Guideline for Marine Nature Restoration through Managed Realignment of Reclaimed Coastal Areas

Center for Marine Restoration

Colophon

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Summary: This guideline aims to provide stakeholders and landowners with a framework for identifying areas where managed realignment could effectively restore valuable coastal ecosystems with high biodiversity, enhance flood protection, and offer climate benefits.

Content

1. Introduction

Shallow coastal lagoons and their associated low-lying land areas constitute only a small part of the world's coastlines but have historically been widespread in Denmark. These areas are characterized by their high productivity, providing favorable living conditions for various plants and animals, including important populations of fish and birds. Therefore, these areas hold significant national and international conservation interests.

There has been a significant areal reduction of Danish shallow coastal areas in the past 150–200 years, leading to a general decline in the nature quality and ecological condition along the coasts. The primary cause has been the reclamation of marine wetlands for agricultural purposes. Through water regulation involving the construction of dikes, drainage systems, canals, and pumping stations, many shallow coastal areas and adjacent salt meadows were reclaimed and cultivated during the 19th and 20th centuries. The reclamation activity, led prominently by the Danish company Hedeselskabet, was particularly intensive from 1940 to the 1960s, with the state covering 2/3 of the costs during this period. Denmark has recorded 930 reclamation projects totaling approximately 40,000 ha below sea level (Fig. 1), representing 20% of the Danish marine areas with depths under 2 meters. Nearly 14% of the danish coastline has disappeared due to these reclamations, while 6% of the current coastline is estimated to be protected by dikes (Waagepetersen et al. 1986; Brandt 1991).

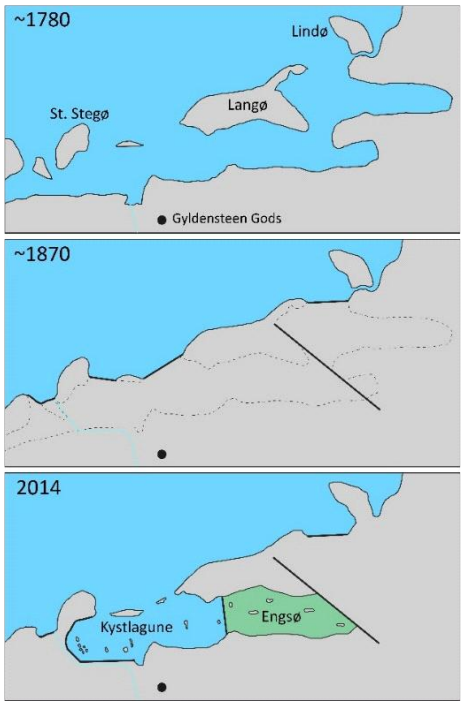
Many of the drained fjords and lagoons now consist of marginal land with limited agricultural value, due to high drainage costs and often poor soil quality. In some cases, these areas have naturally reverted to semi-natural states as cultivation has ceased. Additionally, they are highly vulnerable to future climate-induced flooding from rising sea levels, more frequent storms, and an expected rise in the groundwater table.

Figure 1. Map of Denmark, 2005. Reclaimed areas are indicated in brown (from Stenak 2005).

This guideline aims to provide stakeholders and landowners with a framework for identifying areas where managed realignment could effectively restore valuable coastal ecosystems with high biodiversity, enhance flood protection, and offer climate benefits. Managed realignment refers in this context to the removal of coastal dikes and the re-establishment of natural coastal zones. It is essential to emphasize that managed realignment is not merely flooding agricultural land but rather a deliberate act of nature restoration and new habitat creation. The guideline is partly based on experiences from the largest Danish managed realignment project at Gyldensteen Strand on North Fyn (Textbox 1).

Textbox 1: Gyldensteen Strand

The reclaimed Gyldensteen Strand was created in 1871 through extensive land reclamation and drainage of approximately 616 ha of shallow coastal lagoons and adjacent salt meadows east of Bogense on the island of Fyn. This was achieved by constructing 2,273 m of dikes connecting Lille Stegø, Store Stegø, Lindholm, and Langø via Fåreholm to Jersore Point. The intention by the Gyldensteen Estate was to transform the reclaimed area to agricultural land. However, it quickly became evident that the area was difficult to drain and cultivate. As a result, it was primarily used for cattle grazing until the 1950s. Despite additional drainage efforts and deep plowing in 1959–61, the soil remained marginal, and ideas to restore the original wetlands began to emerge in the 1980s. These ideas were realized when the Aage V. Jensen Nature Foundation purchased the entire area in 2011. The foundation aimed to recreate a tidal wetland on the northern part of Fyn (Gyldensteen Coastal Lagoon) covering 214 ha by removing the dikes between Store Stegø, Lindholm, and Langø. A new dike from the mainland to Langø now ensures that the eastern part of the reclaimed area remains as a shallow lake of 144 ha surrounded by reed beds (Engsø). The northeastern area, covering 258 ha (the "Reserve"), continues as meadows, bogs, and lakes. After negotiations with authorities and significant construction efforts, the plans became a reality when the dikes were breached on 29 March 2014.



2. Why and How Should Managed Realignment Be Conducted?

Climate change affects low-lying coastal areas due to rising sea levels (up to 1 meter by 2100) and a higher frequency of storms. These events can lead to massive flooding of coastal agricultural lands and settlements, resulting in significant economic losses. With current coastal defenses, it is estimated that approximately 8,000 ha and 37,000 ha of these areas will be permanently flooded by 2070 and 2120, respectively (Ebbensgaard et al 2022). This is particularly critical for reclaimed areas, where coastal dikes are often weak and prone to breaches, and the hinterland is frequently below sea level. Adaptation is therefore necessary with the expected sea-level rise in the coming decades (IPCC, 2023). Reinforcing existing dikes is a feasible but costly solution, that is applicable where valuable assets require protection. However, many of the areas reclaimed and drained for agriculture during the extensive land reclamations of the 19th century are now so marginal that protection is not cost-effective. Here, significant societal benefits can be achieved by restoring the natural connection between land and sea.

Managed realignment is the deliberate flooding and re-establishment of low-lying coastal areas (French 2006; Esteves 2014). This process typically involves removing coastal dikes that prevent seawater from entering the reclaimed area. Before removing the old and often outdated dikes, protection for any valuable inland areas must usually be established. This protection does not need to be as extensive as traditional coastal dikes since storm effects will be significantly dampened in the new shallow lagoons and periodically flooded salt meadows situated between the old and new dikes.

3. Nature and Climate Benefits of Managed Realignment

A significant benefit of managed realignment is that the newly created coastal zone can develop into highly productive nature areas with tidal habitats and new salt meadows. These areas, with their diverse habitats and productivity, will support a rich marine flora and fauna, as well as abundant birdlife. Thus, new ecosystems with high biodiversity and significant recreational value will be established.

Furthermore, there is a substantial climate benefit from flooding farmland with seawater. The bacterial decomposition of organic matter in the soil, and thus the release of CO_2, decreases to one-tenth when the land is flooded and becomes anoxic. For example, at Gyldensteen Strand on North Fyn, CO_2 emissions from 214 ha dropped from approximately 6,300 tons per year to zero after the area was flooded with seawater (Petersen et al., 2023). This corresponds to a reduction of approximately 1.2 million tons of CO_2 nationwide if all 40,000 ha of reclaimed areas in Denmark were flooded with seawater. Thus, managed realignment and the restoration of marine wetlands are effective, accessible, and feasible measures that should be part of future climate strategies.

4. Planning and Executing Managed Realignment in a Coastal Area

When assessing the feasibility of nature restoration through managed realignment in a coastal area, a thorough **screening of the area's topography and current land use is necessary** (Fig.2). This initial assessment can involve analyzing orthophotos and geospatial data available through platforms like Dataforsyningen (https://dataforsyningen.dk/) and Danmarks Arealinformation (https://arealinformation.miljoeportal.dk). These tools allow for evaluating the scale of the affected areas and their current use (e.g., agriculture, settlements). From these maps, the need for new inland dikes when removing the original dikes can also be assessed based on elevation contours. **A more detailed feasibility survey should follow, focusing on the area's suitability for nature restoration via managed realignment. Key questions to consider include** (Fig. 2):

1. How extensive will it be to restore the area or modify barriers?
2. Are there technical installations, buildings, or other infrastructure that will be affected?
3. Will managed realignment positively or negatively impact landscape, ecological, and natural conditions?
4. Does the site have recreational value (e.g., proximity to summerhouse areas, camping areas or nature trails) that could be affected positively or negatively?
5. the location within protected areas (e.g., EU Directives, Natura 2000 sites, reserves or conservation areas) that might legally hinder managed realignment?

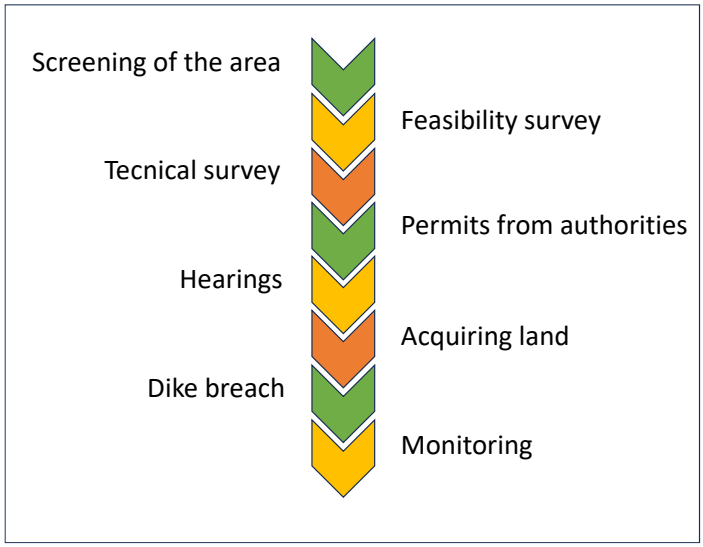


Figure 2. Flow diagram with the most important milestones for the planning and execution of managed realignment. The sequence of individual steps may vary from case to case.

If the outcome of this preliminary survey and the answers to the above questions do not present obstacles to managed realignment, a more in-depth and **detailed technical survey of the site's suitability and the execution of the managed realignment must be conducted** (Fig. 2). The purpose of such a technical survey is: 1. To examine and describe the current conditions in the project area; and 2. To clarify the effects and consequences of the project in relation to nature, environmental, and climate objectives.

To obtain approval for a nature restoration project, authorities may require an environmental impact assessment (EIA) or an equivalent assessment, and the project also depends on obtaining a range of **specific permits from authorities** (Fig. 2) under, for example, the Environmental Assessment Act, the Planning Act, the Nature Protection Act, the Watercourse Act, and the Habitat Order. If the project area is located near a habitat, Ramsar, and/or bird protection area, the requirements of the Natura 2000 Directives for preparing a Natura 2000 impact assessment also apply. The technical investigation must therefore outline the necessary permits required to implement the project.

If the technical investigation does not reveal obstacles to the project, the process for obtaining the aforementioned permits from the relevant authorities can be initiated. This involves, among others, the municipality or municipalities that are the planning authorities for the affected area (https://mst.dk/natur-vand/vandmiljoe/tilskud-til-vand-og-klimaprojekter/). However, it is essential that **hearings with potentially affected stakeholders** (Fig. 2), such as neighboring landowners, local interest groups, and museums, do not result in substantial complaints that could legally block the project. Once the necessary permits are in place and appropriate preparations to protect surrounding areas are completed, **the area can be acquired**, and **the dike breach initiated** (Fig. 2). Depending on the location and status of the area, funding for the acquisition can come from the EU, the state, municipalities, or private foundations.

5. Data Collection, Modeling, Monitoring, and Dissemination

As part of the technical pre-study, thorough data collection and modeling are essential to predict how managed realignment will affect biological and ecological conditions in the reclaimed and surrounding areas. It is also advisable to validate these models through comprehensive **scientific monitoring after managed realignment is implemented** (Fig. 2). Both the expected outcomes and their validation should be communicated to the public, managers, and scientific communities.

Before a managed realignment is carried out, the historical development of the site must be described in terms of topography, geography, hydrology, and biology prior to reclamation. It is also important to understand the history of cultivation and soil management in the period after reclamation. Since each reclaimed area has unique characteristics, generalizations based on existing literature are not possible. Once sufficient historical knowledge about the site has been collected, modeling must be conducted to evaluate how the characteristics of the planned managed realignment in this specific area will enhance or hinder its nature value, greenhouse gas balance, as well as ecological development and succession. These models should be based on existing knowledge of the development of recently inundated areas (Valdemarsen et al. 2018; Kristensen et al. 2021; Thorsen et al. 2021; Petersen 2023). If necessary, the outcomes of these models can guide adjustments to the managed realignment process, such as altering hydrology to prevent eutrophication and thus improve ecological conditions.

After the managed realignment has been implemented, the biology and ecology of the newly inundated area should be closely monitored. This includes sampling to determine nutrient dynamics (Kristensen et al. 2021), recording vegetation succession to track the development of macroalgae and seagrasses (Thorsen et al. 2021), and monitoring the succession of benthic fauna (both infauna and epifauna) and mobile fauna (invertebrates and fish) (Valdemarsen et al. 2018).

To utilize the project’s findings and acquired knowledge in future managed realignment activities, it is desirable to publish the results for managers and authorities, while the data could also be compiled into a national database. This would make future data collection easier and more organized. Local dissemination of the results through newspapers, TV, and public lectures can help the local population in the area where managed realignment is being carried out to follow its development. In this way, the beneficial effects of the managed realignment on ecological conditions, biodiversity, and recreational use can be highlighted.

6. Challenges in Managed Realignment Projects

Each coastal area has its own unique landscape and usage characteristics, which may present various challenges that should be addressed in the technical pre-survey before a managed realignment can be carried out. Below is a brief description of some key (but not all) challenges:

1. Terrain and hydrology
2. Impact on adjacent coastal areas
3. Agricultural interests
4. Local interest and engagement
5. Cultural and archaeological interests
6. Impact on infrastructure
7. Economy

6.1 Terrain and Hydrology

The site may encompass drained areas below sea level and adjacent salt meadows that are periodically flooded. Quantifying water inputs from streams and drains is crucial, as large nutrient loads could affect the area's future ecological condition (Thorsen et al., 2021). If the area was cultivated up to the point of managed realignment, significant releases of nitrogen (N) and phosphorus (P) may occur in the first few years, potentially hindering ecological succession. Over time, nutrient removal by tidal flushing can counteract this and prevent algal blooms. Soil texture

is also critical; sandy soils can quickly develop into natural coastal sediments, while clay soils may impede natural development due to their compact structure and frequent resuspension of clay. The latter obstacle can be prevented and conditions improved by adding a sand layer (approximately 10 cm) on top of the clay soil before managed realignment.

6.2 Impact on Adjacent Coastal Areas

In the short term, a significant release of nutrients from the inundated soil is likely to occur in the first few years after managed realignment, which may affect the surrounding marine area (Kristensen et al., 2021). If the location is adjacent to an open coast — such as the North Sea, Skagerrak, Kattegat, or the Belt Sea — the impact on the adjacent marine environment will likely be limited due to rapid dilution. However, if the location is adjacent to a smaller fjord or another enclosed marine area with low water exchange, managed realignment of former agricultural land could, in the short and medium term, contribute substantial nitrogen (N) and phosphorus (P) nutrients to the surrounding marine areas, negatively affecting their ecological status. Since nutrient input to marine areas not in good ecological status is prohibited under the EU Water Framework Directive, this issue must be addressed by ceasing nutrient input to the agricultural soil for several years (e.g., five years) before the managed realignment is carried out. However, in the long term, nature restoration through managed realignment will enhance nutrient cycling and retention, thereby reducing the net transport of N and P to adjacent water bodies, regardless of whether the area is an open coast or an enclosed fjord.

6.3 Agricultural Interests

A land-based nature restoration project involves a property-related pre-survey to assess the project's feasibility based on landowners' interest in participating. The purpose of a property-related pre-survey is to:

1. Collect information about the study area and landownership.
2. Assess landowners’ opinion about the project.
3. Provide information and clarify property conditions related to the project.
4. Determine whether the landowners within the project area are likely to participate voluntarily in the project.

To minimize conflicts with local agricultural interests, landowners should be involved early in the project plans. This increases understanding, ownership, and trust in the project. Information about landowners' attitudes towards the project should be used to draft a compensation budget, clarify the need for replacement land, and determine the extent to which land consolidation might be necessary to address landowners' preferences.

6.4 Local Interest and Engagement

It is crucial that local interest and engagement are present for a managed realignment project to succeed. This can be achieved by informing the local community well in advance about the plans. It would be valuable to present the unique opportunities for outdoor and recreational activities in the restored area. The framework for outdoor activities (e.g., fishing, swimming, surfing) in the new area depends on the nature protection status assigned to it after flooding. Opportunities for enjoying recreational nature, such as birdwatching, should be facilitated by establishing pathways and observation points connected to the restored area.

6.5 Cultural and Archaeological Interests

Many reclaimed areas contain cultural and archaeological values that should be examined before managed realignment is carried out. There is often archaeological interest in restoring coastal wetlands, as preservation conditions in anoxic seabeds are significantly better compared to drained, oxygen-rich soils. However, there may also be heritage buildings established after reclamation that could be submerged and lost. Additionally, landscapes (e.g., old dikes) may have historical value. These cultural and archaeological factors should be discussed with the Agency for Cultural Heritage and museums, both local and national.

6.6 Impact on Infrastructure

Before managed realignment is implemented, the impact on infrastructure must be thoroughly investigated, and mitigation measures planned. This includes potential changes to roads, power cables, poles, gas pipelines, and more. Consideration must also be given to residential and commercial buildings in the area slated for flooding. Demolishing these structures can be very costly.

6.7 Economy

Before an area is realigned, it must be acquired and prepared by the entity implementing the project, typically the state, municipalities, or private foundations. Land acquisition will represent the largest expense, but costs should also be expected for building new inland dikes to protect the hinterland, dismantling existing dikes, as well as maintaining and managing the new wetland. Additionally, compensation claims from landowners of adjacent areas may arise due to deteriorated farming conditions caused by reduced drainage or changes in coastal erosion. Further costs should include securing technical installations (e.g., power poles and similar infrastructure). Finally, funds should be allocated for scientific monitoring of the ecological development of the restored nature over several years following the managed realignment.

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The main purpose of the Center is to promote a knowledge-based implementation of marine habitat restoration, aiming to enhance the resilience of marine ecosystems, ecological balance, and a wide range of ecosystem services in Danish waters.

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