

Marker Wadden: Results of the first five years of research

English summary of the final report



The islands of Marker Wadden created fascinating new nature soon after its construction; in addition to many birds, aquatic plants and fish appeared. Marker Wadden has considerably increased the amount of habitat for a number of bird species in Lake Markermeer. Moreover, the islands act as a stepping stone to other areas in the vicinity.

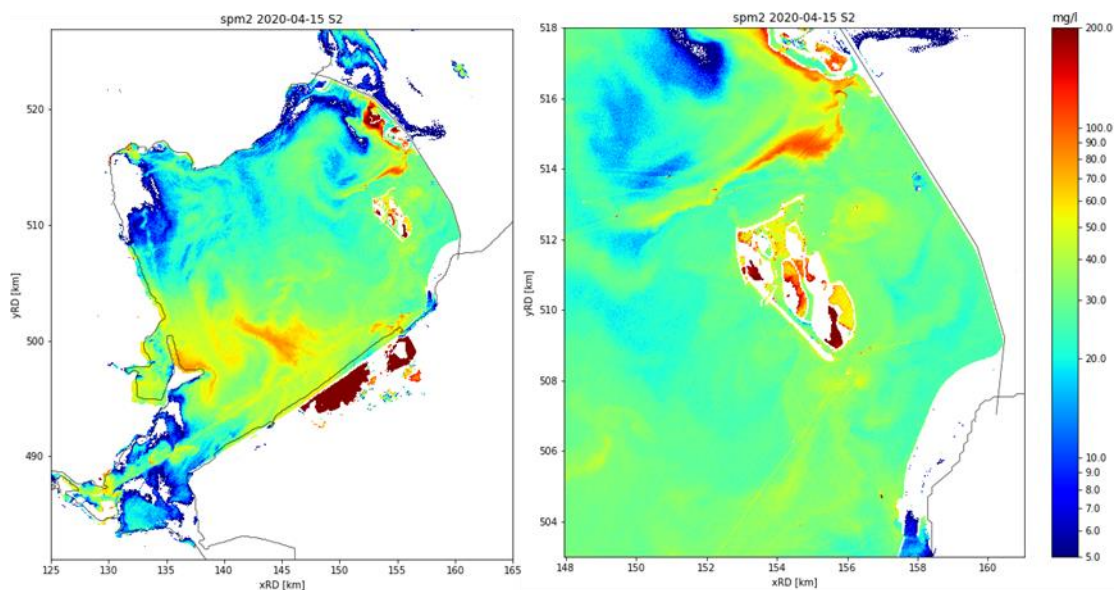
The construction of islands with locally available material - silt and sand - was a success. Initially, there was considerable consolidation (subsidence) of the silt, but this process appears to have slowed down considerably after about 2.5 years. The current subsidence of the soil is just a few centimeters per year, caused by settlement of the subsurface.

Silt has accumulated around Marker Wadden (in a silt channel, pits and on the lee side), where there is sufficient sediment for future maintenance of the current islands. Effects of Marker Wadden on the water quality of Lake Markermeer are tentative; there is a zone of clear water on the lee side of the islands. The total effect on the clarity of the lake cannot yet be indicated due to the building and maintenance activities that cause the upwelling of silt. Although some natural values and species are connected to turbid waters as well, the addition of clear water zones creates new gradients in turbidity (which is positive for fish), while receiving nutrients from the nutrient-rich soil of the islands.

Marker Wadden is also unique in terms of governance. The fact that an NGO (Dutch Society for Nature Conservation) took the initiative for such a large project was innovative. The cooperation between the NGO and a governmental organisation Department of Waterways and Public Works was a new and successful form of public-private partnership. Initially, it was difficult to intertwine the construction process with the monitoring and research programme, but solutions were found during the project that made the exchange possible.

History of Lake Markermeer

In the northern part of The Netherlands, a former brackish inland sea, which was dammed in 1932, has been divided into compartments over the following decades. Some of these were reclaimed, others turned into freshwater lakes. The second largest of these lakes is Lake Markermeer, with a surface area of c. 700 km². The relatively narrow southern part (“Lake IJmeer”) divides the cities of Amsterdam and Almere, the much wider northern part is surrounded by less densely populated rural areas. Depth of this lake is c. 4-5 m and the sediments are mainly clay. A thick blanket of silt lies on the bottom, which swirls up as the water moves under the influence of the wind, creating turbid water. The turbid water affects the food web of Lake Markermeer and the life of insect larvae, crustaceans, shellfish, and plants, among other things. Shallows and land-water transition zones are almost absent and ecological diversity and production is low.



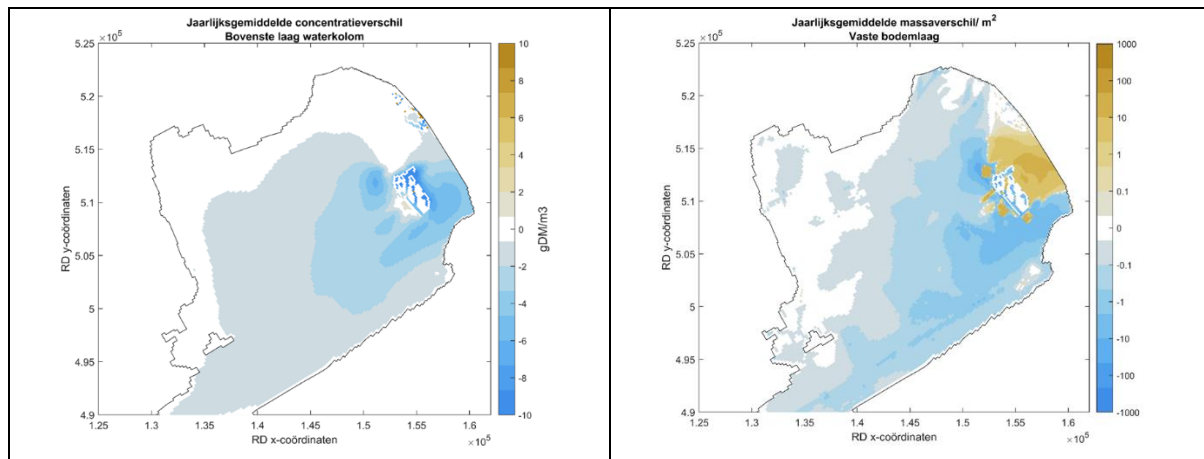
Lake Markermeer with Marker Wadden as it was on April 15, 2020 and the distribution of suspended sediment according to a satellite image. Increased concentrations to the north are related to another nature development project, Trintelzand.

Construction of islands

Starting in May 2016, an archipelago of artificial islands is growing in the northeastern part of the lake. The islands consist of excess silt, clay and sand from the bottom of Lake Markermeer. The reason for the construction of these islands was the decline of the ecosystem and the desire to strengthen the nature values in Lake Markermeer. By increasing the amount of marshland and shallows and creating habitat for breeding and migrating birds. The archipelago was named “Marker Wadden”, referring to the dynamic landscape of the Wadden Sea area. So far, five marsh islands have been built (total of 1300 ha), and two more will be finished in 2023.

Marker Wadden is intended to create a win-win situation: silt from the bottom of Lake Markermeer will be reused in nature islands. Also, sedimentation of suspended solids will take place on the lee side of the islands. This will improve the water quality and the habitat under water and add underrepresented habitat like marshes, creating a new nature and recreation area. The Marker Wadden project has the following policy objectives:

- Improving the ecological qualities and recreational use of Lake Markermeer (contributing to a 'Future-Proof Ecological System');
- The development of a bird paradise with an optimal contribution to the Natura 2000 objectives for Lake Markermeer and The Netherlands;
- Learning, monitoring effects, and innovating.



Calculated effects of Marker Wadden on the average amount of silt in the surroundings in 2020; on the left concentration in the water column, on the right mass distribution on the lake bottom. Blue is decrease, orange is increase.

KIMA, the Knowledge and Innovation Programme Marker Wadden

At the start of the construction of Marker Wadden there were still many uncertainties. Uncertainties about the construction technique, the development of the ecosystem, the effects on the environment and the cooperation between the partners in the project. Never before has a totally new ecosystem been constructed on such a large scale in the Netherlands and that raised numerous questions. In 2017, this prompted Rijkswaterstaat (the executive agency of the Ministry of Infrastructure and Water Management), Natuurmonumenten (Dutch Society for Nature Conservation), Deltares and EcoShape to set up the Marker Wadden Knowledge and Innovation Programme (KIMA). This can be seen as an umbrella under which all learning and research activities take place around Marker Wadden.

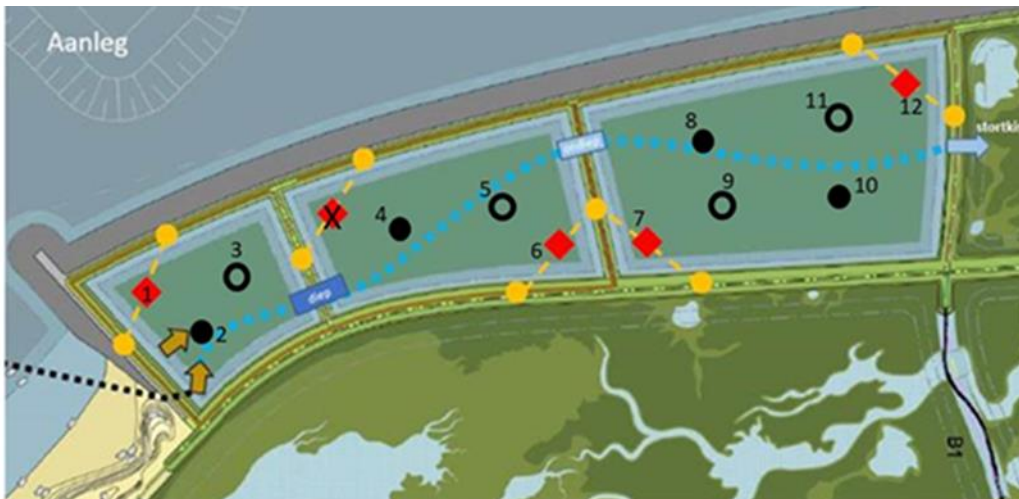
KIMA is designed to generate knowledge for the evaluation of the policy goals of Marker Wadden in 2022 and to add knowledge about the construction of an innovative, large-scale hydraulic and nature development project. Three research themes have been appointed for this purpose: Building with silt and sand, Ecosystem of value and Adaptive governance. Research questions have been formulated for each of these themes, focusing both on the developments at Marker Wadden itself and on their effects on Lake Markermeer.

The aim of KIMA is to increase the social added value of Marker Wadden and thus maintain and strengthen the leading position of the Netherlands in the field of ecology, hydraulic engineering and water governance. This is done by working together with companies, research institutions, governments and NGOs .

The natural processes taking place at Marker Wadden are (as expected) not progressing fast enough to be able to draw any far-reaching conclusions after four years of monitoring. However, thanks to the cooperation between those involved in the monitoring, applied research, academic research and construction, many insights have already been obtained in this short period. The insights obtained are described in this report. More detailed information can be found in the underlying reports, to which reference is made in the text. It is important to realize that the situation that has been examined is a pioneering one and will develop strongly in the coming years. The first conclusions are presented below.

New insights on the construction of Marker Wadden

For the development of the islands, ring dykes of sand were constructed ('sandy ridges'), creating compartments in which silt was deposited. After consolidation (maturation) and settling of the silt, the process was repeated until the new land was above waterlevel. Much of the Building with Silt theme research took place in three relatively small compartments (of 10 hectares), which were also filled with silt (the so-called silt compartments).



The three silt compartments, built for experiments in the research theme "building with silt and sand". Dots and numbers represent several kinds of research tools.

Main findings on Building with silt

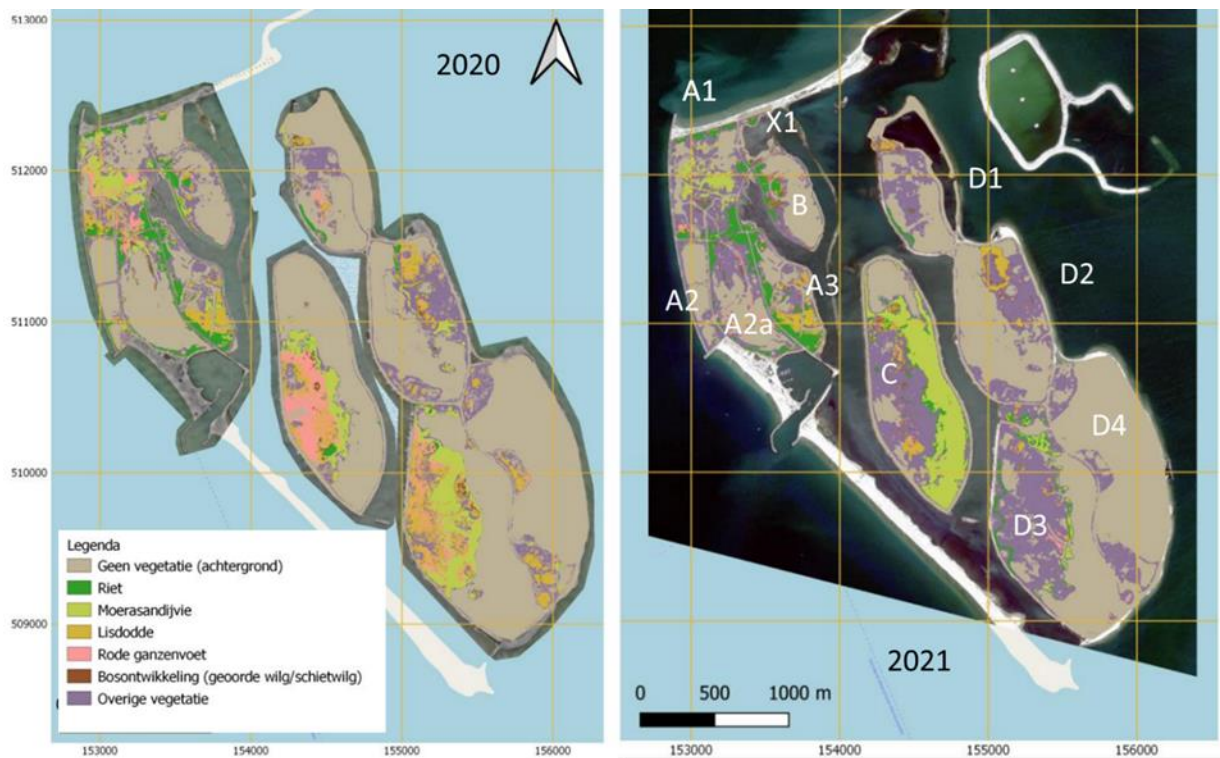
- Building islands with the locally present Holocene material - the silt - has proved possible.
- During filling, strong segregation occurred. Sandier material was deposited near the filling point and the finer silty sediment with a higher organic content flowed out over a longer distance.
- Subsidence occurred due to consolidation of the silt layer and settlement of the subsoil. The average thickness of the applied silt layer in the silt compartments was 4.4 metres. More than two years later, approximately 2.7 metres of this remained. This means that 1.7 metres of subsidence had occurred, of which approximately 1.6 metres was due to consolidation of the sludge and approximately 0.1 metres to subsoil settlement. The consolidation process mainly took place in the first three months after filling (1.3 metres) and was completed after approximately 2.5 years. Subsoil settlement varies greatly per location between a few and 5 cm per year and dominates from the second year onwards.
- The final density of the sludge in the sludge compartments was higher than expected. The original expectation was a density of 1250 kg/m³, but the density profiles measured in the

sludge compartments showed an average bulk density of approximately 1400 kg/m³ in the sludge-rich profiles and a higher density in the profiles with a little more sand. This means that more sludge is needed to fill the compartments than the volume assumed in the design.

- Crust formation has an important influence on the consolidation process. The crust increases the 'top load' and thus the force that drives the consolidation of the saturated mud layer under the crust. In addition, the crust becomes very compacted when it dries out. The process of crust formation started soon after filling, resulting in a top layer that could be walked on by geese within a few weeks. Rooting with vegetation was rapid, with reed (*Phragmites communis*) rooting the soil much more strongly than a vegetation cover consisting of marsh ragwort (*Tephrosia palustris*) and red goosefoot (*Oxybasis rubra*). Due to its strong and deep rooting, reed is important for silt retention and erosion control.
- With water level management, the consolidation speed can be partly controlled. When the water level is high, consolidation is slowed down, while it is accelerated when the water level is low.

Main findings on sandy margins

- The sandy edges offer sufficient stability to protect the silt-rich islands behind them, even in heavier storm conditions. However, measurements by KIMA show that sand can be lost laterally, partly due to currents, causing the profile to shift landwards. This can be particularly undesirable for beaches on the outer edges of the islands.
- The three unprotected depressions in the row of dunes - "washovers" - on the southern beach did not function as active washovers during the survey period (until 2020). It is possible that some overwash occurred at the northernmost washover site during the Ciara storm in February 2020. However, this did not result in a clear morphological response. The purpose of constructing these lowered embankments was to allow waves to pass over them during storms, thus increasing the interaction with the area behind.
- Especially in the context of the Marker Wadden project, the construction of a 'soft edge' was a useful and more natural alternative to the use of a hard construction.
- In addition to their protective role, the sandy margins themselves are increasingly valued as a natural transition. They offer animals and plants a habitat and thus form one of the various habitats of Marker Wadden.
- Furthermore, the application of (beach) replenishment is an excellent adaptive and natural measure for combating local beach degradation. However, it is by definition a temporary solution that requires long-term maintenance.



Developments in the presence of several types of pioneer and marsh vegetation from 2020 to 2021, based on satellite images and field data.

New insights into the pioneering situation of Marker Wadden

The construction of the islands with the nutrient-rich Holocene silt ensured an immediate high biological production and the rapid germination and growth of vegetation. Pioneer vegetation, in particular marsh ragwort and red goosefoot, developed almost immediately on the shallow mudflats and in land-water transition zones. Underwater vegetation such as pondweeds (*Potamogeton* spp.) stoneworts (*Chara* spp.), watermilfoil (*Myriophyllum spicatum*) and zannichellia followed after little more than a year.

Key findings on the new ecosystem:

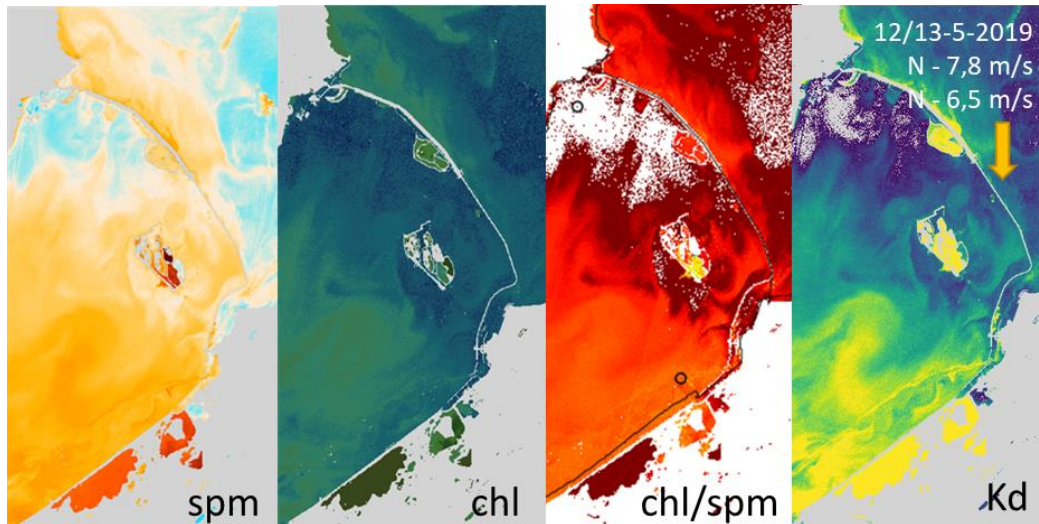
- The development of a reed marsh - the ultimate goal - only started on a few islands. Reed development was mainly initiated by sowing and, in a few places, by planting rhizomes and spreading grass clippings, but only if the planting was protected from being eaten by geese. Without protection against grazing, fields of bulrush (*Typha* spp.) formed in which reed was practically absent. In the wettest parts, no reed was left either. Meanwhile, reed is spreading in the drier areas from the protected stands.
- The general picture of the fish population is that it is mainly common, non-critical species that have found their way to Marker Wadden.
- The nutrient-rich land-water transition zones, in combination with the shallow waters rich in aquatic macrophytes around Marker Wadden, are attractive as spawning and juvenile fish habitat. If a considerably larger part of the lee shore zones develop into plant-rich inlets and marsh vegetations, there are good chances for a further increase in the local fish population.

- The deeper, sheltered water bodies - such as the harbour and deep sand extraction pits around Marker Wadden - fulfil an important role as refugia for both small and large fish.
- In just a few years' time, a diverse breeding bird community has emerged on Marker Wadden, with 43 species in 2020 and 47 in 2021. The first breeding birds to settle on the islands were those that nest on bare sand and among the low pioneer vegetation: common tern, little tern, avocet, Kentish plover, common and little ringed plover and, at a somewhat later stage, black-headed and Mediterranean gull. During the breeding bird survey in 2020, the first signs of development of a marsh bird community were recorded in accordance with the vegetation development. Apart from a few rails and nine species of ducks (including the first breeding case of long-tailed duck ever in the Netherlands), these were mainly passerines like sedge warbler and bearded reedling.
- New habitats for foraging and resting birds are also developing in and around Marker Wadden. In part, these are the breeding birds of Marker Wadden itself, but breeding birds from surrounding areas are now also foraging here as well. In addition, large numbers of migratory birds settle in the area, attracted by food and shelter. Between July 2020 and July 2021, more than 60,000 migratory birds made use of Marker Wadden.
- Some developments in the bird population are temporary, because they are linked, for example, to pioneering stages of vegetation succession. Without specific management, the habitat for bare-ground breeders such as terns, plovers and avocets will shift to the newly constructed islands and eventually decline. Other communities, such as the nesting birds of reed land, shrubbery and thickets will increase in the coming years.
- The open landscape of Marker Wadden means that birds are sensitive to disturbance from recreation (walkers and boats), construction activities and researchers. The more islands are left alone, the more birds will use them. Sensibility to disturbance differs per species. A certain degree of habituation may occur, but for many bird species a negative relationship with human co-use of the islands can be observed.

Importance of Marker Wadden for the functioning of Lake Markermeer

Silt concentrations, turbidity and sheltered areas

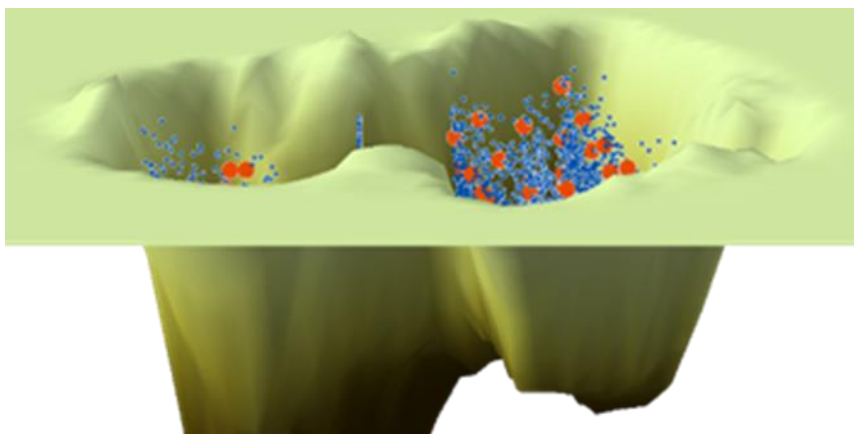
- The KIMA study shows that approximately 250 kilotons of silt is captured annually in the silt channel, the extraction pits and the other lee zones around Marker Wadden. According to the calculations, this has a significant influence on the local silt balance and turbidity of the Marker Lake. The collected silt can be used for maintenance of the islands.
- Leeway effects can be seen on the northeastern side of Marker Wadden and between the islands. Part of the suspended matter settles in the sheltered areas and new gradients in transparency are created.
- In the sheltered sedimentation areas, the ratio of chlorophyll to suspended matter appears to be high. This does not mean that there is more phytoplankton, but it does mean that the phytoplankton is more available for the food web. The high proportion of algae in the suspended matter means it is of better quality as food for water fleas and mussels, for example.



Processed satellite image, taken on May 13, 2019, with wind from the north. On the south side of the islands concentrations of suspended matter (spm) and chlorophyll (chl) are lowered, due to sedimentation, and transparency (Kd) is higher. The decrease of chlorophyll however is not as strong as the decrease of total suspended matter (chl/spm ratio increased), suggesting better food quality of suspended matter to filter feeders on the next level in the foodweb.

Effect of construction and maintenance activities

- The work on the islands plays a major role in turbidity dynamics via silt plumes. New gradients are created and nutrients are released because dredged material has a higher nutrient concentration than the top sediment layer of Lake Markermeer. This is also the case when windblown material is stirred up or by more regular activities, such as sand extraction and channel maintenance.
- In the area affected by the construction works, the density of filamentous sulphur bacteria (*Thioploca* spp.) was much higher than elsewhere. In these areas, the biomass even reached several hundred grams per m², comparable to the biomass of macrofauna. The bacteria form mats on the bottom, which have a large share in the primary production (via chemosynthesis, i.e. without light) of the system and, on the other hand, have an effect on the rest of the bottom life and the degree of upwelling of the sediment. The role of these bacteria as a food source is still unclear (DNA or other remains were not found in the stomachs of several fish species studied).



Echousing image of fish in a silt collection pit on adjacent to Marker Wadden, August 2018. Blue dots are small fish, red dots are large fish.

Spatial impact on birds

- Marker Wadden acts as a stepping stone between other marshland areas in the vicinity. Birds of various species commute between breeding, resting and foraging areas in different parts of Lake Markermeer and surroundings. This spatial component contributes to the biodiversity of the region.
- Marker Wadden has substantially increased the habitat supply in Lake Markermeer for a number of bird species. This applies to gadwall, shoveler and common teal, to the breeding birds common tern and avocet, but also to migrants like black-tailed godwits and black terns. Shoveler, black tern and pochard numbers constituted a significant part (>1%) of the international population. Especially in autumn (Sept-Nov), the numbers of migratory birds were high. In the winter months, the islands are not yet used so intensively.

Natura 2000 targets

- Of the species with a Natura 2000 conservation target in Lake Markermeer-IJmeer, four have a poor conservation status. So far, out of these four Marker Wadden has only brought some improvement for the wigeon, although the target has not yet been reached. Marker Wadden does make an important contribution to the national Natura 2000 targets by providing habitats for species such as common tern, avocet, common ringed plover (>10%), little ringed plover, Kentish plover, Mediterranean gull, black-headed gull, little tern and sand martin.



Enclosure for monitoring of breeding success of common terns, 2019.

Governance

Cooperation and tender process

- The cooperation between Natuurmonumenten and Rijkswaterstaat was a new and successful form of public-private cooperation. The fact that the initiative for such a large hydraulic engineering project was taken by a nature organisation was innovative. The fact that both organisations were so different and complementary added value to the cooperation. The tasks were divided on the basis of core qualities.
- Current developments are to a large extent driven by choices made prior to construction. Ecological development, for example, appears to be partly driven by the requirements set in the contract (e.g. the requirement to prevent large-scale forestation). As a result of this requirement, the construction aimed at the establishment and development of reeds. The water level in the compartments was also controlled to stimulate reed development and prevent willow from growing.
- Initially, it proved difficult to intertwine the construction process with the research process. Partly because the two processes did not run simultaneously and at the same speed, the lessons learned from the research could only be partially incorporated into the construction. The same applied vice versa: knowledge gained during implementation did not automatically flow through to the research programme. During the project, however, solutions were found that improved the exchange of knowledge.

Participatory monitoring

- Participatory monitoring proved to be a promising way to create support for nature development and to collect data for research and monitoring. In the future, there will be opportunities to continue involving volunteers, schoolchildren and visitors in data collection on Marker Wadden, in addition to the basis of regular monitoring.



Volunteers contribution to data collection and processing in several ways

Funding

- The ecosystem services that the islands can provide offer opportunities for private co-financing. To attract this type of financing for the construction of new islands, it is important to speak the investor's language and to know which objectives are important to an investor. In return for financing, the investor's interest must clearly be part of the project objective and quantification of the objectives must be part of the monitoring programme.

Recommendations for management

Development of marshland nature

- Filling the compartments with silt just once without level management afterwards is a risky strategy in which the final height is uncertain and in practice can deviate considerably from estimates based on lab research and calculations. Multiple filling layers with level management and interim monitoring of the settlement is a much more certain strategy whereby the final height can be properly adjusted.
- Water level management is an important control parameter for the development of vegetation on the islands. The water level in Lake Markermeer favours willows and disfavours reed, which makes rapid forestation a threat. By keeping the quays around the islands closed for a longer period of time, it is possible to realise a separate water level development within the islands, adjusted to the vegetation development, with the help of a mobile pump and an outlet.
- The rapid development of willow forest can be counteracted by implementing a specific seasonal water table management that provides for inundation during the period that seed dispersal via willow fluff occurs (May-June). In this way, the development of reed marsh is promoted.
- It is advisable to wait before connecting the islands to Lake Markermeer until a sufficiently robust reed marsh has developed that can withstand the pressure from water bird grazing for several years. The preservation of marshland in the longer term benefits from dynamics.
- Goose grazing can be limited by (temporary) foraging protection and the development of higher vegetation, which blocks the geese's view of the surroundings. Higher reed beds also fulfil this function.
- In the silt channel, the extraction wells and the sheltered area between Marker Wadden and the Houtribdijk, extra silt is deposited compared to the situation before the construction of Marker Wadden. The silt channel accumulated up to approximately 40 cm per year and the extraction wells even to approximately 80 cm per year. In principle, this silt can be used for the maintenance of Marker Wadden.



Little ringed plover, Marker Wadden, August 2022

Knowledge position

- At this moment it is of course still difficult to see what contribution Marker Wadden will make to the knowledge position of the Netherlands, but there is a lot of potential for the future. In addition to scientific and technical knowledge, the Marker Wadden project has generated knowledge about the realisation of the concept. Both public and private parties can apply this knowledge internationally, for example in large lakes and dammed rivers and estuaries.
- The research on Marker Wadden has yielded three doctoral theses, 10 scientific articles and 46 KIMA reports.
- KIMA organised an annual conference and a field trip to share results and get input 'from outside'. The website, social media channels, the KIMA newsletter and publications were also used to share interim results.

