the Baltic Sea. As a result of the Baltic Sea workshop, nine EBSAs were pinpointed, together covering 23% of the Baltic Sea (Figure 9). One of these EBSAs was the Quark.[91]

The expert group evaluated the Quark as scoring High against the EBSA criteria 1, 2, 3, and 6, and Medium for the remaining criteria. Many of the same aspects that are highlighted in this report were used as arguments for identifying the Quark as an EBSA, such as land upheaval and its influence in shaping marine life, the area’s relatively high biodiversity and unique species composition, and the range of fish and bird species that rely on the Quark for spawning, nesting, or foraging.[3]

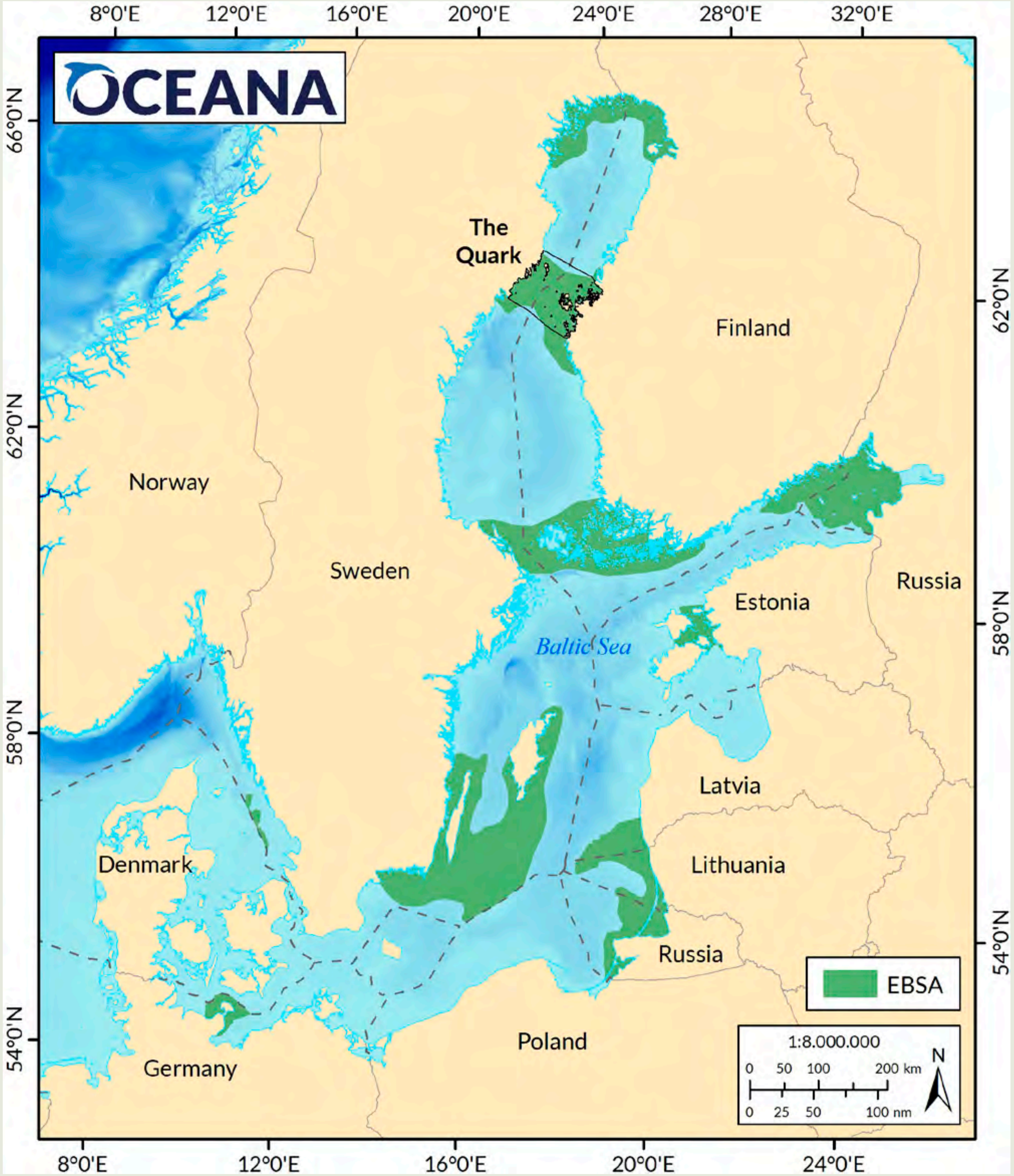

Figure 9. The Quark is one of nine Ecologically and Biologically Significant Areas (EBSAs) that were identified in the Baltic Sea in 2018. Sources: EMODnet, European Environment Agency, and HELCOM.

METHODS

Oceana surveyed the Quark during the period of 1-20 September 2018. The first leg of the expedition was carried out in Swedish waters (1-8 September) and the second part in Finnish waters (9-20 September). Surveys were carried out from three different vessels: the 22 m-long yacht *Sea Dream*, a 9 m-long rigid-inflatable boat (RIB), and a 3 m-long dinghy.

Survey areas were selected based on input from regional and national scientists, published literature, grey literature, and from previously collected survey data (e.g., SEAGIS 2.0 Map Service, VELMU Map Service).[92,93] The areas were chosen both to give a representative picture of the Quark and its habitats and species, and to fill identified gaps in existing knowledge about the area (Figure 10). For example, offshore reefs were specifically highlighted by officials at the Västerbotten County Administrative Board as a habitat type for which data were lacking. Unfortunately, poor weather conditions limited some of the planned surveys in open-sea areas. For example, not all of the planned offshore reef sites could be visited, and only one dive could be carried out in the seal protection area *Snipansgrund-Medelkallan*, due to strong winds and waves.

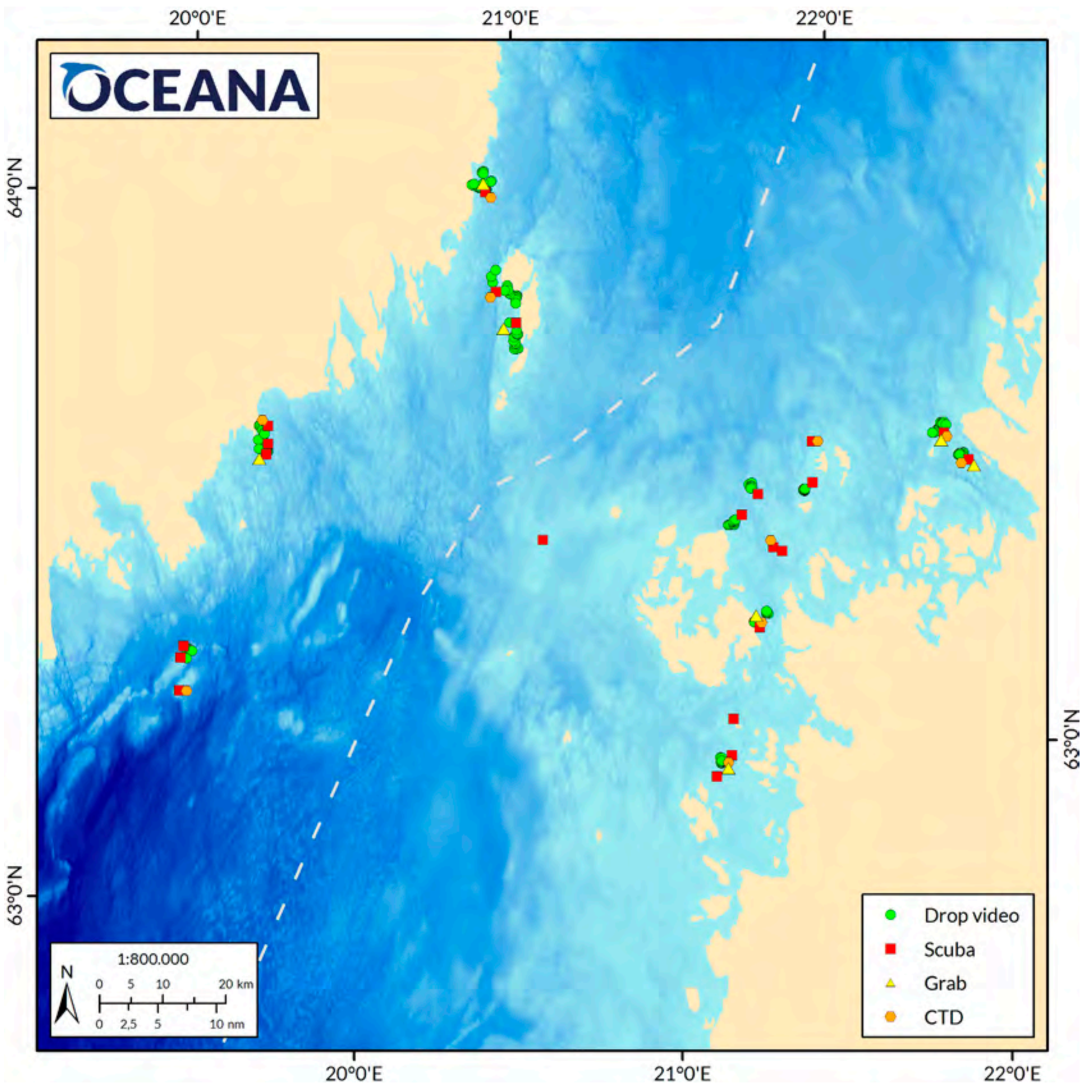

Figure 10. Survey sites from the Oceana 2018 Quark expedition, shown according to survey method: drop video (n=179 points); SCUBA dives (n=24); benthic grabs (n=7 points); and CTD measurements of oceanographic parameters (n=10 points). Survey points were spread throughout the Quark area and covered a variety of depths, substrates, and habitat types. Sources: EMODnet and European Environment Agency.

Data were collected using a combination of methods: a drop video camera was deployed; a team of SCUBA divers took samples, videos and photographs; abiotic factors were measured with a conductivity, temperature, and depth (CTD) instrument; and benthic faunal communities were surveyed with a Van Veen grab. Each of these methods is detailed below.

In total 24 SCUBA dives were carried out, and 179 drop video points were recorded. In addition, the CTD was deployed in ten locations and benthic grab samples were taken in seven locations. For the majority of dives (17 out of 24), specimens of species were collected by divers to help confirm preliminary taxonomic identifications.

Drop video camera

Deploying a drop video camera is a cost-efficient way to survey relatively large areas quickly, and is a widely used method in the Baltic Sea.[94,95] Oceana's drop camera system consisted of both a primary recording high-definition camera and a secondary recording and live-streaming back-up HD-SDI camera (see Figure 11 for details of the drop video camera system). Drop video survey areas were chosen to cover a wide variety of habitats and depths; surveyed depths ranged from 0.3 m to 43.0 m. Within each survey area, drop video points were randomly chosen within different depth strata and, where relevant, within both inshore and offshore areas. Surveys were usually carried out by a two-person team using the dinghy, which enabled the team to survey both open and shallow, sheltered areas. In some cases, the drop video camera was deployed from the larger vessel (*Sea Dream*).

Figure 11. The drop video camera system used in the Quark 2018 surveys. The system consisted of a GoPro Hero 5 Black video camera with underwater housing, mounted on the Sea Viewer 6000 HD Sea-Drop, with two external diving torches mounted on the sides for additional lighting. The Sea Viewer system is the HD PRO PACKAGE console with live feed at the surface and recording capability (https://www.seaviewer.com/). Each drop video survey point was recorded with both the GoPro (primary camera) and the Sea Viewer (secondary, back-up camera). © OCEANA/ Carlos Minguell.

The drop video camera methodology followed the national methodologies used in Finland and Sweden, in that the camera was lowered at a chosen point and the geographic coordinates recorded for that location. Coordinates were taken when the bottom was first sighted, which was also the time when the analysis of the footage started. From each point, approximately 30 seconds of good quality footage was obtained, covering an area of ca. 5 m^2. This footage showed the substrate, vegetation, and in some cases fauna. In addition, the depth was recorded for each point. The videos were later analysed in their entirety, estimating percentage coverage from the whole video for vegetation and substrate. Percent coverage of vegetation could exceed 100% if there were epiphytes, while substrate always totalled 100%. The abundance of any observed fauna was approximated (i.e., abundant, moderate, few/present), with the exception of blue mussels, for which percentage cover was estimated. Observed vegetation and fauna were identified to the highest level of taxonomic resolution possible. Substrate was categorised as precisely as possible, for the entire video, as one of seven different categories (i.e., bedrock, boulder >200 mm, stones 20-200 mm, gravel 2-20 mm, sand 0.2-2 mm, soft bottom, other (e.g., iron manganese nodules)).

It should be noted that, in general, drop video camera surveys are primarily useful for broad-scale habitat classification. With the exception of vascular plants, drop video footage provided less detailed information about individual species present in surveyed sites than did the images and videos from SCUBA surveys (see below).

SCUBA Diving

Professional SCUBA divers carried out the surveys in two teams of two, with each team consisting of one videographer/photographer and one safety diver. All 24 dives were carried out by all four divers, and diving was done either from the *Sea Dream* or from the rigid-inflatable boat. Dives varied in length from 1 h 12 min to 2 h 21 min.

Diving was conducted both inside and outside of MPAs. Since the collection of samples was restricted in most of the protected areas, the diving methodology differed slightly depending on the type of survey area.

Most of the dives (n=17 of 24) were done outside of protected areas; during those dives, surveys were carried out using a combination of taking samples, taking still images, and filming high-definition videos. For each dive, the divers were assigned a general direction, in which to dive and document the habitats and species. When close to land, dives started in the deepest area and headed towards the shallowest areas. During each of these dives, conditions permitting, a 1 m^2 quadrat (Figure 12) was placed on the bottom five times; the first quadrat was placed where the dive began and the fifth where the dive ended, and the remaining three were placed to cover the various depths and habitats between the dive start and finish. For each quadrat, geographic coordinates, depth, and substrate were noted, and samples of the species that occurred inside it were taken for later identification. The aim of taking samples was to try to obtain samples of all the species of vegetation present within the quadrats, so that macroalgae and tracheophytes could be identified to the highest taxonomical resolution possible. Each quadrat was also photographed, before any samples were taken, to enable later estimates of total vegetation cover and individual species percentage cover, based on identification of the collected samples, the photographs, and the divers' descriptions. In total, 71 quadrats with coordinates were surveyed during the expedition, at depths ranging from 0.5 m to 20.3 m. In addition to identifying the vegetation present and its coverage, any observed fauna in the quadrat and/or in the samples was approximated as either abundant, moderate, or few/present.

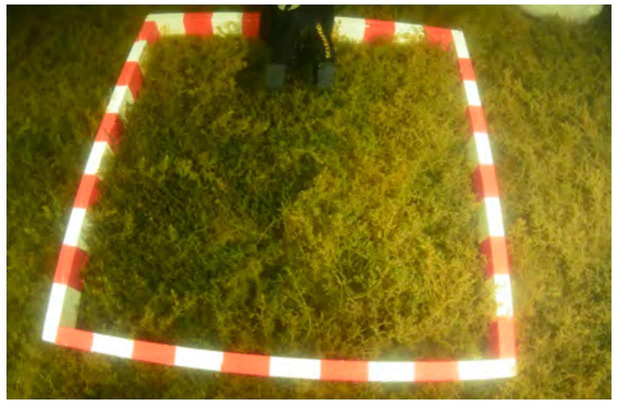

Figure 12. Quadrat being surveyed during a SCUBA dive at Norrörarna, in Finland. For each quadrat, species present were determined by identifying samples brought to the surface and from underwater still images of the quadrat. The total percentage cover of vegetation for each quadrat and for the individual species present was estimated from the still images. © OCEANA/ Carlos Minguell

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Throughout each dive, photographs and videos were taken in addition to the quadrats, to further document the diving sites. Those videos and still images were analysed following the expedition and all visible species were identified.

For the dives carried out inside protected areas (n=7 of 24), neither quadrats nor samples were taken. Coordinates for the start and end points of the dive were noted, and vegetation, fauna, substrate and conditions were documented via still images and videos taken throughout the dives. Following the expedition, Oceana scientists analysed the high-definition videos and still images taken and identified all visible species to the highest level of taxonomic resolution possible. No estimates of abundance or percentage cover for species were made.

In contrast to the drop video surveys, the videos and images filmed by the SCUBA divers yielded particularly useful data about macrofauna and substrate types. SCUBA surveys of quadrats provided the most detailed information about individual species, habitats, and substrates. It should be noted that, given the differences between the drop camera and SCUBA surveys, the results attained cannot be directly compared between the two methods.

Oceanographic parameters

Temperature, salinity and dissolved oxygen were measured using a conductivity, temperature, and depth (CTD) device. The *Valeport MIDAS CTD+* instrument was deployed ten times during the expedition. It measured each parameter at 1 m depth intervals as it descended from the surface, and made the final measurements when it reached the sea bottom. The sites surveyed with the device ranged in depth from 6.7 to 14.0 m.

Benthic fauna

A 1.4 L Van Veen grab sampler was deployed in seven locations during the expedition, at depths ranging from 6.7 m to 27.0 m. Whenever possible, three replicate samples were taken from the same point and analysed together, although in some cases weather conditions did not allow for all three replicates to be taken. The samples were then filtered using 1 mm and 0.5 mm sieves. The retained sub-samples were preserved in 70% ethanol. Following the expedition, specimens of benthic fauna from these samples were identified by Oceana scientists to the highest taxonomic resolution possible and the individuals of each species/taxon counted per sub-sample.

FINDINGS & DISCUSSION

The following section outlines the main results of the expedition. Oceanographic parameters, habitats, and species documented are presented in detail, with an emphasis on the biological features present in the Quark, and the conclusions that can be drawn from these findings.

Oceanographic parameters

Abiotic factors strongly impact marine life in the Quark. In particular, salinity is a key factor in determining species distributions. During the expedition, values of surface (and bottom) salinity measured ranged from 3.1-4.9‰, with a clear decrease evident from the southern to the northern parts of the Quark (Figure 13). These values are consistent with the general pattern of salinity that is known from the region. Salinity levels are known to drop from around 5.5‰ in the southern parts of the Quark to 3.5‰ in the northern parts of the Quark, and to fall to zero in the innermost areas of the archipelago.[96,97]

Measurements of sea bottom temperatures, also from the CTD device, are shown in Figure 14. Temperatures ranged from 9.5-15.7 °C at the seabed, with the warmest temperatures recorded from areas shallower than 8 m. The summer of 2018 was unusually warm across Europe and the warm weather continued during early autumn as well, which lead to higher-than-average marine air temperatures over the Baltic Sea in September 2018.[98] From the figure, it is evident that even offshore waters reached unusually high temperatures of over 15 °C, while long-term data show that the sea surface temperature in most of the Quark during September was 1-2 °C higher than average.[99] Worryingly, 2018 was the warmest year since 1990 for both sea surface temperature and air temperature in the Baltic Sea, and a clear linear trend of strong warming in the Baltic region has been documented from 1990 to 2018.[103]

Figure 14 also shows values of bottom dissolved oxygen that were measured during the expedition, and which ranged from 8.8-10.8 mg/L (mean=9.8 mg/L; n=10). The spatial pattern of these concentrations illustrated the closely linked relationship between temperature and dissolved oxygen, with warmer waters capable of containing less oxygen than cooler waters. Under climate change, as the waters of the Quark continue to warm, oxygen levels are therefore likely to decrease. Given the oxygen and temperature requirements of different species, these changes could have large-scale impacts on the ecosystems and species distributions in the Quark and the broader Baltic Sea.[100] This is of particular concern considering that extensive areas of the Baltic Sea are already hypoxic or anoxic.[101,102] Although there are no such large oxygen-depleted areas in the Quark,[106] local and seasonal hypoxic and anoxic conditions can nevertheless be found there, especially in shallow and coastal locations that are eutrophied.[23,103]

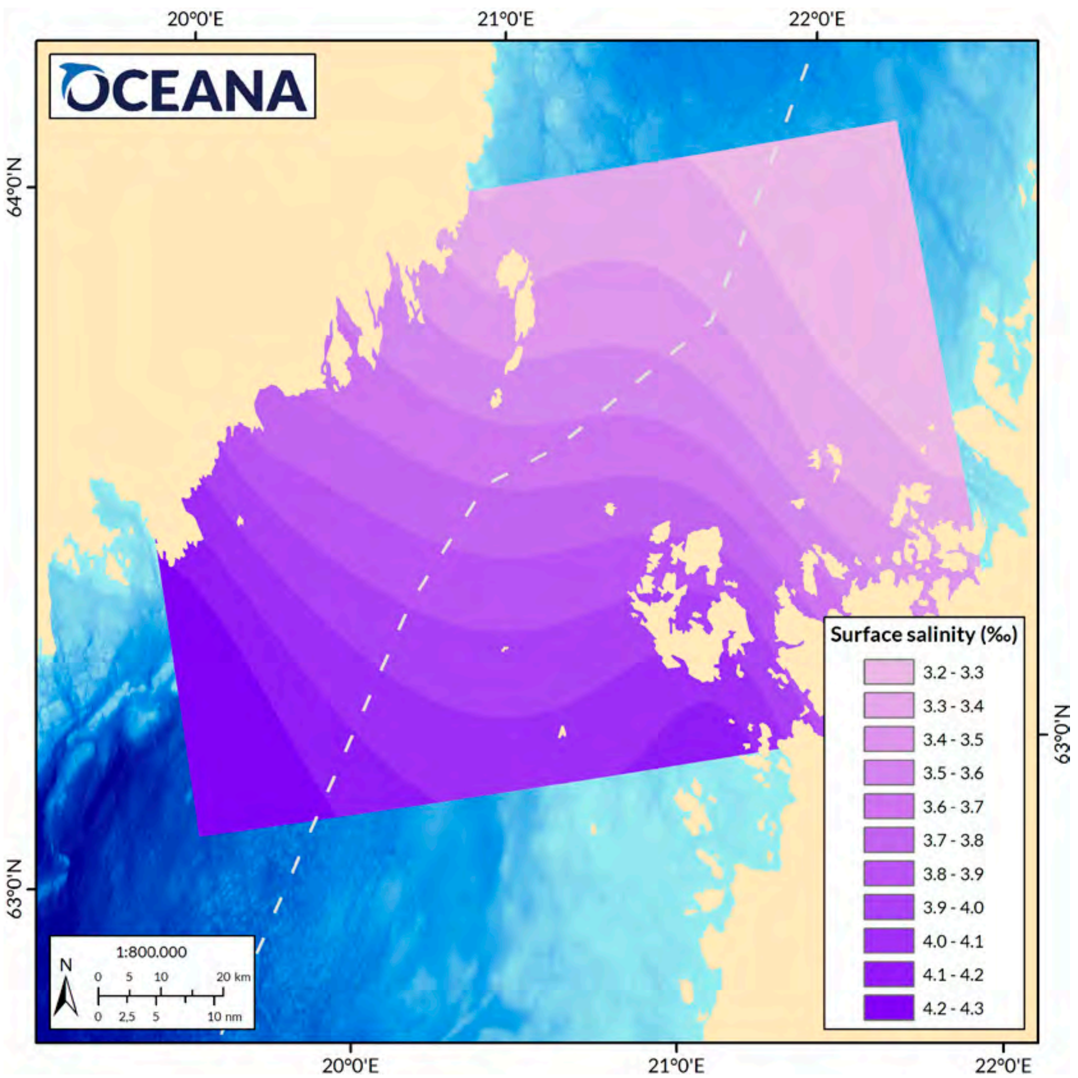

Figure 13. Surface salinity (in parts per thousand) in the Quark area, from measurements taken during the Oceana Quark expedition, September 2018. Sources: EMODnet and European Environment Agency.

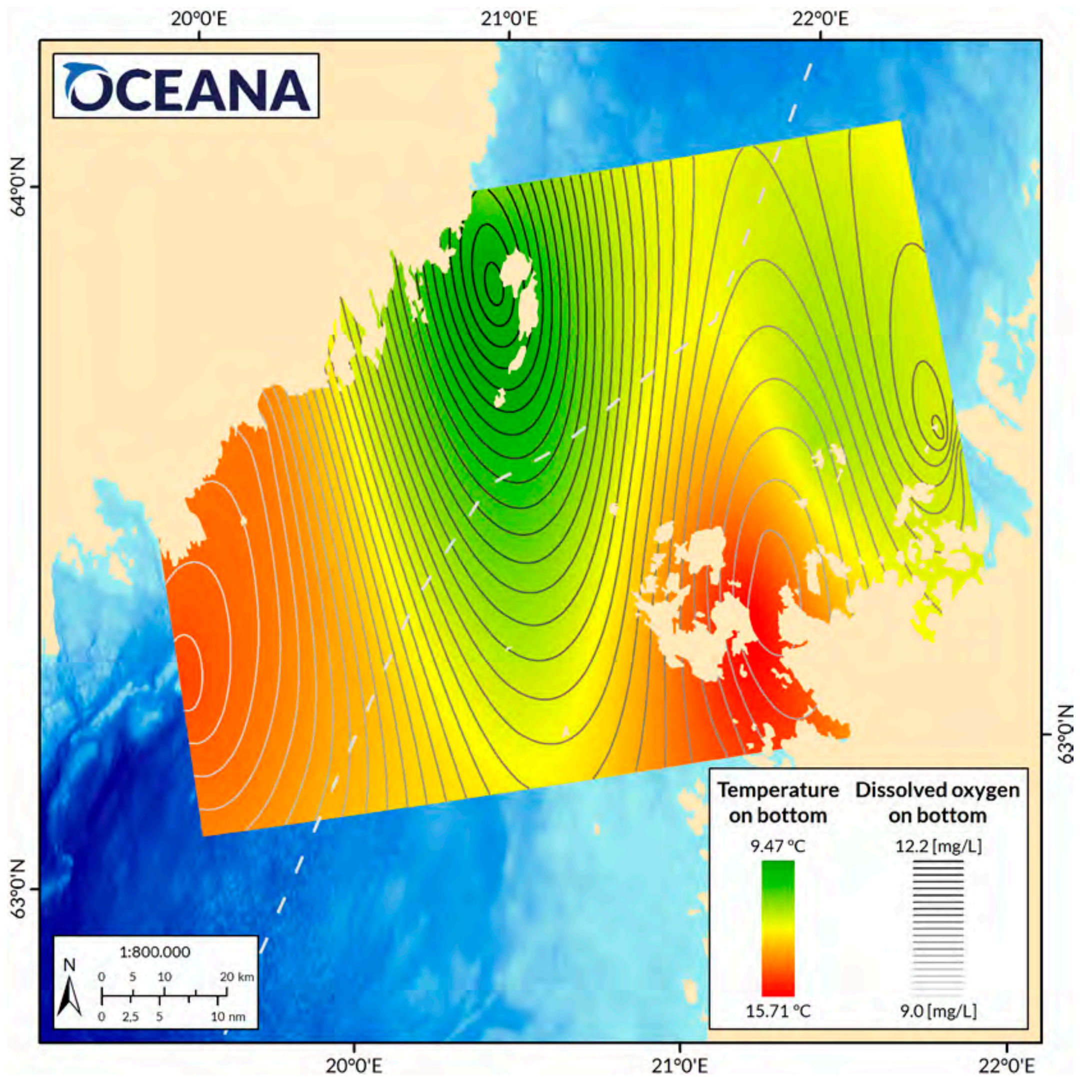

Figure 14. Bottom temperature and dissolved oxygen levels in the Quark, from measurements taken during the 2018 Oceana Quark expedition. Dissolved oxygen at the bottom is directly correlated with water temperature, such that warmer sea water contains less oxygen. Sources: EMODnet and European Environment Agency.

Water temperature affects a wide range of additional factors in the Baltic Sea, such as the extent of cyanobacterial blooms.[70] During the expedition, significant cyanobacterial blooms were observed at the surface, in the water column, and on the seafloor. Aggregations of cyanobacteria were documented from offshore reefs at Långrogrunden, in the water column and on the bottom, highlighting how widespread the blooms were in 2018. The cyanobacteria genera *Nostoc* and *Rivularia* were spotted in more sheltered locations, on top of the substrate and/or vegetation (Figure 15). Unsurprisingly, given that 2018 was the warmest year recorded since 1990,[103] the Swedish Meteorological and Hydrological Institute characterised that summer as extreme in terms of the extent of cyanobacterial blooms.[70] Such events are likely to become much more commonplace is the Quark, given that average temperatures in both Finland and Sweden have been rising at approximately double the rate of increase in global average temperatures.[104,105]

Figure 15. The cyanobacteria genera *Nostoc* and *Rivularia*, together with the macroalga *Ulva* spp., observed at 1-2 m depth at Elisgrund, Finland, September 2018. All of these species are commonly found in eutrophied locations. © OCEANA/ Carlos Minguell

Although the unusually warm summer was a contributing factor to the very extensive blooms observed in the Quark area during the expedition, and in national and regional surveys,[68,69,70] the main culprit remains eutrophication.[67] Despite extended efforts to reduce nutrient inputs across the Baltic Sea, eutrophication is likely to remain a serious long-term problem. For example, modelled projections for the waters to the north and south of the Quark suggest that recovery to a healthy, non-eutrophic status might only occur by roughly 2200 or even later.[106]

Together, projected ongoing eutrophication and increased frequency of climate change-driven extreme weather occurrences in Sweden and Finland will likely lead to cyanobacterial blooms becoming even more frequent (Finnish Environment Institute 2018).[69] The change is especially noticeable in the Quark area, since it had been largely free of cyanobacterial blooms until recent years, due to its northern location.[67]

Dense cyanobacterial blooms limit light availability for other vegetation and also impact water clarity, which was also evident during the expedition, especially at certain locations. For example, in Långrogrunden the water was very turbid and cyanobacterial blooms were visible to the naked eye, both from the surface and during diving.

Cyanobacterial blooms are also a concern because they impact oxygen levels at the seafloor, because when the blooms die and sink to the bottom, they are broken down by bacteria. This process requires oxygen and thus further depletes oxygen levels.[107]

Habitat types

Various classification systems exist for defining living environments in the Quark, such as the regional Baltic Sea HELCOM HUB system,[108] the EU-wide Natura 2000 nature types,[109] and national classifications, such as national definitions of Natura 2000 habitat types and the Finnish national Red List of threatened habitats.[25,110] While each of these systems has its strengths, none comprehensively covers the full range of habitats observed during the expedition in a straightforward way. Therefore, habitats are instead described here on the basis of being easily distinguishable from one another, drawing on elements of the various existing systems rather than following one system in particular.

In total, ten habitat types were documented during the expedition. For clarity, these are divided into exposed and sheltered habitats, because the level of exposure is a key factor that explains their distributions. Exposure to wave motion impacts the type of substrate at any given location. During the expedition, the most common substrates observed were boulders and stones in exposed survey areas, whereas fine-grained sandy/muddy substrate dominated sheltered areas. Vegetation reflected the same pattern, with macroalgae dominating in exposed, hard-substrate sites, while various tracheophytes and charophytes were abundant in sheltered, soft-substrate survey areas.

Below are presented more detailed descriptions of the habitat types recorded during the expedition.

Habitats: Exposed survey areas

In the Quark, there is a deficiency of data from deeper, offshore areas, partly because they are costlier and more difficult to survey and access than the more extensively-surveyed sheltered and coastal areas. Oceana's surveys in offshore areas therefore provided particularly valuable information about lesser-studied habitat types and associated species. These exposed areas are characterised by having hard substrate, usually a mixture of bedrock, boulders and stones, since finer-grained substrates are continuously removed by wave motion. Due to the substrate and strong water movements, the dominant vegetation consists of macroalgae, in association with blue mussels (*Mytilus edulis x trossulus*). However, deeper down, below the photic zone where there is no vegetation, the substrate can either be mixed or mostly soft. Such areas are home to fauna such as *Saduria entomon* and *Marenzelleria* spp., rather than blue mussels.[111]

Offshore reefs, which represent one of the most typical and productive exposed habitats in the Quark, were identified during both SCUBA dives and drop video camera surveys in three locations at Långrogrunden in Sweden (Figure 16). SCUBA dives at these reefs were carried out at depths of between 4.4-20.3 m, and vegetation was found throughout this depth range. In contrast, no vegetation was observed during drop video camera surveys of deeper areas next to the reefs (20.6-36.0 m). The dominant vegetation on the reefs was brown and green macroalgae, especially *Battersia arctica* and *Cladophora* spp., and vegetation cover at the surveyed sites varied between 0 and 100%, (average=59%; n=19 points). Some red macroalgae were also noted, such as

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Ceramium tenuicorne and *Vertebrata fucoides*, albeit typically at lower coverage than the brown and green algae. The dominant substrate was bedrock, boulders and stones, and no sedimentation was observed, indicating the exposed location of the reefs. Blue mussel (*Mytilus edulis x trossulus*) was also seen at low densities, with the exception of one quadrat in which it covered 10% of the bottom. All of these observed species and the substrate are typical of this habitat type.[25,37] Other associated species included *Amphibalanus improvisus*, *Theodoxus fluviatilis*, and *Electra crustulenta*.

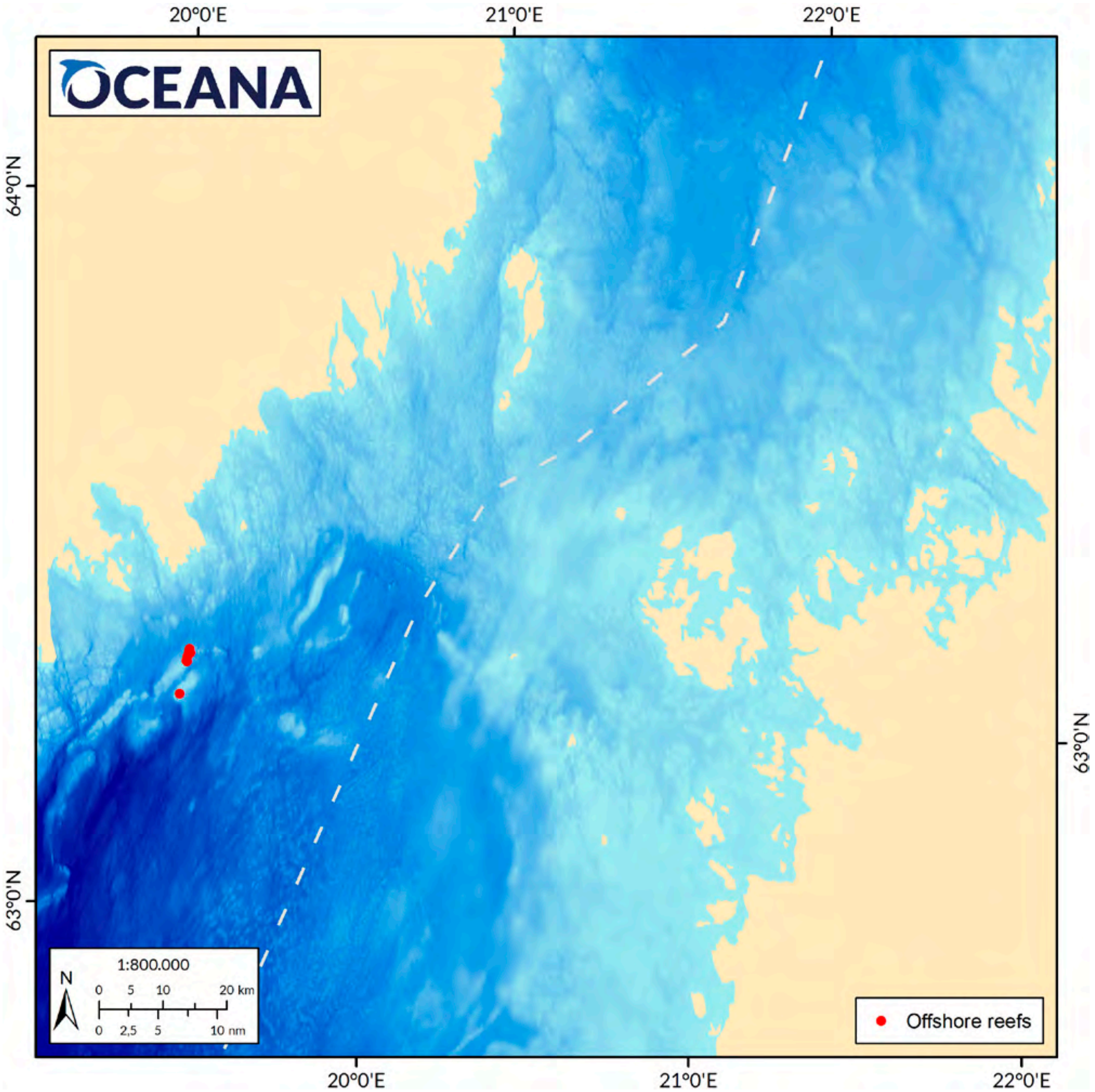

Figure 16. Locations of offshore reefs documented during the 2018 Oceana Quark expedition. Sources: EMODnet and European Environment Agency.

Vegetation dominated by perennial filamentous brown and green algae characterised another habitat documented from exposed locations. This habitat type was particularly common in the area to the northeast of Björkö in Finland, for example at Ritgrund (Figure 17) and Dundran. As the name suggests, this is a habitat where perennial algae (often *Battersia arctica* and *Cladophora* spp.) dominate on bedrock and boulders in the photic zone. Sites surveyed were quite barren, aside from the short, filamentous brown and green algae that almost entirely covered the substrate. Grazing fauna such as river nerite (*Theodoxus fluviatilis*) and pond snails (Lymnaeidae) was also observed, as is typical of this habitat.[25]

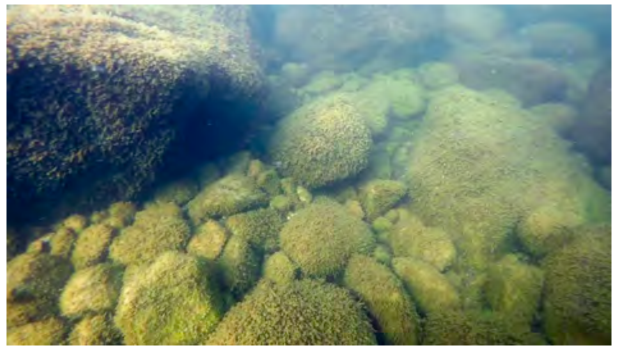

Figure 17. Perennial filamentous brown and green algae covering bedrock and boulders in the photic zone, in Ritgrund, Finland. © OCEANA

Vegetation dominated by annual filamentous algae represented another, similar habitat type surveyed. It was encountered, for example, outside Holmön in Sweden (Figure 18) and at Holmgrundberget, in Finland. Such areas are often dominated by algae such as *Pylaiella littoralis* and *Ectocarpus siliculosus*, which was the case at the sites visited during the expedition. This habitat can generally be found from just below the surface to approximately 4 m depth. At Holmgrundberget it was recorded at 2.7 m depth, while at Holmön it was observed in shallower waters (0.5-1.5 m). The substrate was a mix of boulders and stones and, as is typical of this habitat type, even smaller stones were often densely vegetated.

Figure 18. Dense vegetation of the annual filamentous algae *Pylaiella littoralis/Ectocarpus siliculosus* on boulders and stones outside of Holmön, Sweden, at 0.5 m depth. © OCEANA/ Carlos Minguell

Habitats: Sheltered survey areas

In the Quark, sheltered habitats and areas have been studied much more intensively than offshore and exposed areas. Sheltered habitat types are also home to most of the species found within the waters of the Quark.[5,97]

Fladas and shallow marine bays (which are precursors to fladas) were documented at various sites in both Finnish and Swedish waters, as shown in Figure 19. These sheltered habitats were found in locations where the topography of the area provided protection from wave motions, resulting in fine-grained substrate, typically with heavy sedimentation. During the expedition, fladas and shallow marine bays were surveyed at depths ranging from 0.4-3.0 m.

> **"In the Quark, sheltered habitats and areas have been studied much more intensively than offshore and exposed areas.**

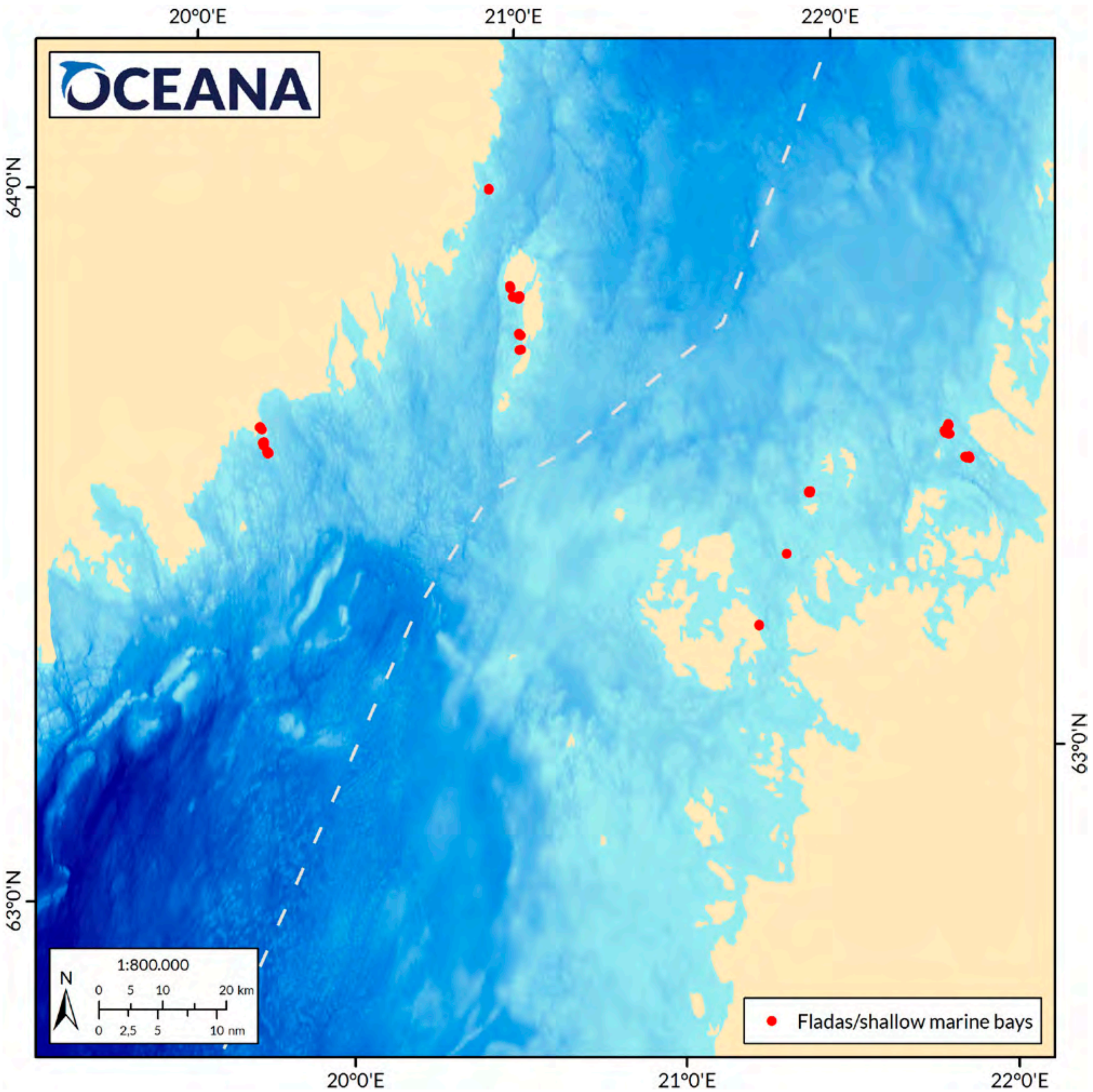

Figure 19. Locations of fladas and shallow marine bays documented during the 2018 Oceana Quark expedition.

Depending on the stage of development of a flada (i.e., how much water exchange occurs between the flada and the open sea) and nutrient levels, the vegetation present also differs. For example, stonewort meadows are common vegetation in fladas, although many charophytes are sensitive to increased nutrient inputs.[112] The vegetation in a flada can therefore change in response to changes in nutrient levels, with stonewort meadows disappearing in favour of tracheophytes, such as *Myriophyllum* spp. and *Potamogeton* spp.

One flada that was surveyed near Norrörarna in Finland was characterised by an overall high coverage of *Chara* spp. and, in places, high coverage of *Chara tomentosa*, *Najas marina*, *Ruppia maritima/ Stuckenia* sp. and *Myriophyllum* spp. (Figure 20). This was also the only site visited during the expedition that could be definitively confirmed to be a flada, due to the challenges associated with conducting surveys of these very sheltered, difficult-to-enter habitats (see *Methods*). Surveys in this flada were carried out at 0.8-2.5 m depth. The substrate was very fine-grained, and the level of sedimentation was high. Parts of the flada showed clear signs of eutrophication, since a dense mat of filamentous, loose algae covered the substrate and any potential vegetation (Figure 21). This observation showcases the fragility of fladas, and how the very factors that make them highly productive and diverse also make them vulnerable: namely that they are shallow, the substrate is very fine-grained and prone to resuspension when disturbed, the waters warm quickly, and the slow exchange of water allows nutrients to accumulate within them.

Figure 20. A flada documented near Norrörarna in Finland, characterised by an overall high coverage of *Chara* spp. © OCEANA

Figure 21. Clear signs of eutrophication in parts of the flada, with dense filamentous loose algae covering the substrate. Norrörarna, Finland. © OCEANA

The latest Finnish Red List assessment of threatened habitat types lists fladas as a habitat complex that comprises all the different stages of a flada up until it becomes a gloe lake, and defines the typical dominant vegetation of each of these stages.[25] In that assessment, fladas are classified as Vulnerable, and increased nutrients leading to increased filamentous algae are identified as one of the main threats, alongside dredging.[25] The threatened state of fladas is indicative of the more general scale of threats facing coastal lagoons in the Baltic Sea; such lagoons (which include fladas, gloe lakes, and related habitats) are Red Listed by HELCOM as Endangered,[113] on the basis of severe declines in habitat quality resulting from human activities.[44]

Charophyte (stonewort) meadows can also be found in more exposed locations, outside of fladas, where they form **Charales-dominated exposed bottoms.** This type of habitat was found in Swedish waters, in the areas of *Holmöarna*, Käringskär, and Vapplan; these sites were characterised by *Chara* spp. growing on mostly sandy substrate mixed with stones, gravel and fine-grained matter, at depths of 0.7-2.9 m (Figure 22). In these habitats, in addition to the stoneworts, vegetation included various brown macroalgae and individual plants of *Myriophyllum* spp., *Potamogeton* spp., *Stuckenia pectinata*, and *Zannichellia palustris*. Although not assessed in Sweden, this habitat type has been classified as Near Threatened in the Finnish national Red List assessment of threatened habitat types, due to threats such as dredging and increasing water turbidity, algal blooms, and bottom sedimentation.[25]

Figure 22. Charophyte (stonewort) meadows in exposed locations of Käringskär, Sweden, at depths of 0.9-2.3 m. © OCEANA

Within the Quark, tracheophytes represent another large habitat-forming group of plants. The following three habitat types within this category were documented during the expedition: **Vegetation dominated by *Potamogeton*, Vegetation dominated by *Myriophyllum* spp.**, and **Vegetation dominated by *Najas marina*.** These habitats share similar traits, such as the substrate being mostly fine-grained and soft, with *Najas marina* found at a site with very fine-grained substrate and heavy sedimentation (Figure 23), whereas the substrate for the other two habitats was more mixed, with some sand and gravel in addition to the more fine-grained substrate. All habitats were observed at depths of 3.0 m or less. Worryingly substantial growths of filamentous, loose algae were observed covering *Myriophyllum* spp., the substrate, and making the water column turbid at Vapplan in Sweden. Although species of the genus *Myriophyllum* are more tolerant to excess nutrients than, for example, charophytes, turbid waters eventually hamper their growth.[25]

Figure 23. *Najas marina* in a heavily sedimented area in Hamnskärskobban, Finland. © OCEANA

A habitat observed in several locations in both Swedish and Finnish waters was characterised by ***Vaucheria*-dominated bottoms.** The habitat is defined as having a very fine-grained (i.e., sludge/ mud) substrate, and vegetation dominated by the yellow-green algae *Vaucheria*. This habitat differs from other algal-dominated habitats in that it requires a soft substrate upon which *Vaucheria* can form dense mats, sometimes causing anaerobic conditions.[25,114] During the expedition, *Vaucheria*-dominated habitats were observed at depths of between 2.5-5.7 m in mostly sheltered locations, such as marine bays (e.g., Käringskär, Norrörarna and Hamnskärskubban) and in some cases in moderately exposed locations, such as Dundran. One example of this habitat type is shown in Figure 24, where it was documented in *Holmöarna* (a national Swedish MPA), inside a shallow and narrow marine bay.

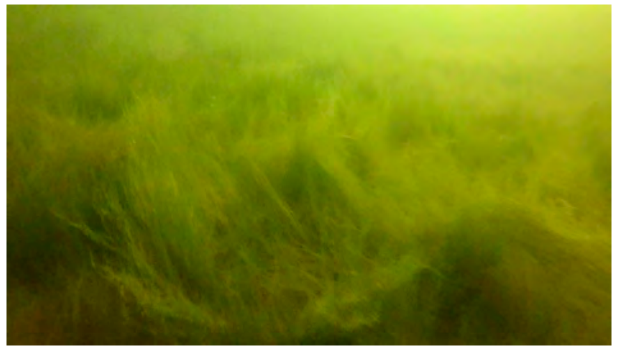

Figure 24. *Vaucheria*-dominated habitats between 2.5-5.7 m depth in Holmöarna, Sweden. © OCEANA

A relatively unknown habitat type in terms of distribution and species composition in the Quark is that of **soft bottoms dominated by polychaete tubes** (Figure 25). Prior to the 2018 Finnish Red List of threatened habitat types, this habitat had not previously been assessed in Finland[25] and there is still uncertainty concerning how common the habitat was prior to the introduction of the non-native polychaetes *Marenzelleria* spp. During the Oceana expedition, tube-dominated habitats were encountered in two locations in Finnish waters (Dundran and Rödgrynnorna) at roughly 7 m depth, on mixed substrate. Unfortunately, the precise species that formed the habitats observed during the expedition were not identified. Based on analyses of still images of the tubes, it is likely that the habitat was formed by one or two species of polychaetes. The most probable species, given their size and the fact that they are relatively common, are *Hediste diversicolor* and *Marenzelleria* spp.[25] *Marenzelleria* spp. was observed significantly more times than *Hediste diversicolor*, since only one individual of the latter was observed, in one location (Vapplan), whereas Marenzelleria spp. was observed in seven locations (i.e., in the areas of Hamnskärskubban, Holmgrundberget, and Norrörarna in Finland, and Holmärna, Käringskär, and Vapplan in Sweden), and in larger quantities (see *Species*).

Figure 25. Habitat formed by polychaete tubes at Rödgrynnorna, Finland, 7 m depth. © OCEANA/ Carlos Minguell

Worryingly, no **red algal habitats** or ***Fucus*-dominated habitats** (as defined by Kontula & Raunio)[25] were found during the expedition. Both of these habitat types are listed as Endangered on the Finnish Red List of threatened habitat types;[25] their status in Swedish waters has not been assessed, and information is lacking about many of the species that form these habitats. For example, 18 of 26 red algal species included in the 2015 Swedish Red List of threatened species are categorised as Data Deficient.[115] Although the apparent absence of these habitats could reflect the particular choice of sites surveyed, it is nonetheless suggestive of the trend that the Finnish Red List highlights, that these habitats are declining and action is needed to halt and reverse their loss.

Species

In total, 123 different taxa were documented during the expedition, of which 70 were identified to the species level. This constitutes approximately one-third of all macrospecies known to occur in the Quark.[116] A list of all the taxa observed during the expedition can be found in Annex 2. The major species groups observed in the Quark are presented in more detail below, under the following categories: vegetation (i.e., algae, stoneworts (algae of the family Characeae), vascular plants (tracheophytes) and animals (i.e., invertebrates, fishes, and seals)). Also discussed are the non-native species recorded during the expedition.

Vegetation species

In addition to salinity and substrate types, both of which are strong drivers of species and habitat distributions, another major factor is depth, because it influences the amount of sunlight that reaches vegetation. The majority of the observed vegetation was indeed found at less than 5 m depth during surveys (Table 2). As shown in the table, across all of the survey areas, vegetation cover decreased sharply below depths of 10 m.

	SCUBA quadrats	Drop video points
Depth (m)	**Average percentage cover of vegetation**	
0 - 4.9	51.9 (n=45)	47.4 (n=137)
5.0 - 9.9	47.4 (n=20)	39.9 (n=18)
>10.0	17.9 (n=13)	3.6 (n=24)

Table 2. Average percentage cover of vegetation for three different depth intervals, from SCUBA diving and drop video surveys, and excluding epiphytic vegetation. The number of observations for each value are indicated in parentheses. For drop video points, the average percentage vegetation cover for the deepest interval decreases to 0.9% if the one and only point taken at precisely 10.0 m is excluded.

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This clear depth limitation on vegetation is a well-documented characteristic of the Quark[5] which underscores the importance of sheltered, shallow habitats, since they host the majority of the biodiversity and biomass in the area. It also highlights the importance of the rarer offshore reefs, as is known from previous studies,[46] for supporting vegetation at greater depths than other habitats – in this case, at depths below 20 m. This vegetation, in turn, provides habitat for associated species at greater depths than elsewhere in the area.

During the expedition, green, brown, and red algae were observed to occur intermixed at different depths, in line with previous observation that algae in the Quark do not usually follow the vertical zonation commonly found elsewhere in the Baltic Sea.[46] However, green algae, such as *Cladophora* spp., were generally absent from depths greater than 4 m.

Various species of brown algae were a common sight throughout the Quark area. Among the brown algal species typically seen was the species pair *Ectocarpus siliculosus/Pylaiella littoralis* (which are difficult to distinguish from one another and are therefore often noted together as a species complex) (Figure 26). These filamentous brown algae were found at one-third of all dive sites and at 24 of 179 drop video points, with records across the main Swedish survey sites (i.e., Långrogrunden, Holmöarna, Käringskär, and Vapplan) and throughout the Finnish part of the Quark (e.g., Bullergrund, Holmgrundberget, Norrörarna, and Ritgrund). They were documented from depths of 0.5-7.4 m, but were most frequently observed in shallow locations (<3 m).

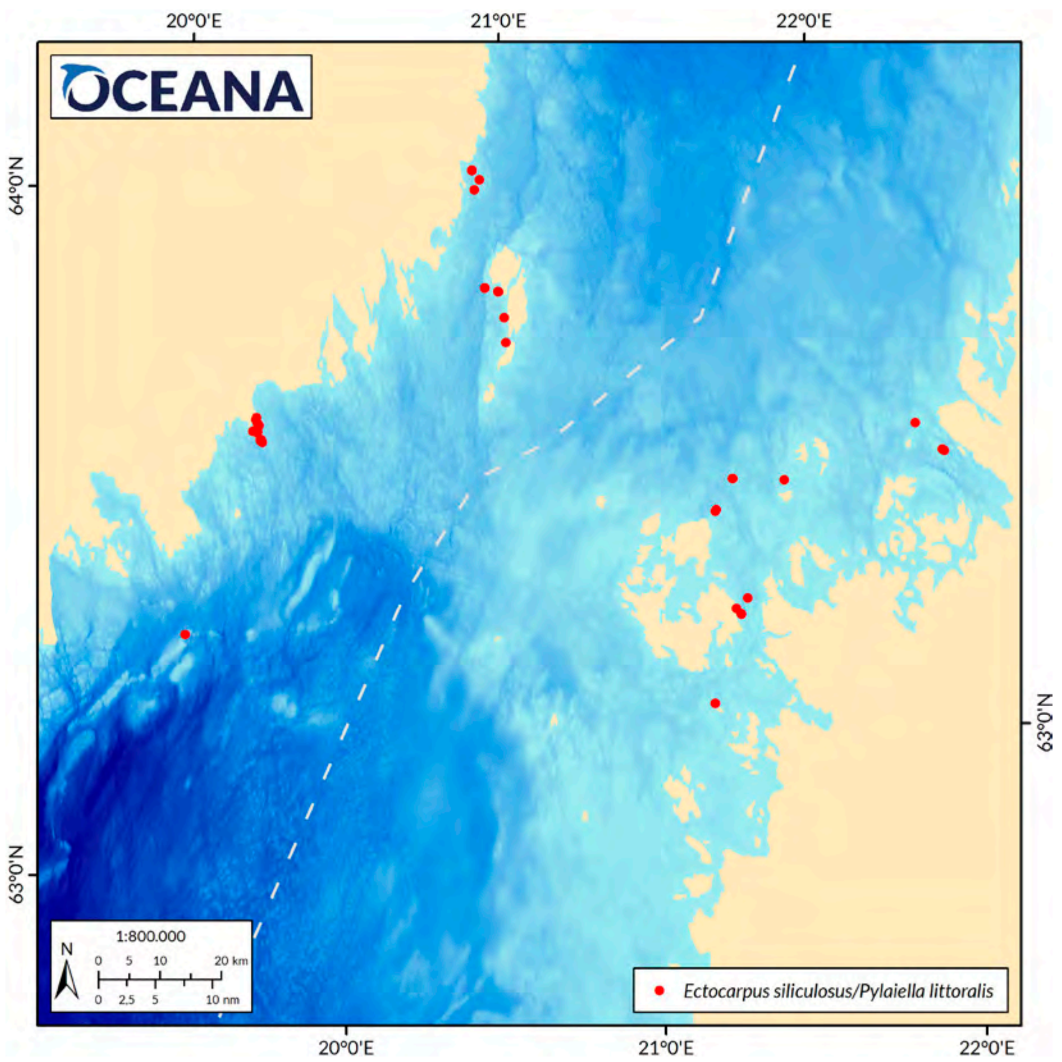


Figure 26. Locations of brown algae *Ectocarpus siliculosus/Pylaiella littoralis* documented during the 2018 Oceana Quark expedition. Sources: EMODnet and European Environment Agency.

At greater depths, another brown alga, *Battersia arctica*, dominated, particularly in the southern, more marine parts of the Quark (Figure 27). The deepest vegetation observed during the expedition comprised patches of *Battersia arctica* found at a depth of 20.3 m, at an offshore reef at Långrogrunden in Sweden. Vegetation at depths greater than 20 m is fairly uncommon in the Quark area, and usually only occurs in offshore areas where the waters are generally clearer.[5] Another brown alga that was noted during surveys, although sparsely, was the Baltic Sea keystone species narrow wrack (*Fucus radicans*). This species was identified from three locations (i.e., Kobbådan, Vapplan, and the *Snipansgrund-Medelkallan* seal protection area; Figure 28.). It may have also occurred in another three potential areas (i.e., Bullergrund, Långrogrunden, and Vapplan) where *Fucus* spp. were present but could not be identified to species level. All of these occurrences were recorded at depths of between 1.5-3.5 m.

Figure 27. The brown alga *Battersia arctica* dominated in deeper areas, particularly in more marine waters in the southern part of the Quark. The image shown was taken at the offshore reef Långrogrunden, Sweden. © OCEANA/ Enrique Talledo.

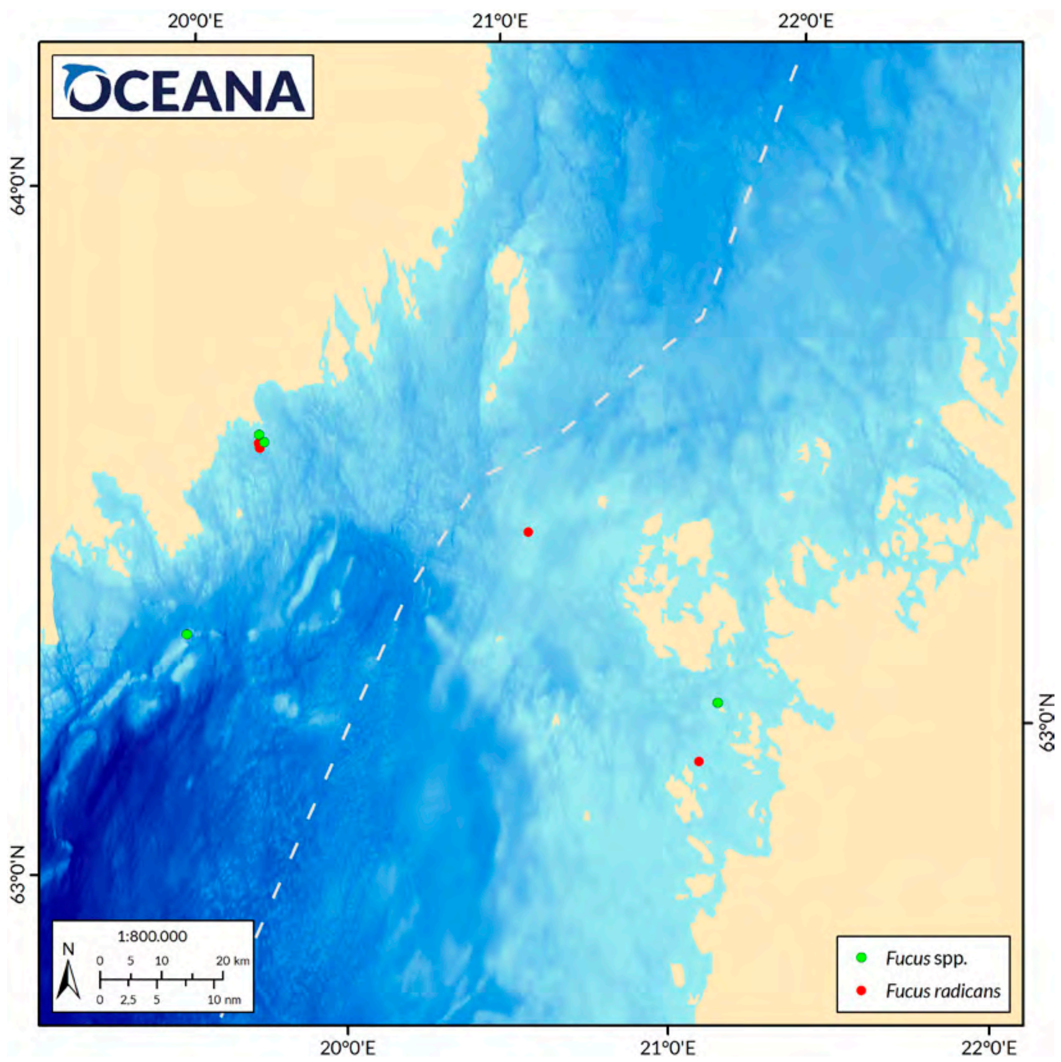


Figure 28. Observations of narrow wrack (*Fucus radicans*; four records) and potential observations of narrow wrack (*Fucus* sp.; four records) documented during the 2018 Oceana Quark expedition. Sources: EMODnet and European Environment Agency.

Of the red algae, the most frequently noted species was *Ceramium tenuicorne* (Figure 29). This species was widespread, as could be detected through photo quadrat from diving surveys in all but one of the dive sites where samples could be taken (i.e., the sites outside of protected areas). *C. tenuicorne* was recorded in both Finnish and Swedish waters, at depths of between 1.2-12.6 m, albeit with low coverage (1-10%, median=1%, n=34).

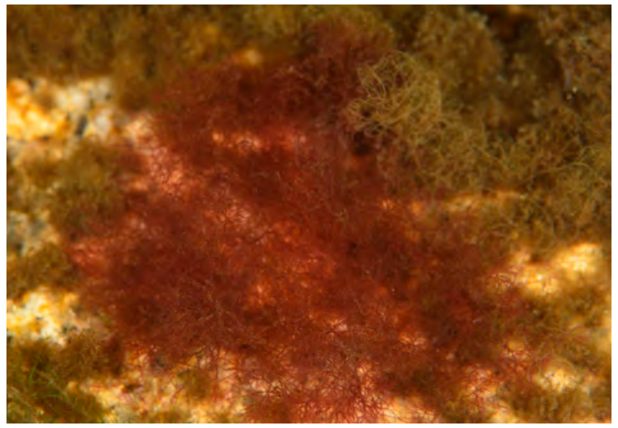


Figure 29. The red alga *Ceramium tenuicorne* was frequently noted during diving surveys in the Quark. The image shown was taken at the offshore reef Långrogrunden,at 6-7 m depth. © OCEANA/ Carlos Minguell

The other most commonly seen red algae were crustose algae of the genera *Audouinella*, *Hildenbrandia*, and *Rhodochorton*, which form a film on top of hard substrates. These species are difficult to distinguish from one another, and definitive identification relies on microscopic analysis.

Among the green algae, the most frequently observed species were those belonging to the genus *Cladophora* (see Figure 30). Species of this genus are typical of underwater reefs in the area,[37] and several observations of *Cladophora glomerata* and *Cladophora* spp. were recorded from the area of Långrogrunden, at a maximum depth of 12.6 m. Most other records were also from Swedish waters, with *Cladophora* sp. documented from Holmöarna, Käringskär, and Vapplan, while the only observations from the Finnish side of the Quark were from shallow waters (2.6-2.9 m) by Holmgrundberget.

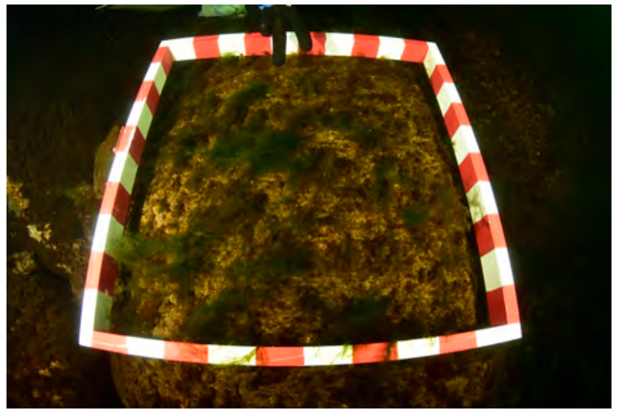


Figure 30. The green alga *Cladophora* spp., at 6.3 m depth, at the offshore Långrogrunden reef, Sweden. © OCEANA/ Carlos Minguell

The yellow-green alga *Vaucheria* spp. was observed growing in dense mat-like structures with coverage of 50-100%, at 11 drop video points in sheltered, mostly soft substrate areas. These mats were recorded from depths of between 2.5-5.7 m, in both Finnish waters (i.e., Dundran, Hamnskärskubban, Holmgrundberget and Norrörarna) and Swedish waters (i.e., Holmöarna and Käringskär). The mode of growth of this alga, which is commonly known as 'water felt' can be problematic, because the dense mats that it forms can lead to anaerobic conditions at the bottom, below the *Vaucheria*. In such locations, bacterial activity can then lead to the formation of pockets of methane gas.[119]

Epiphytic, annual, free-living, filamentous algae (Finnish: *rihmalevät*; Swedish: *trådalger*) were also observed at various locations in Finnish waters (i.e., Holmgrundberget and Norröarna) and in

Figure 31. Annual, epiphytic algae (Finnish: rihmalevät; Swedish: trådalger) growing on tracheophytes *Stuckenia pectinata* and *Callitriche hermaphroditica* at Holmgrundberget, Finland, depth <3 m. The abundant epiphytic algae indicate local eutrophication. © OCEANA/ Carlos Minguell

Figure 32. Meadow of coral stonewort (*Chara tomentosa*), Norröarna, Finland. © OCEANA/ Carlos Minguell

Swedish waters (Holmöarna, Käringskär, and Vapplan). In some cases, these algae partially or completely covered the underlying vegetation (Figure 31), with estimated coverage of up to 40%. The majority of these observations were made with the drop video camera, since more shallow and sheltered areas were surveyed with this method in comparison to diving, and most of the sightings were made at points shallower than 2 m depth. Epiphytic algae can be detrimental to local ecosystems, since they can suffocate and/or outcompete more slow-growing vegetation, such as tracheophytes or charophytes.[117] Eutrophication also favours the fast-growing annual, filamentous epiphytic algae; their increase during recent decades, and their projected continuous increase, are considered a major factor leading to declines in threatened habitats such as fladas, stonewort meadows and red algal-dominated bottoms.[25,118,118]

Also commonly observed during the expedition were stoneworts, green algae from the family Characeae. At least five different species were identified from the data collected (*Chara aspera*, *C. globularis*, *C. tomentosa*, *Nitella* spp., and *Tolypella nidifica*) (Figure 32). Stoneworts were widespread in the Quark, with observations from nearly one-third of drop video points and at 10 of 24 diving sites (Figure 33), on soft or mixed substrates, at depths ranging between 0.3-10.6 m (average=2.3 m, n=143 observations). Sites at which stonewort densities were particularly high (≥50% coverage) included Mickelsörarna and Norrörarna in Finland, and Holmöarna, Käringskär, and Vapplan in Sweden. Characeae are a specific type of freshwater green algae, which are believed to be the closest relatives to plants on land. Among their distinguishing characteristics are rhizoids (i.e., rootlike structures that attach them to soft substrates) which differ from the means by which other algae anchor themselves to hard substrates.[122] Charophytes are also sensitive to eutrophication and often vanish from areas when nutrient inputs increase.[116] Of the 21 species that occur in Finland, ten are included in the most recent Red List of Finnish Species,[31] whereas in Sweden, 20 out of the 39 known species are included on the latest national Red List.[119,119] The threats to charophyte-dominated habitats also affect the distribution of the individual species that comprise them (see *Habitats: Sheltered survey areas*). Oceana's numerous and widespread observations of charophytes during the expedition emphasises the fact that the Quark, with its many shallow areas and habitats such as fladas, constitutes a particularly important sea area for this sensitive and valuable algal family.

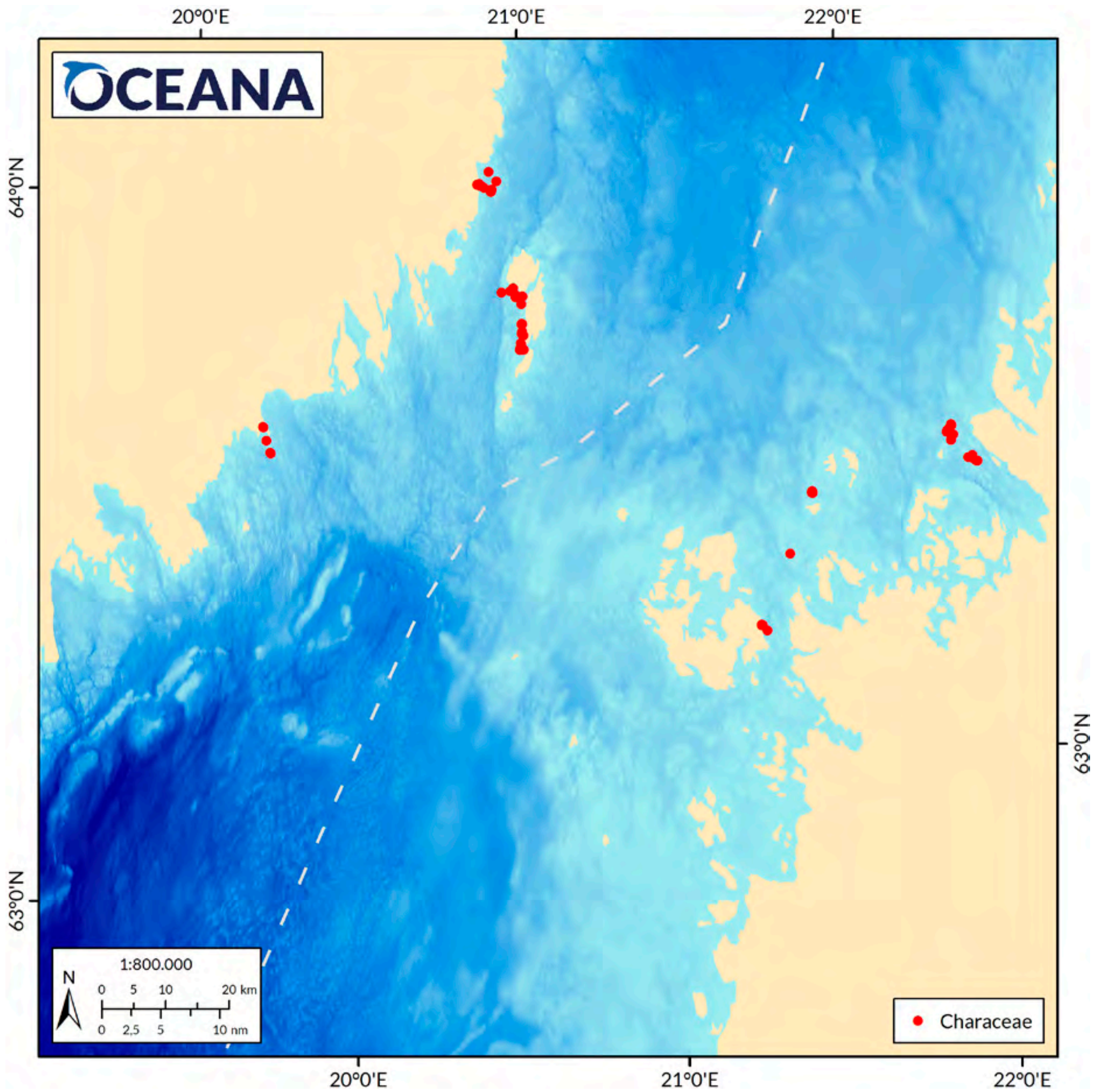


Figure 33. Locations of stoneworts (green algae of the family Characeae) documented during the 2018 Oceana Quark expedition. Sources: EMODnet and European Environment Agency.

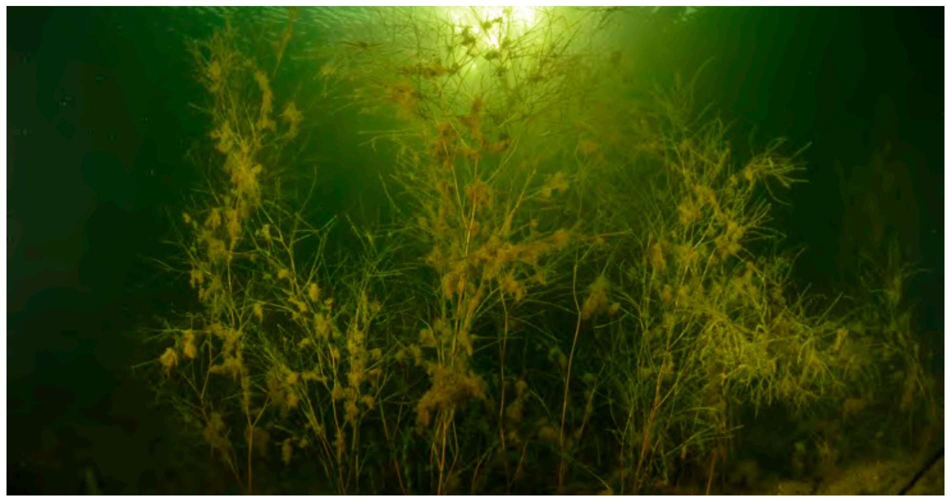


Figure 34. Fennel pondweed (*Stuckenia pectinata*) growing densely and reaching heights of 1-2 m, outside of Holmön, Sweden. © OCEANA/ Carlos Minguell

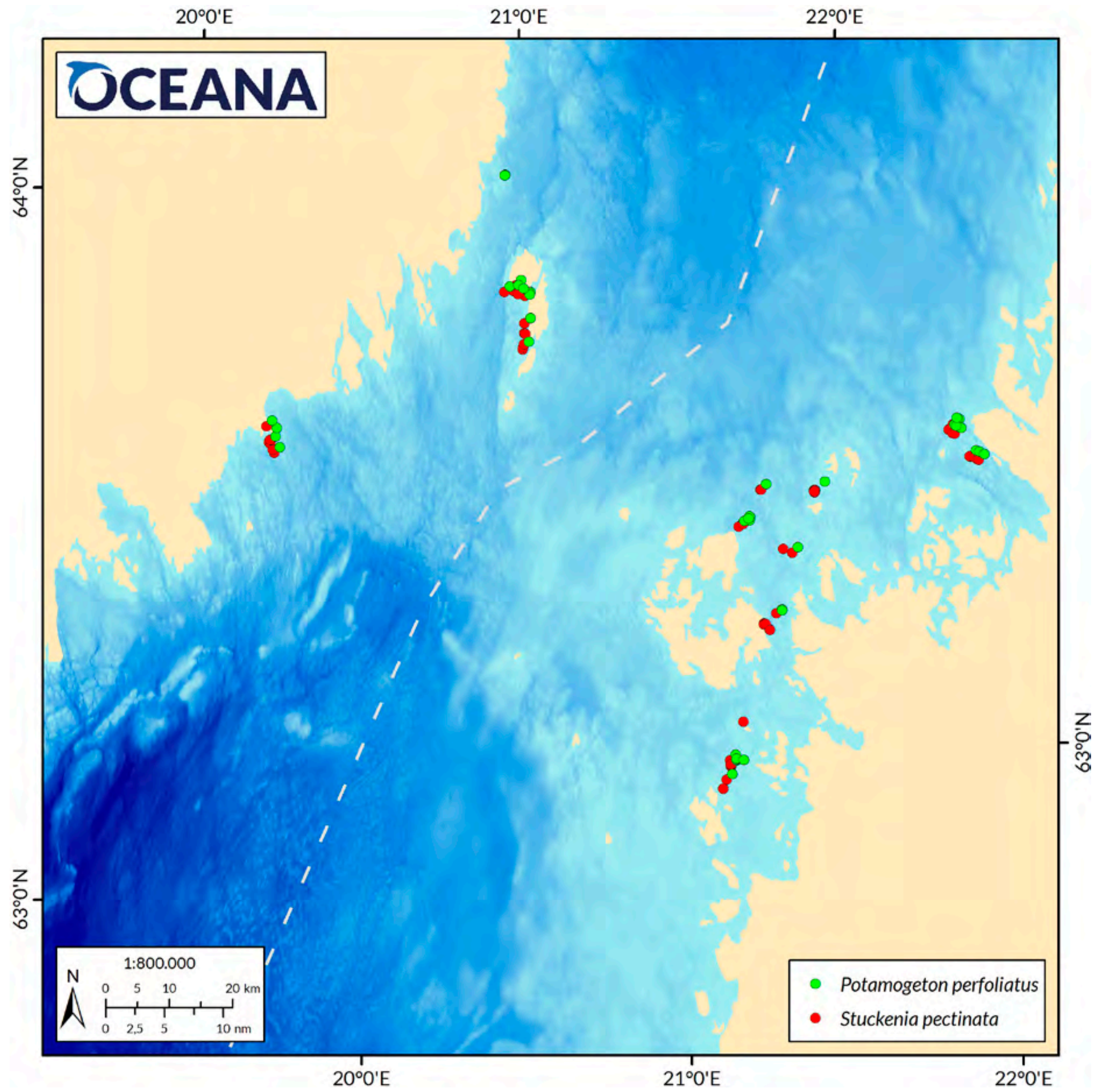


Figure 35. Locations of claspingleaf pondweed (*Potamogeton perfoliatus*) and fennel pondweed (*Stuckenia pectinata*) documented during the 2018 Oceana Quark expedition. Sources: EMODnet and European Environment Agency.

A group of species commonly observed in the Quark that also require soft substrate for their roots are the tracheophytes (vascular plants), which constitute an important and widely distributed group in the area.[120] They are also frequently found in fladas.[121] The most prominent varieties of these plants observed were freshwater species from the pondweed family Potamogetonaceae, especially claspingleaf pondweed (*Potamogeton perfoliatus*) and fennel pondweed (*Stuckenia pectinata*).

Claspingleaf pondweed (*Potamogeton perfoliatus*) was commonly observed in both Finnish and Swedish survey areas. It was recorded during both drop video and SCUBA surveys, at depths of between 0.7-6.8 m (Figure 35). Fennel pondweed (*Stuckenia pectinata*) was similarly widespread, at depths ranging from 0.6 m to 9.4 m. Percentage coverage of these two species (individually or in was as high as 50-70% at some survey points in Finland (e.g., in Dundran, Elisgrund, Mickelsörarna, and Norröarna).

Other tracheophytes documented during the expedition include *Callitriche hermaphroditica*, *Najas marina*, *Myriophyllum* spp., and *Zanichellia palustris*.

Further highlighting the mixture of marine, brackish and freshwater species found in the Quark were observations of the freshwater aquatic moss *Fontinalis* spp. These submerged bryophytes were seen in two survey areas: in several points around Vapplan (Sweden) (Figure 36) and inside the *Snipansgrund-Medelkallan* seal protection area (Finland). Recorded depths ranged from 1.4-5.9 m.

Figure 36. The freshwater aquatic moss *Fontinalis* spp., Vapplan, Sweden. © OCEANA/ Carlos Minguell

Animal species

Although the survey methods used during the expedition were not especially targeted at gathering data on fishes and other highly mobile animals (such as seals), all animal macrospecies observed were noted and identified to the extent possible. These findings are described below.

Invertebrates were documented during the expedition via drop video, benthic grab sampling, and dive surveys. However, because drop video surveys are not well suited to the detection and identification of invertebrates, the results presented here focus on the findings of the grab samples and dive surveys.

From the seven locations from which grab samples were taken, 24 taxa were documented, of which 11 were identified to the species level. The most diverse group were arthropods (e.g., water mites, insects, amphipods, and isopods) and annelids (e.g., polychaetes such as *Pygospio elegans*, oligochaetes, and the great tailed leech *Piscicola geometra*), followed by ribbon worms (Nemertea), molluscs (i.e., *Limecola balthica* and *Mytilus edulis x trossulus*), nematodes, and one bryozoan species (*Einhornia crustulenta*) (Figure 37). Of these groups, the most numerous were nematodes, ostracods, the amphipod *Monoporeia affinis*, and larvae of Chironomidae (midges). The latter, which are known to comprise roughly one-third of the macrozoobenthos species in the Baltic Sea,[122] were found from five of seven sampled sites, in both Finnish and Swedish waters.

Figure 37. Encrusting bryozoan (*Einhornia crustulenta*) with little ivory barnacle (Amphibalanus improvisus). Långrogrunden, Sweden. © OCEANA/ Carlos Minguell

Of particular interest was *M. affinis*, which is an important food source for various fishes, and was found in four of seven sampled locations. This species is found in most of the Baltic Sea but has declined in abundance in some areas due to eutrophication, reduced oxygen levels, and potentially competition with the invasive polychaete *Marenzelleria viridis* (which was also obtained in the grab samples).[123,124] The fact that it was relatively common during the Quark surveys is encouraging, although it may reflect the fact that the sampling sites were exposed or semi-exposed, (and therefore less likely to experience hypoxic conditions because of greater water exchange). Grab samples were also taken from relatively shallow areas (maximum depth 27 m), and so oxygen was less likely to be limited than in deeper areas.

From dive surveys, molluscs represented the most diverse and abundant group of invertebrates, including both gastropods (e.g., pond snails (Lymnaeidae), river nerite (*Theodoxus fluviatilis*), and broad-headed lanceolate sea slug (*Limapontia capitata*)) and bivalves (i.e., *Limecola balthica* and *Mytilus edulis x trossulus*, the latter of which was observed only from Långrogrunden). Also relatively common were crustaceans such as the isopod scavenger *Saduria entomon*, little ivory barnacle (*Amphibalanus improvisus*; Figure 37), and *Gammarus* amphipods. Other documented fauna included hydrozoans (*Cordylophora caspia*, *Gonothyraea loveni*, and *Hydra* spp.), bryozoan *Einhornia crustulenta*, freshwater sponge (*Ephydatia fluviatilis*), and triclads (free-living flatworms of the order Tricladida), which were identified at one-third of all diving sites (Figure 38). In general, the dive sites with relatively higher epibenthic invertebrate diversity were Långrogrunden and *Holmöarna*.

Figure 38. A free-living flatworm (order Tricladida), photographed at Rödgrynnorna, Finland. © OCEANA/ Carlos Minguell

Among the fishes observed were species of freshwater origin such as pike (*Esox lucius*) and perch (*Perca fluviatilis*), as well as species of marine origin such as the straightnose pipefish (*Nerophis ophidion*; Figure 39). Sightings of *Pomatoschistus* spp. and sticklebacks (Gasterosteidae) such as *Gasterosteus aculeatus* were especially prevalent. Schools of juvenile fishes were documented from various locations (i.e., Käringskär, Holmöarna, and Norrörarna) in shallow, protected and vegetated areas.

Figure 39. Straightnose pipefish (*Nerophis ophidion*). Kobbådan, Finland. © OCEANA/ Carlos Minguell

In addition to the fish species mentioned, several viviparous eelpout (*Zoarces viviparus*) were also sighted, in three locations in Swedish waters (i.e., Käringskär, Långrogrunden, and Vapplan). However, on several separate dives more dead individuals were seen than live ones (Figure 40). Reasons for the numerous dead viviparous eelpouts observed are unclear; this may have been caused by reproductive stress and/or the unusually warm water temperatures. The viviparous eelpout has been used as an indicator species in Swedish national environmental monitoring since the 1980s, as it is very sensitive to environmental toxins. The species is also thought to be disadvantaged by climate change and warming waters, because it prefers colder conditions.[125,126]

Figure 40. Bottom-dwelling scavengers Saduria entomon feeding on a dead viviparous eelpout (*Zoarces viviparus*). Vapplan, Sweden. © OCEANA/ Carlos Minguell

One of the dive surveys during the expedition was carried out inside the Finnish national seal reserve *Snipansgrund-Medelkallan* and was the first recorded dive inside this area.[97] During the surveys, a total of 17 grey seals (*Halichoerus grypus*) were observed with a drone and by divers (Figure 41). The seals were mostly observed resting in small groups on boulders visible above the surface and were not disturbed by the divers or the boat. In general, the seal protection area is shallow and exposed, with relatively dense vegetation, which consisted mostly of different types of red, green, and brown macroalgae.

Figure 41. Grey seal (*Halichoerus grypus*) resting on a rock in the *Snipansgrund-Medelkallan* Finnish national seal reserve. © OCEANA/ Carlos Minguell

Non-native species

Given the threat that non-native and invasive species pose to ecosystems in the Baltic Sea and the Quark, all non-native species and their distribution were carefully noted during the expedition. In total, four non-indigenous species were observed throughout the expedition (Figure 42). These species were the amphipod *Gammarus tigrinus*, the commonly-found polychaete *Marenzelleria* spp., the gastropod *Potamopyrgus antipodarum*, and the well-established crustacean *Amphibalanus improvisus*.

As is evident from Figure 42, all four species were found in both Finnish and Swedish waters, and appeared to be spread throughout the Quark. Even though these organisms have been classified as established and their eradication is no longer considered feasible,[127] there remains uncertainty about the extent of potential negative effects they may have on ecosystems in the Quark, and a need for further monitoring and studies of impacts. New non-native and possibly invasive species, such as the round goby (*Neogobius melanostomus*), are furthermore a continuous threat in the Baltic Sea and the Quark.[23] The round goby has been observed to the north of the Quark,[74] therefore making it highly likely that it occurs in the Quark as well.

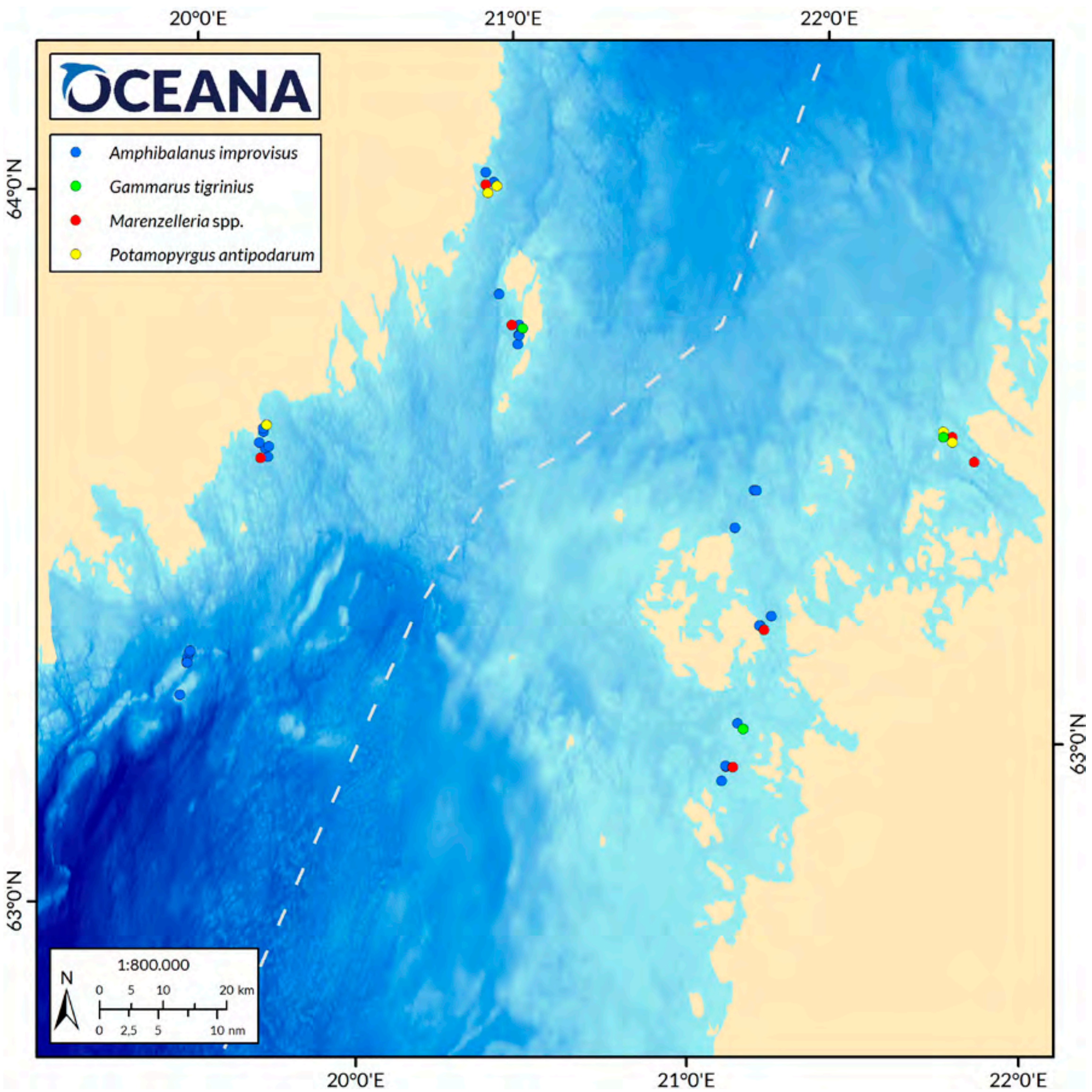


Figure 42. Observations of non-native species documented during the 2018 Oceana Quark expedition. Observations were made primarily through benthic fauna sampling, as well as from vegetation samples in which fauna was present. Sources: EMODnet and European Environment Agency.

OCEANA'S PROPOSAL FOR PROTECTING THE QUARK

The Quark is a unique and ecologically valuable area. Its importance is recognised both nationally within Finland and Sweden, and internationally, as is highlighted by the designation of parts of the Quark as a UNESCO World Natural Heritage Site, and more recently, of the entire area as an EBSA. However, even though the Quark has been relatively well studied, there are still gaps in knowledge about the area's marine habitats and their distributions, and the distributions of species. Without adequate information about the nature values and specific marine features in the Quark, effective protection and management cannot be achieved.

Therefore, in the interest of advancing marine conservation in the Quark, Oceana identified specific data gaps which it sought to fill during the 2018 research expedition. The expedition and the data it yielded were unique, in that information was gathered in both Finland and Sweden, during a limited time span, via surveys that were carried out in both exposed offshore areas and sheltered coastal areas. This provides a broadscale yet detailed overview of the Quark's underwater environment, highlighting key features, areas, and evidence of threats.

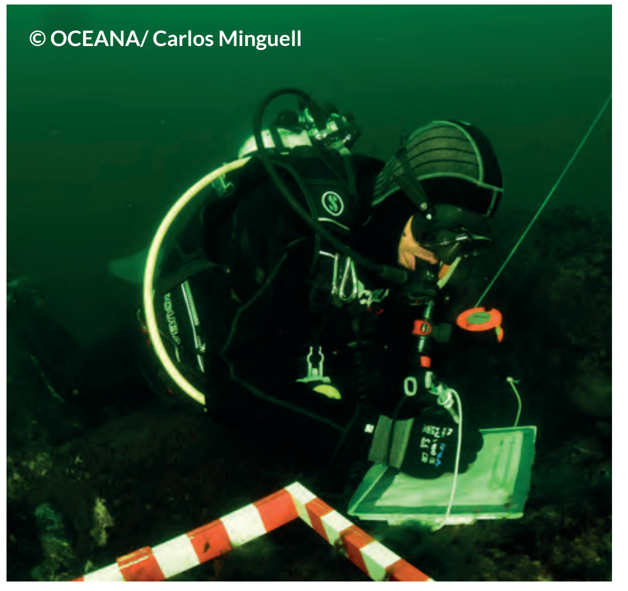
The Oceana expedition documented approximately one-third of all the known macrospecies described from the Quark, and ten habitat types, spanning a variety of habitats that have previously been well-surveyed (e.g., fladas) as well as those that are lesser-known or surveyed (e.g., polychaete bottoms and offshore reefs). From the results, it is evident that the highest levels of productivity and associated biodiversity are concentrated in the shallow parts of the Quark (see Table 2), in addition to the offshore reefs, where clear-water conditions permit vegetation to reach deeper depths than in waters closer to the coasts.

Many of the habitats found in the shallow parts of the Quark have been classified as threatened (Table 1) and/or are recognised as priority habitats for protection under the EU Habitats Directive (e.g., reefs, coastal lagoons, large shallow inlets and bays, and sandbanks). The threats and primary reasons for observed declines in these habitats include eutrophication, increased turbidity, increased filamentous algae, decreased salinity, dredging, and marine traffic.[25,128] During the Oceana expedition, some of these worrying impacts were directly observed. Eutrophic conditions were documented at sites in both Finnish and Swedish waters, where the vegetation was covered or partially covered by epiphytic filamentous algae. Also striking were the extensive cyanobacterial blooms seen throughout the Quark; such blooms were observed at the surface, in the water column, and on the bottom. As outlined in *Findings & Discussion*, the summer of 2018 was unusually warm – the warmest year in nearly three decades in the Baltic Sea[102] – and cyanobacterial blooms were a common sight even in the Quark, which had previously to a large extent been exempt from those types of blooms.[67]

In conjunction, the biodiversity importance of the Quark in terms of its unusual mix of marine, brackish, and freshwater species[3,25] and the high number of threatened habitats it hosts, the significant ongoing threats to marine life in the area, and the immense risk that climate change poses to the region point to the need to safeguard this unique area before it is too late. While on paper nearly one-third of the area of the Quark sub-basin is recognised as either valuable and/or protected, many of the designated MPAs in the Quark offer little if any protection to marine biodiversity features. Furthermore, there is a bewildering array of different protections layered on top of one another, which makes it extremely challenging to assess the actual state of protection of any given area or the marine life that it supports.

In order to effectively conserve the marine ecosystems of the Quark and to maintain the ecosystem goods and services that they provide to the area's inhabitants, Oceana recommends that Finland and Sweden jointly develop stronger measures of spatial marine protection for the area. Specifically, Oceana proposes the establishment of a transboundary MPA in the Quark sub-basin, which would be underpinned by a joint management plan addressing all of the key habitats, species, and the threats that they face.

There are several reasons why a transboundary MPA would be the most appropriate means of achieving marine biodiversity protection in the Quark. First, Finnish and Swedish waters of the Quark are very similar; the marine life that they support and the major threats of concern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(e.g., eutrophication, overexploitation, and climate change) are essentially the same on both sides of the border. Therefore, a holistic approach based on joint management is likely to make conservation and management measures more effective at the scale of the entire Quark sub-basin. Second, having a single transboundary MPA that consolidates existing measures of protection within one overarching framework would help to increase transparency and improve access to information about protected features and specific measures in place to protect them. This, in turn, would make it much easier to evaluate actual levels of marine protection across the area and to identify gaps in coverage that must be addressed. Third, Finland and Sweden are close to one another, both culturally and geographically, thus facilitating dialogue and collaboration around a shared transboundary MPA. In fact, Sweden stated in its 2016 national action plan for marine protection that the possibilities for a transboundary MPA in the Bothnian Bay should be examined and collaboration with Finland deepened.[73]

There are multiple possibilities of how best to designate and manage a transboundary MPA in the Quark. For example, under existing legislation there is scope for creating a single new joint unit of protection, such as a transboundary UNESCO Biosphere Reserve or a nature park. Alternatively, two separate but adjacent MPAs could be designated under Finnish and Swedish national legislation, but managed under a joint management plan. In the Quark, a strong foundation is already in place upon which this shared approach could be built. There are already numerous cross-border collaborations in the Quark between the countries, in terms of marine projects (e.g., Kvarken Flada[92] and ECOnnect[129]) as well as regional collaboration on projects about trade and tourism.[4] These existing networks can help to facilitate the establishment of a transboundary MPA.

Ideally, a transboundary MPA in the Quark would comprise different zones with varying levels of restrictions, depending on the ecological features of each zone and the identified threats. Such an approach aims to provide a balance between conservation and use, to ensure that biodiversity features are safeguarded whilst not imposing unnecessary restrictions on the local communities and sectors that depend on marine ecosystems and resources. Of the habitats identified during the Oceana expedition, those that warrant a higher level of protection are associated with shallow and sheltered locations, namely fladas and all their stages, stonewort meadows outside of fladas, and *Najas marina*-dominated vegetation. Although no *Fucus* spp.-dominated habitats or red algal habitats were encountered, both of these habitat types are known to be present in the Quark and are categorised as Endangered in Finland.[25] They should therefore also be given special consideration.

Among the specific management measures that should be established to protect fragile shallow-water and sheltered habitats are restrictions on human activities that resuspend sediments, leading to the suffocation of perennial plants and benthic suspension-feeders, and returning sedimented nutrients back to the water column. In particular, the following types of measures are needed to safeguard these ecologically valuable areas:

- Restrictions on all types of dredging in the most valuable fladas, such as those that are relatively pristine (so-called 'reference fladas') and those that provide spawning habitat for fishes. Small-scale dredging is very common in the Quark, particularly on the Finnish side (see Figure 7), where more fladas are located. Dredging represents one of the main identified threats to fladas,[25] and should be strictly prohibited in sites of the highest ecological value, regardless of the scale of dredging.

- Restrictions on boat traffic and anchoring in very shallow areas with fine substrate. Such limitations are particularly important in areas with high coverage of slow-growing vegetation such as charophytes, which represent important habitats for many species of fishes and crustaceans, and which are slow to recover from mechanical tears caused by boat propellers or anchors.[79]
- Temporal restrictions on recreational fishing for top predator fishes (i.e., pike (Esox lucius) and perch (Perca fluviatilis)) during their peak mating season, from March/April to late May or mid-June. Such conservation measures for pike in the County of Stockholm, for example, led to a doubling of pike catch per unit effort in comparison with marine bays where no such measures were in place.[85] In the Quark, the magnitude of recreational fishing in sensitive habitats – and in the sub-basin as a whole – is not well known and merits further attention and study.

Beyond the above measures for the most vulnerable habitats, Oceana's recommendations for the establishment, management, and monitoring of a joint Finnish-Swedish MPA in the Quark include the following:

- Documenting natural features found within existing MPAs, and critically evaluating the management measures (or lack thereof) for those areas. For example, threatened habitats and species occur within some areas which are designated on paper as MPAs, but where in fact the legal designations do not refer to any habitats or species, and there are no specific management measures in place for biodiversity protection (see *Current protection and management*).
- Limiting eutrophication from farming and other sources, with special attention paid to those habitats that are most vulnerable to the impacts of excess nutrients (e.g., fladas).
- Closely continuing to monitor shipping and developing measures to ensure, to the extent possible, that any risks of spills of fuels or other pollutants are minimised.
- Deepening collaboration between Finland and Sweden with respect to curbing climate change and locally raising awareness of measures that can be taken to help mitigate and adapt to its effects.

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- Developing joint research and monitoring programmes to gather data about specific habitat types for which information is lacking. For example, there is a need for mapping and detailed biological inventories to be completed on offshore reefs. As the threats currently facing these reefs in the Quark are broadscale in nature, regular monitoring should also be carried out, so that any potential negative changes in water clarity, vegetation cover, and/or diversity can be detected and addressed. Another habitat type for which distribution data are lacking are those formed by polychaetes; it is also unknown to what extent such habitats are formed by the non-native *Marenzelleria* spp.
- Monitoring and assessing the distribution and potential impacts of non-native species in the Quark, including those that have already become established in the area as well as those that have not yet done so.

In a wider context, conservation and management of marine ecosystems in the Quark would benefit from increased broad-scale efforts to ascertain the threat level of specific features, particularly in Sweden. Finland has carried out a national-scale Red List assessment of threatened habitats[25] – including marine habitats – which underscores the importance of the Quark for many of the systems identified as threatened or near-threatened in Finnish waters. To date, however, a similar evaluation has not been carried out Swedish waters. Such an assessment should be conducted to help spur the collection, compilation, and analyses of the best available data on distributions and threats and to determine the relative importance of the Quark, at the national scale, for habitats in Sweden. Assuming that the Swedish side of the Quark, like the Finnish side, represents a relatively important zone for threatened marine habitats, the assessment could then serve as a key tool for prioritising their protection within Sweden.

Similarly, national-scale efforts in Finland to integrate information about threatened species and habitats, human activities, and protected areas into marine spatial planning could also shed light on the real state of protection of marine features in the Quark and highlight key gaps in protection.[130] Ideally, such work would be extended to cover the entirety of the Quark, in order to fully evaluate protection at the scale of the sub-basin and its populations, and to develop appropriate measures to safeguard against both localised and large-scale threats to this unique area.

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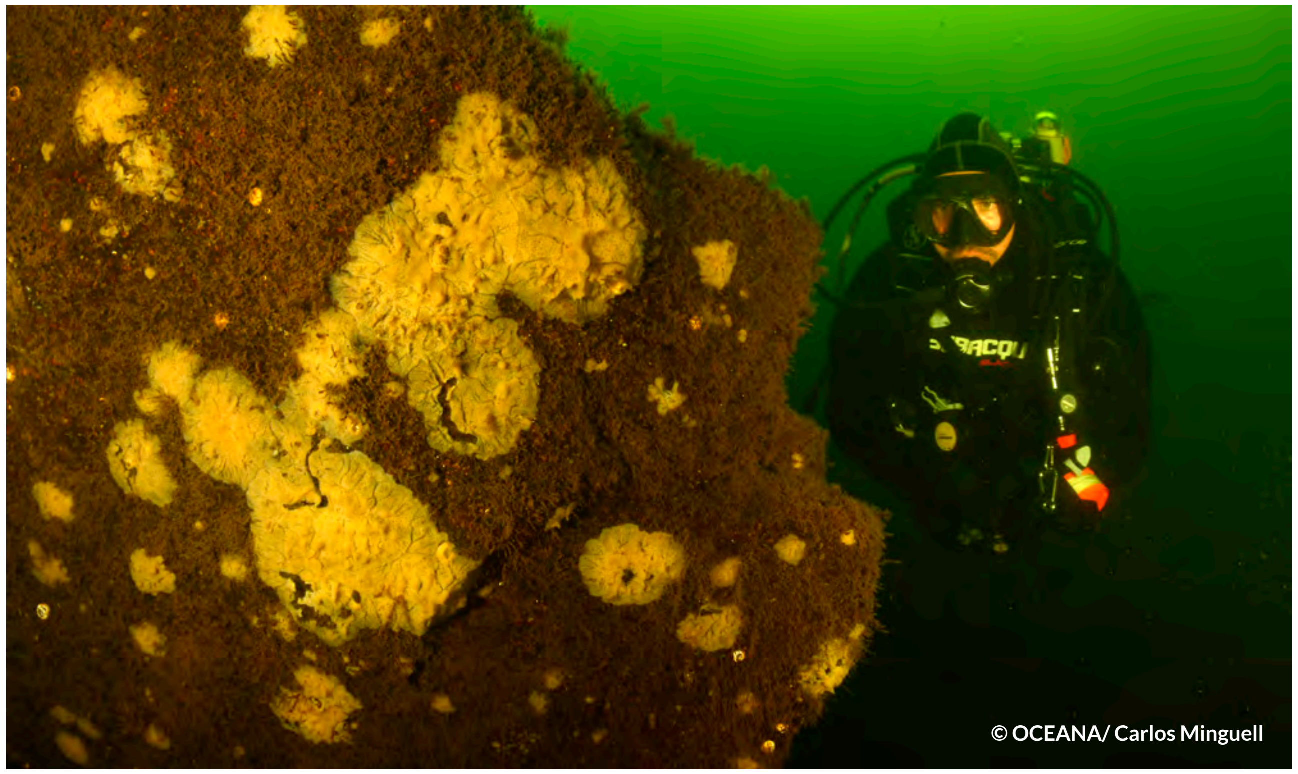

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ANNEX 1

Summary of marine protected areas in the Quark, according to protected area type and country. Note that many designations are spatially overlapping within the same areas. Sources: European Environment Agency and HELCOM.

Protected Area Type	Finland	Sweden	Finland and Sweden
Habitat Protection Area (national)		1	
Nature Reserve (national)		10	
Old Growth Forest Reserve (national)	1		
Private Nature Reserve (national)	199		
HELCOM MPA	2	1	
Natura 2000 (Habitats Directive)	1	8	
Natura 2000 (Habitats and Birds Directives)	5	2	
Natura 2000 (Birds Directive)		2	
Ramsar Site	2	1	
Seal Protection Area (national)	1		
World Heritage Site			1
Total	**211**	**25**	**1**

ANNEX 2

List of taxa identified during the 2018 Oceana Quark expedition, according to survey methodology.

	Drop video	Grab samples	Quadrats	Samples	SCUBA	Sightings
ANIMALIA						
Annelida						
Hediste diversicolor		X				
Manayunkia aestuarina		X				
Marenzelleria sp.		X				
Oligochaeta		X				
Piscicola geometra		X	X		X	
Polychaeta		X				
Pygospio elegans		X				
Sabellidae		X				
Arthropoda						
Amphibalanus improvisus	X		X		X	
Amphipoda	X					
Asellus (Asellus) aquaticus			X		X	
Chironomidae		X	X		X	
Copepoda		X				
Corophium volutator		X				
Gammaridae			X			
Gammarus sp.		X	X		X	
Gammarus salinus			X			
Gammarus tigrinus			X	X	X	
Gammarus zaddachi			X			
Hydrachnidia	X	X				
Idotea sp.	X				X	
Insecta		X				
Jaera sp.		X	X			
Monoporeia affinis		X				
Mysida	X				X	
Ostracoda		X				
Saduria entomon	X	X	X		X	
Trichoptera	X		X		X	
Bryozoa						
Einhornia crustulenta	X	X	X		X	
Chordata						
Actinopterygii	X				X	
Cottidae					X	
Cottus gobio					X	
Esox lucius					X	
Gasterosteidae					X	
Gasterosteus aculeatus	X				X	
Gobiidae					X	
Gymnocephalus cernua					X	
Halichoerus grypus					X	X
Hirundinidae					X	
Nerophis ophidion					X	
Perca fluviatilis					X	
Phoxinus phoxinus					X	
Pomatoschistus sp.	X				X	
Pungitius pungitius			X		X	
Zoarces viviparus					X	
Cnidaria						
Cordylophora caspia					X	
Gonothyraea loveni					X	
Hydra sp.					X	
Mollusca						
Bithynia sp.					X	
Bithynia leachii			X			
Bithynia tentaculata			X			
Gastropoda	X		X		X	
Hydrobia sp.		X	X		X	
Limapontia capitata			X			

Limecola balthica		X	X		X	
Lymnaeidae			X	X	X	
Mytilus edulis	X	X	X		X	
Physa fontinalis					X	
Potamopyrgus antipodarum		X	X	X		
Tenellia adspersa					X	
Theodoxus fluviatilis	X		X	X	X	
Valvata sp.					X	
Nematoda						
Nematoda		X				
Nemertea						
Cyanophthalma obscura		X			X	
Gordius sp.		X				
Platyhelminthes						
Tricladida					X	
Porifera						
Ephydatia fluviatilis	X		X		X	
BACTERIA						
Cyanobacteria						
Cyanobacteria	X				X	
Nostoc sp.	X		X		X	
Rivularia sp.	X		X	X	X	
CHROMISTA						
Ochrophyta						
Battersia arctica	X		X		X	
Ectocarpus siliculosus	X		X		X	
Fucus sp.	X				X	
Fucus radicans	X		X		X	
Phaeophyceae	X		X		X	
Pylaiella littoralis	X		X		X	
Vaucheria sp.	X		X			

PLANTAE						
Rhodophyta						
Audouinella sp.	X		X		X	
Ceramium tenuicorne			X			
Coccotylus truncatus			X			
Furcellaria lumbricalis			X			
Hildenbrandia sp.	X		X		X	
Phyllophora pseudoceranoïdes			X			
Polysiphonia sp.			X			
Rhodochorton sp.	X		X		X	
Rhodophyta	X		X		X	
Vertebrata fucoides			X			
Bryophyta						
Fontinalis sp.	X				X	
Fontinalis dalecarlica			X			
Charophyta						
Chara sp.	X		X		X	
Chara aspera	X		X			
Chara globularis			X	X		
Chara tomentosa	X		X	X		
Characeae	X		X		X	
Nitella sp.			X			
Tolypella nidifica	X		X			
Tracheophyta						
Callitriche hermaphroditica	X		X	X	X	
Lemna trisulca	X					
Myriophyllum sp.	X		X		X	
Myriophyllum alterniflorum					X	
Myriophyllum sibiricum	X			X		
Najas marina	X			X		
Phragmites australis					X	
Potamogeton sp.	X					
Potamogeton berchtoldii	X					

Potamogeton compressus					X	
Potamogeton filiformis	X					
Potamogeton friesii					X	
Potamogeton perfoliatus	X		X		X	
Potamogeton pusillus	X					
Ranunculus peltatus					X	
Ranunculus peltatus subsp. baudotii	X					
Ruppia maritima	X		X			
Stuckenia sp.	X					
Stuckenia filiformis			X			
Stuckenia pectinata	X		X	X	X	
Tracheophyta	X				X	
Zannichellia palustris	X		X		X	
Chlorophyta						
Chlorophyta	X		X		X	
Cladophora sp.			X			
Cladophora glomerata	X		X			
Monostroma grevillei			X			
Ulva sp.	X		X			

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