Dynamic Tidal Power in the North Sea

An exploration of ecological effects and socio-economic opportunities

An Academic Consultancy Project

Commissioner

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Summary

This project aims to evaluate possible environmental and socio-economic risks and opportunities that are connected to the construction and application of a Dynamic Tidal Power-dam (DTP-dam). In this research we investigated the impact of the DTP-dam on the ecological system, the possibilities and problems for the fishing and aquaculture sector and identified and contacted several stakeholders. After investigating the impact of the DTP-dam on sedimentation, we recommend placing the dam offshore in the IJmuiden Ver windfarm. This is expected to result in a relatively smaller impact on coastal protection and coastal biodiversity. Implementation of structures in different shapes and sizes (e.g. roof tiles or old pipes) at the walls of the dam is recommended. This will create shelter and nursery habitat for a wide range of species, which will further enhance biodiversity. Furthermore, the dam can be used as a steppingstone along which species will be able to move. The location of the dam does not influence current nursery habitats and the impacts on migratory fish are found to be small except for bigger species like whales. Small migrating fish will be able to swim through the turbines. The mink whale is the only species which might be disturbed. Sonar can be used to steer whales around the DTP-dam but this is yet not allowed because of interference with marine activities. Migratory birds might be able to use the DTP-dam as a rest place, source of food or even as a breeding ground.

Since the DTP-dam will be mostly located in the IJmuiden Ver windfarm, fishing is not allowed. The DTP-dam will enhance biodiversity, so a spillover effect might happen which will be beneficial for fisheries. We investigated the potential for aquaculture and found that oysters and mussels are the most economically viable species. Passive fishing of lobster and crab will also be possible. We recommend creating strict regulations in order to prevent overexploitation. Seaweed is an interesting species with high potential for future cultivation, but with the current knowledge offshore cultivation is not economically feasible yet.

Overall, we state that the negative ecological impacts of the DTP-dam will be minimal, whilst the potential for improving ecosystem health in the surroundings is high and could provide considerable conservation benefits. Looking towards the future and the realization of this dam, it is evident that the project impacts a wide spectrum of actors. It currently lacks powerful support and has economically and politically influential opposition. Round tables, workshops and discussions with the networks who support and oppose the project will aid future developments and enable conflicts to be minimized early on.

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Source: dutchwatersector.com

1. Key Findings

- The DTP-dam would be best located in the IJmuiden Ver wind farm.
- The expected effect of the DTP-dam on currents and related sedimentation patterns further offshore is limited.
- Support from economically and politically powerful stakeholders is lacking.
- Stakeholders can be described as two networks, comprising a less influential group of environmental NGOs and foundations, and a group comprising the fishing industry, the energy companies, the shipping industry and the government.
- The DTP-dam could help counter the ongoing trend of some migratory bird species declining.
- The DTP-dam will most likely increase biomass and biodiversity in the North Sea ecosystem.
- The DTP–dam should function as monitoring station for water quality.
- The DTP-dam might be used as a nursery habitat in future as fish move to deeper cooler waters to escape increasing coastal water temperatures.
- Implementing structures of different shapes and sizes as the walls of the DTP-dam can be used as shelter or habitat for a wide range of species. This will enhance biodiversity and possibilities for sea ranging.
- Direct impact of the DTP-dam on fisheries is small if it is built in wind farm.
- DTP-dam could have positive indirect effect on fisheries due to spillover effects.
- Mussels and oysters are a potential economically viable option for aquaculture in the V-shaped areas of the DTP-dam.
- The area around the DTP-dam can be used to restore natural oyster beds.
- There will be possibilities for sea ranging/passive fishing around the dam. Crab and lobster are expected to be suitable species for immediate cultivation, with the potential to introduce other species in later years.
- Seaweed cultivation around the DTP-dam is not yet economically feasible, but we recommend investigating the possibilities for seaweed again in the future, since demand for it is expected to increase.
- A wide array of ecosystem services are provided by the area in which the DTP-dam is recommended to be located and most of these services are likely to benefit from it's introduction.

2. Introduction

The construction of a Dynamic Tidal Power Dam is an innovative project designed by Humsterland Energie. The project proposes to construct a 60 km long dam in the North Sea to harness the power of the changing tide, producing 20 % of the total Dutch power as baseload. It will measure 65m in width and 30m in height. This technology aims to produce energy through the difference between the potential and kinetic energy of the tide and appears to be a promising way to phase out fossil fuels in the Netherlands (Humsterland Energie, 2019).

The dam will be designed as a structure comprised of a current-catching base in which the turbines are located, with two V-shaped structures extending from the ends to direct further current towards this base (Figure 1).

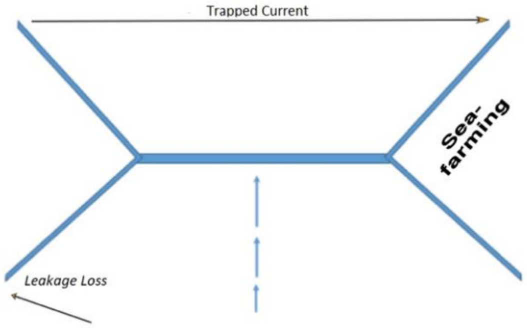


Figure 1: Visualization of the DTP-dam (source: www.humsterlandenergie.nl).

As is to be expected with an unprecedented project of this magnitude, there are a variety of unforeseen challenges which may hinder its progress. Therefore, this report has been commissioned in order to identify the impacts associated with its development. The dam is expected to affect the ecological, economic and social landscape of the North Sea; therefore, a thorough and detailed analysis of possible effects is vital to ensure the project is realized.

This report aims to assess the environmental and socio-economic effects of the DTP-dam, and with this knowledge the optimal decisions for development can be made. This, in turn, will stimulate broad support for the project and increase the likelihood of construction. This is key to the project, as negative environmental effects could delay or even prevent construction. Assessing and mitigating these impacts is essential to the development process, as neglecting ecological effects could lead to the disruption or even the collapse of ecosystems. Understanding the potential benefits, the DTP-dam can provide to local fish stocks and aquaculture industries may then help reduce any negative environmental impacts and improve socio-economic effects.

In order to assess the impacts on the environment of the North Sea, an examination of the current biodiversity was undertaken in the location of a currently existing wind park. This location was chosen as it provides sufficient tidal current power for energy production, and within it, the dam will cause the least obstruction to fishing and shipping activities within the North Sea.

Within this report, literature research was done on several topics. First, the current food web of the area was mapped. Key species, current habitats, and the potential for the dam to provide habitat as a hard structure were then examined. Also, several experts were consulted on the aquatic life and hydrology to assess how these would be impacted by the DTP-dam. The socio-economic effects were examined through an assessment of current fisheries within the North Sea, the future effects upon these due to the dam, and the potential for aquaculture upon the structure. The above sections were then synthesized into an ecosystem service assessment to identify any possible disruptions to be expected in these services.

In order to identify and understand the opinions surrounding the project a stakeholder analysis was carried out. Stakeholders were identified, contacted and then mapped according got their interest and influence. This was done to aid fair and inclusive decision making for both the dam's design and implementation.

As a consultancy team, we want to make sure that the positive and negative effects of the dam on the ecosystem and economy are considered. Our purpose is to provide advice for Humsterland Energie on what the impacts of the DTP-dam will be and in what way the dam can create opportunities for the ecosystem and economy. To provide unbiased advice, we created an overall main research question and several sub questions, which are given after the recommendations.

2.1. Research questions

The main research question of this report is as follows:

What are the potential environmental impacts of the DTP-dam and its socio-economic consequences?

In order to answer this main research question, we created eight sub-questions:

1. Which location will be best suitable for the DTP-dam concerning sediment transport in the North Sea?
2. How will the current state of biodiversity in the surrounding area of the DTP-dam be affected by the DTP-dam?
3. What will the influence of the DTP-dam be on patterns of migratory fish and other animals in the North Sea?
4. What is the potential of the DTP-dam to provide nursery habitats through, among other things, hard structure design?
5. Which ecosystem services are provided in the surrounding area of the DTP-dam?
6. What are the main stakeholders involved in the DTP-dam project?
7. What fisheries take place in the area where the DTP-dam will be built and how will these be affected by the DTP-dam?
8. What types of aquaculture systems would be best suited to the conditions of the DTP-dam and the local ecosystem, what are the economic potentials?

Source: dailymail.co.uk, novinite.com, eap-magzine.de, energymartketproce.com, durch-aquaculrture-experts.com

2.1. Our team

Bart Berlee - *Aquaculture and marine systems*

Engineering background. Specialist in aquaculture, salmon farming, offshore and nearshore. Providing guidance on the implementation of IMTA (integrated multi-trophic aquaculture).

Sytse de Jong - *Management, economics and consumer studies; spec. Environmental economics*

Economic analysis, monetary evaluation of the projects. Background in environmental policy. Could advise on the business development of the project.

Isa Vroom - *Biology; spec. conservation and systems ecology*

Specialized as assessing the biotypes and how these may be affected by the construct. Analyzing the species and structure of the biotic and abiotic components of the ecosystem. Experience with GIS. Can provide advice on environmental policy. Experienced in coordinating meetings and decision making (logistics).

George Chanarin - *Environmental science; spec. Environmental Systems Analysis*

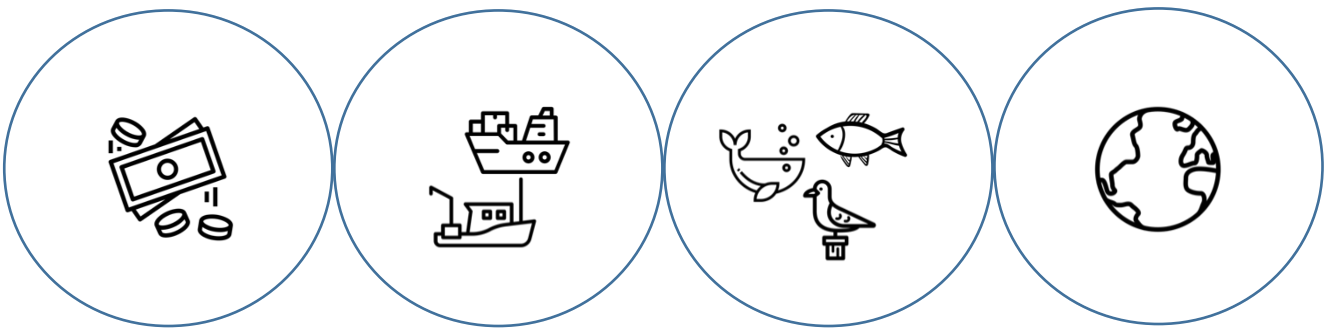
Experienced in ecosystem service analysis. Assessing different management scenarios and the broader impacts these will have. Background in designs and able to offer innovative thinking for the project.

Sarah Foley –*Environmental science;* spec. *Environmental Policy*

Ecology background with specialization in the interactions between humans and environmental services. Experience with semi-structured interviews and GIS, with contacting stakeholders and the formulation and performance of interviews.

Doke Schoonhoven - *Earth and environment; spec. hydrology*

Flow dynamics and GIS. Can give guidance on the sediments and tidal patterns that will be influenced by the project.



3. Research methodology

In order to answer the sub questions, we used literature and expert interviews. To answer Question 1, a literature study was performed about the current sediment transport in the North Sea. To find the impact the DTP-dam might have on this sediment transport, we examined comparable structures and their impact on this. An expert was also consulted to assist in answering this question.

When a location was selected for the DTP-dam, the impact upon ecology and fisheries were researched. To answer questions 2-4, we searched for literature on the current status of the ecology and contacted an expert in this field. Literature research was again used to answer questions 5-8. For question 7, we contacted several researchers in order to ascertain which fisheries take place where in the North Sea. Finally, for question 6, possible stakeholders were identified using available literature and then mapped onto an influence/interest matrix. Several stakeholders were then interviewed and resulting in an updated influence/interest matrix and a new onion diagram.

4. Stakeholder analysis

4.1. Introduction to Stakeholder Analysis

A stakeholder analysis is used to systematically identify the actors who are most integral to a project and who's interests should be considered during a project (Schmeer, 1999). This can help the project coordinator to "avoid inflaming conflicts, ensure that the marginalization of certain groups is not reinforced, and fairly represent diverse interest" (Prell, 2009). The framework used is drawn from "Stakeholder Analysis Guidelines" written by Schmeer (1999).

4.2. Objective

The stakeholder analysis is deemed necessary to this project due to the large scale and broad impacts it may have. As a common resource, the North Sea is an area where many actors have interests and claim the right to access. The DTP-dam is likely to influence these interests and how certain actors can access resources. In addition, the high cost and long lifespan of the project necessitate government, and therefore public support. Understanding these interests and where support can be garnered, or conflicts may arise, is essential to improving the project's chances of success.

The stakeholder analysis will help ensure that all relevant people are consulted on or, where deemed necessary, involved in decisions that are made regarding the project. It will enable the identification of the common and conflicting interests of parties and how these interests will influence the construction of the DTP-dam. Appendix section B consists of a longlist of stakeholders. Actors will be identified who will have the greatest impact on, or be most impacted by, the construction of the DTP-dam. Particular attention will be paid to those whom may be considered less influential and whose relationship with the project may be less obvious.

This work will provide a reference for developers when considering how and whom to communicate, consult and collaborate with throughout the design, development and construction phases of the project.

4.3. Main stakeholders

A combination of internet resources, conversations with the commissioner and group discussions were used to identify the key stakeholders for the project. Further research was then undertaken to write a profile for each of these actors. These profiles were structured to answer; who the stakeholder is, what they do, what experience they have with related projects, and what their stance is likely to be on the construction of the DTP-dam. This provided the foundations for the stakeholder mapping. The intent was then to use these profiles as the basis for the stakeholder interviews, the questions of which are presented in the appendix section A. Unfortunately, due to time constraints, only GFF and VisNed were available to interview. These interviews, however, supported and gave nuance to many of the stakeholder profiles we had outlined. The information given below is sourced from a combination of information given on the stakeholder websites and other online media sources, along with information given during interviews with actors and conversations with the commissioner.

4.3.1. Government of the Netherlands

Finding and developing renewable energy solutions are central to the government's commitment: "To boost sustainable energy production and find smarter ways of using and saving energy (Government of the Netherlands, 2019).

The government wants to reduce emissions of greenhouse gases in the Netherlands to zero by 2050 and, by 2023, to make 16% of produced energy sustainable. This has been planned along with a diverse group of 40 stakeholders. They provide grants and support for renewable energy projects in the Netherlands. Committed to ensuring electrical supply to the Netherlands (Government of the Netherlands, 2019)

Currently, the government is working to stimulate growth in solar, offshore and on land wind power, biomass and geothermal heat production. They incentivize solar energy by providing tax cuts, grants and credit payments. On their website the governments states that "by 2020 the Netherlands must have an onshore wind capacity of 6,000 MW", a doubling of the capacity in 2015. They propose an even greater growth in production offshore, in 2015 257MW of energy was produced through offshore wind, by 2023 production of 4450MW is targeted. They encourage this capacity increase by providing grants and designating sites for offshore production. On their website the Government gives references to offshore projects awarded to companies such as Nuon, Shell and Vattenfall implying working relationships with these companies have been established.

The Dutch government's opinion on this project is uncertain and could take two contradictory routes. Firstly, the government's overall aim is to supply carbon neutral, reliable power to the Netherlands. Evidence implies that DTP could be beneficial towards this aim. On the other hand, the government has invested heavily in wind and solar and frames these positively. This conflicts with how Humsterland energy present these forms of renewable energy. Vested interest and an unwillingness to admit flaws with these energy technologies may lead to the government to be less willing to invest in a technology such as DTP.

4.3.2. Humsterland Energie

Humsterland Energie is a consultancy company that provides advice on sustainable energy conservation and generation. A network within policy, business and education is used to scientifically validate sustainable projects. They provide practical advice to companies and projects on energy saving and generation. By working with a range of stakeholders and projects they intend to improve the viability of the renewable energy sector.

As a consultancy firm, the organization is interested in securing paid projects and expanding its network. As the stakeholder in charge of the project they have a vested interest in ensuring the project goes ahead. Their website presents DTP power as leading to "spectacular energy yields" and as being capable of producing "30 - 70% of the electricity supply in the Netherlands as a base load" (Humsterland Energie, 2019). DTP is presented as a potentially cheaper and more reliable source of energy than wind or solar. Humsterland Energie are coordinating a range of research projects to further investigate these claims. They aim to prove the economic and ecological benefits of the DTP-dam.

As a consultancy agency Humsterland Energie has had interactions with a variety of projects in the renewables sector. Their work spans solar, wind, energy efficiency and hydrogen fuel cells. Studies they have produced present solar and wind as being inconsistent and inefficient forms of energy production that are reliant on expensive storage or fossil fuels for a baseload. Whilst these claims are evidenced, it is important to remember that these energy sources stand in competition for space and investment with DTP power. This company is the party most in favour of commencing construction. They present a consistent message in support of the energy source and are key to substantiate these claims.

4.3.3. The EUCC International Secretariat in Leiden (The Netherlands)

The EUCC is a network of experts and NGOs that operates in five countries across Europe. This network bridges "the gap between scientists, environmentalists, site managers, planners and policy makers, it is the largest network of coastal & marine practitioners and experts in Europe." (EUCC, 2019)

They are focused on sustainable management of the coast and sea and aim to improve the sustainability of a variety of sectors including tourism, fishing and energy. Their activities include consultation, research and collaborative projects with other stakeholders working in related areas.

Referring to similar projects, the EUCC states that "In general, wave energy is being recognized as suitable for steadier and more predictable energy production, high power density, a relatively high utilization factor, low visual impact and presumably lower impact on the environment compared to other renewable sources (EUCC, 2019)."

For wind energy the group has published a piece titled: "Birds and offshore wind farms – a double-edged sword?" Although generally positive towards wind power and acknowledging the benefits, the group appear wary of the risks to migratory birds (EUCC, 2019).

Given the group's support of wave energy they are likely to be supporters of the dam. They explicitly acknowledge the additional benefits to coasts that wave energy can provide. This implies that they would be open to the synergistic benefits that the DTP-dam may offer, such as habitat provision. Given the organizations doubts about wind power and the size of its network they could be a useful supporter of DTP.

4.3.4. Netherlands Wind Energy Association (NWEA)

The NWEA is the conversational representative of ministries and other organizations on a variety of topics surrounding wind energy.

They provide members with a voice in discussions about the national energy transition and climate change. In order to do this effectively, NWEA maintains contacts with national and regional governments, politicians, policy makers, the scientific community, and both the economic and environmental sectors (Veldman, Diest & Diest, 2019).

NWEA also participates in international partnerships, such as with foreign wind associations. They emphasize their goal of promoting export of Dutch wind power through the establishment of an export committee set up at the end of 2018.

As a collaboration of all parties concerned with Dutch wind energy, they have extensive experience with the development and construction of wind infrastructure both on land-Commission Wind on Land, and offshore-'Commission on Wind at Sea'.

Members are manufacturers and suppliers of actual wind energy, the system composite parts, and other forms of energy. They therefore have experience in large scale energy production projects at sea, meaning if collaborations are possible with the developers of the dam, utilization of infrastructure already in place would significantly reduce the costs and complexity of this project.

NWEA has members which have constructed hydropower dams within their own companies, for example TenneT. As mentioned earlier, a possible collaboration between the developers of the DTP-dam and this organization could result in wind power in conjunction with the dam.

In theory they are said to represent large- and small-scale wind farms, but increasingly they are dominated by 'big businesses'. Purchase of 'premium membership' allows holders to place a representative of their choice on the board, a position from which they can then influence the organisations direction and policies (Steringa, 2015).

As premium members include Shell and Eneco, companies which have shares in fossil fuel energy. Combined with the fact the group also emphasizes the fact that they are pro-wind, not anti-fossil fuel, the potential of the dam to replace fossil fuels may not be supported by them.

4.3.5. Stichting de Noordzee

The North Sea Foundation, in Dutch '*Stichting de Noordzee'*, is an independent foundation concerned with protecting North Sea and ensuring it is used sustainably. For the last 35 years this environmental organisation has been committed to its four goals: allowing space for nature, a clean sea, sustainable seafood and nature-friendly energy (Stichting De Noordzee, 2019). They have done this through interaction with, and monitoring of, the stakeholders who use the North Sea.

They have previous experience analysing the effects of constructions at sea. In 2019, a report was commissioned in which they examined the impacts of wind farm construction in the North Sea- therefore it is clear they have high interest in any energy developments taking place (Vrooman et al., 2019).

They have collaborated with TenneT in the last 5 years for the development of wind farms and appear to be strong supporters of wind. However they may be open to other forms as ecological protection is their main concern, stating: ''The North Sea Foundation is for the extraction and generation of energy at sea, provided that this is done in a nature-friendly manner with minimal negative impact on the North Sea ecosystem" (Stichting De Noordzee, 2019).

They also view the development of wind energy as an activity that offers opportunities for new life, due to its potential as an artificial habitat for species.

From this view, it could be assumed that they may support the dam due to their interest in experiments to actively strengthen or restore nature using hard structures.

4.3.6. VisNed

VisNed are the the largest representative of the fishing industry in the Netherlands. They claim to aim for sustainable production and to fish within maximum sustainable limits. They represent fishermen who predominantly use the techniques: beam trawl fishing for flatfish and shrimp, twinrig fishing, fly-shoot fishing, pulse fishing and fixed-fishing (VisNed, 2019).

This organisation maintains relationships with a range of stakeholders including; governments, NGOs and scientists. They represent the interests of fishermen both domestically and abroad and provide advice on fishing requirements, quotas etc. They represent the interest of their members on a broad range of boards and committees.

VisNed have interacted with offshore wind as the parks limit the area that the cutter fishermen can operate within and the organization sees this as a limitation on their activities. By working with wind energy companies, they are aiming to ensure pathways for fishing boats are established through planned wind farms. They have had considerable interaction with these projects and are in the process of establishing, with several other actors, a participatory board to discuss, plan and vote upon the future spatial management plans for the North Sea. In short, they have had considerable influence and interest in related projects, and this could potentially increase. Besides the renewable energy industry, they have had interactions with marine protection areas and offshore aquaculture, both of which they claim have need greater amounts of evidence to prove their viability. They call for peer reviewed validation of the gains these projects can yield before they would support them.

During an interview carried out with Pim Visser, the Director of Visned, it became evident that the organization will react negatively and fight the construction of the DTP-dam if it is perceived as limiting their fishing activities. Given the solid barrier the dam creates over distances exceeding any windfarm they have reacted negatively to the proposed project and view it as even more detrimental than windfarms. In addition to the issue of accessibility, they are worried about the effects the DTP-dam will have upon ecology and tidal dynamics. They are sceptical of benefits the dam may bring to fish populations and want to see peer reviewed evidence before they would back such claims.

4.3.7. Good Fish Foundation (GFF)

GFF are a foundation that works with NGOs and business to improve the sustainability of seafood in the Netherlands. They aim to improve the sustainability of the seafood sector by informing the consumers and businesses on responsible practice. Traceability, fair trade and reducing illegal practice are some of the ways they tackle this. They collaborate with stakeholders throughout the supply chain, sharing knowledge to business about responsible practice and informing on sustainable consumption, they also work to build and connect a network of sustainable practitioners (Good Fish Foundation, 2019).

The GFF seems to have little interaction with related projects as it is more focused on the supply and consumption of sustainable fish than on energy and spatial management of the oceans. They do, however, have close collaborations with Stichting de Noordzee, through which they obtained experience in the sector of marine developments.

It is unlikely that GFF will have strong opinions on the DTP-dam, as it is not directly connected to the supply of sustainable fish. On the other hand, if co-benefits of the dam for nursery habitat and increase in fish stocks can be substantiated and communicated then the foundation's support may be stimulated. Having GFF validating the project and certifying the fishing operations that occur in association with the dam could help garner support for the project.

4.3.8. MSC – Marine Stewardship Council

Marine Stewardship Council is an international non-profit organization that aims to tackle overfishing and improve the sustainability of the seafood industry (Marine Stewardship Council, 2019).

The aim of this organisation is to certify fish under certain criteria, thereby attempting to encourage sustainable practice and consumption. MSC works with a network of partners to stimulate a global market for sustainable seafood. The stated goal is to improve the health of marine ecosystems by rewarding sustainable fishing and influencing customer decisions. (Marine Stewardship Council, 2019)

No evidence was found of interactions between MSC and renewable energy projects that could be said to be analogous to the construction of the DTP-dam, meaning they have no history of objections to marine developments.

Given the organizations prominent position within the seafood sector they will be an important stakeholder to involve in validating the ecological and economic benefits associated with the dam. Given that we propose opening the dam for sustainable fishing practice in the form of sea ranging, MSC are likely to be in favour of the DTP-dam's construction. Both sustainable fishing and aquaculture would be of interest to MSC and therefore ensuring these practices meet the certification criteria could be a useful tactic for increasing support for the project.

4.3.9. ASC - Aquaculture Stewardship Council

The Aquaculture Stewardship Council is an independent non-profit organisation and labelling organization that establishes standards for fish farms, and other forms of aquaculture. Along with the MSC, they are described by the NL Fisheries website as: "The most important certifying bodies for sustainable fisheries" (Government of the Netherlands, 2019).

Through the application of their logo they want to ensure aquaculture products are sustainably produced, and to provide companies with a competitive advantage through proof of their achievement of responsibly farmed seafood. The logo is said to represent the environmental and social integrity of the product with buyers feeling they are in support fully traceable aquaculture practices that have minimal societal and environmental impact (ASC, 2019).

The ASC has little to no previous experience with related projects, due to their focus on aquaculture farms, which have yet to be introduced in similar developments, such as offshore windfarms.

The consumption of sustainably sourced seafood with an eco-label has been increasing in the Netherlands in recent years. In 2017, when purchasing seafood, two in every three euros was spent on a product with the ASC or MSC certification mark – making up 66% of supermarket seafood sales (ASC, 2018). This shows the growing importance of this organisation in the Dutch seafood industry and therefore they could be considered if farms are to be introduced upon the dam.

However currently, as they are not currently certifying the Dutch mussel or oyster market yet, it could be considered that they will have little to no interest in the DTP-dam and as a result of this, low influence. ASC is involved in creating a standard for seaweed production and did perform pilots for ASC-certified mussels in the UK, however.

4.3.10. Sportvisserij

Sportvisserij are an organization who aim to promote and support opportunities for the practice of sport fishing in the Netherlands. They are concerned with the protection of this activity as an important form of recreation at both national and international level. Sportvisserij support federations, specialist organizations and fishing associations in order to ensure all affiliated sport fishermen can fish nationally with as little limitations as is feasible (Sportvisserij Nederland, 2019). They attempt to do this by, among other things, issuing the VISpas, which allows holders to fish in all waters regulated by the organization.

This group would have little previous experience with projects of this magnitude. Apart from fishing in areas nearby to / created by freshwater dams, it is highly unlikely they would have experience in being highly affected by marine developments.

It can be assumed that if this group are encouraged to collaborate with dam designers regards the introduction of a space to sustainably sports fish at sea, they will be in support of it. As a group with over 350.000 members in the Netherlands, they could aid the conservation efforts of the structure by preventing unlicensed fishing and monitoring licensed fishing and gather national support for the project.

4.4. Stakeholder Mapping

4.4.1. Interest/influence diagram

Each of the stakeholders was rated on their interest and influenced based on the profiles that were written for each actor. These were then mapped accordingly onto the matrix shown in (Figure 2). From here the matrix was presented for further discussion and actors were rearranged according to group consensus. As interviews and discussions took place the matrix was incrementally adjusted until the final diagram was produced. Each actor was also coloured according to their observed stance on the project. Green indicates support for the project, orange neutrality, and red opposition.

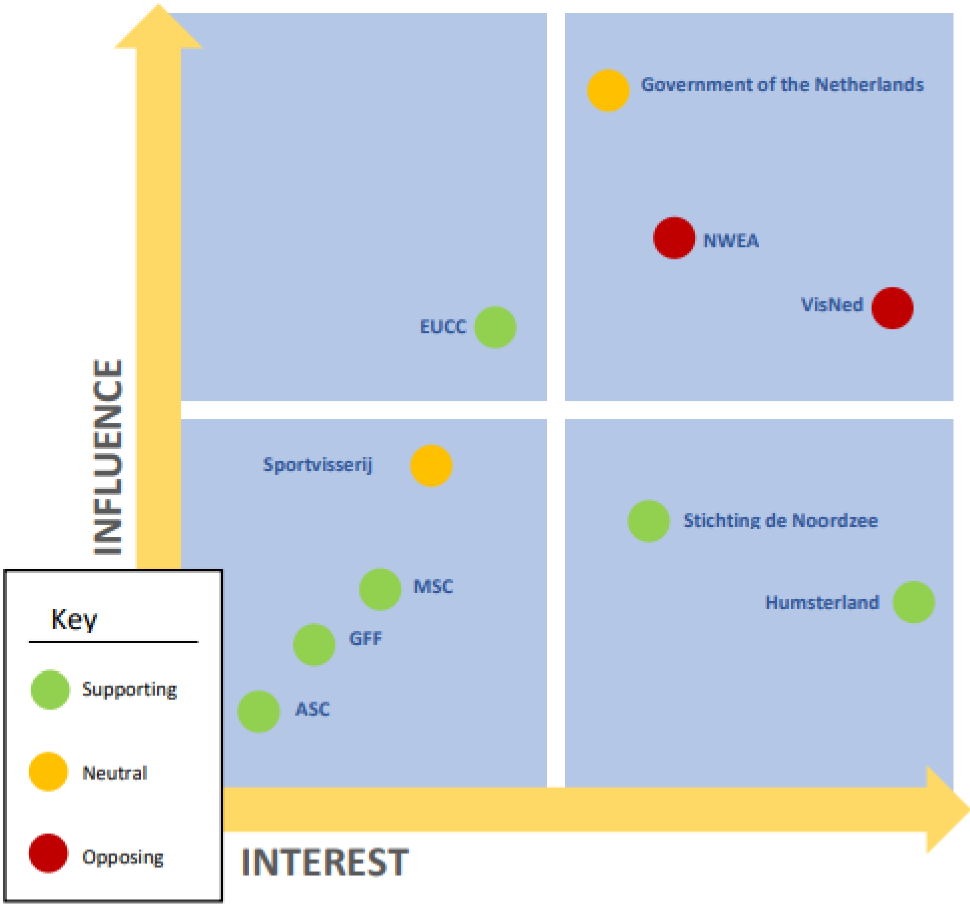


Figure 2: Influence/interest diagram

4.4.2. Onion diagram

The onion diagram, shown below in Figure 3, was produced as a visual representation of the stakeholder's relations with the project and other stakeholders. This enables key networks to be communicated. Stakeholders are shown by the coloured circles and relationships are indicated by the black line that interlink them. Stakeholders were connected if information had been found on working relationships between these actors, or the stakeholders clearly had common interests. The colour of the stakeholder's circles is the same as in Figure 2, apart from the fact that secondary stakeholders, stakeholders who had not been profiled, were left pale blue to indicate there is ambiguity around their stance. Size of each stakeholder circle indicates the respective influence of each stakeholder. The central circle indicates the DTP-dam and the distance of each stakeholder from it corresponds to how interested they will be in the project.

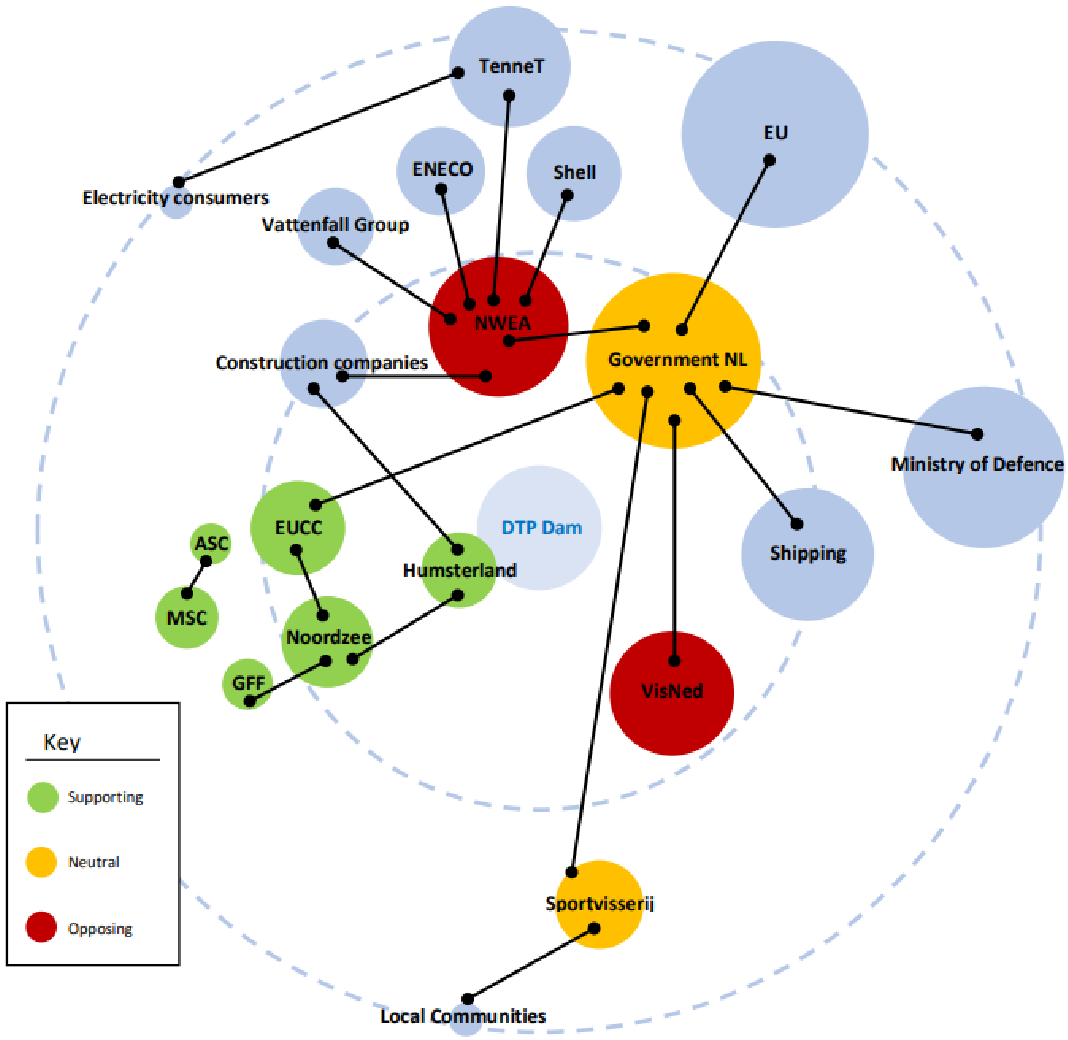


Figure 3: Onion diagram

4.5. Discussion

Dynamic Tidal Power has the potential to greatly alter the energy landscape of the Netherlands. As the country strives to meet its renewable energy targets and phase out fossil fuels over the next few decades, the dam could be a ground-breaking solution to the challenges associated with this.

Unsurprisingly, a project of this magnitude comes with a variety of affected parties. From our above results, these actors can be categorised by their general interests surrounding the project; Environmental and Energy.

From Figure 3 above, the largest opposition to the DTP-dam can be expected to come from shipping companies, VisNed and the NWEA. The dam's potential to eradicate fossil fuel use is a direct threat to the interests of certain members within the NWEA, such as Shell and the Vattenfall group.

The NWEA challenge may further be bolstered due to their tight links with the government. The Dutch government is heavily invested in the development of offshore windfarms within the North Sea, therefore rechannelling this funding towards a new energy source may be an obstacle.

Another sector of resistance to the dam, which should not be underestimated, may be found within the fisheries group- namely from the cutter fishermen representatives of VisNed. This group have already had their activities limited by windfarm development, and therefore would be extremely opposed to any further encroachment upon their remaining fishing grounds.

From an interview with a representative of this group, it was also understood that any future wind farm developments will be likely to allow access for fishing, meaning any obstacle within the North Sea would be seen as a regression of the interactions between the energy sector and the fishing sector.

VisNed also have strong connections within the identified 'Environmental' sector as a result of their policy involvement –such as their frequent involvement in discussions regarding the future 'North Sea Agreement'. Therefore, they may be more support for their views than initially considered.

On the other hand, there is also a small conglomerate of actors who may be in favour of the project. These actors have been identified as most likely to be in favour of the development are as follows; MSC, ASC, Humsterland Energie, EUCC, North Sea Foundation and Good Fish Foundation. This group shares a common goal to ensure sustainable use of the North Sea and its resources. With this in mind, a sound ecological assessment in which no negative effects upon the biodiversity of the area are found, would be crucial to ensure their support.

Certain organisations, particularly MSC and ASC, stand to gain a lot if they can be swayed to support the project. It could be assumed that once farms and sustainable fisheries are attracted to the dam, these parties could follow. The introduction of aquaculture and fishing, which could then be certified by either one of these groups, would boost their presence in the seafood market of the Netherlands.

Overall, the stakeholders who have been identified as being neutral/ uninterested in this project stand to gain the most- if they can be convinced. Parties such as Good Fish Foundation and Sportvisserij could sway consumers in support of the development through their strong public presence in the food and leisure sector. Sportvisserij, in particular, could be helpful in performing a monitoring function, in order to ensure any fishing that takes place on, or around, the dam is done in a sustainable way that does not overtly deplete the ecosystem. Consulting them in what they would want from the development in return for monitoring may be useful to maintain the viability of the area for conservation.

From the diagram in Figure 3, it could also be seen that the most influential stakeholders may not be the most interested in the dam initially. In the case of the government for example, this project is contingent on their support and permission for it to go ahead. However, currently the government has supported multiple subsidiary and investment schemes into the development and continuation of wind energy in the Netherlands. If the benefits of this project can be adequately communicated to this stakeholder, the realisation of the DTP-dam is significantly more likely, and it could be assumed that other powerful actors would follow in support.

4.6. Conclusion stakeholder analysis

From the stakeholder analysis the key finding is that powerful support for the project is lacking. Whilst less influential environmental groups are likely to show support for the project the more influential, and particularly economically powerful, groups have vested interests to oppose the project. The government has invested heavily into wind power, NWEA competes directly in the renewables market, VisNed stands to lose access to fishing grounds and shipping will be economically impacted by having to lengthen routes. These conflicting interests are likely to prevent the project from commencing. It is therefore recommended that the interests of these parties are taken directly into account in the future developments of the dam and considerable effort is mobilized to garner support from one or more of these parties.

Another major finding is that the stakeholders can be described as comprising two networks. The first is a less influential group of environmental NGOs and foundations, these are likely to support the project if the ecological benefits can be clearly communicated and evidenced. The second network is comprised of the fishing industry, the energy companies, the shipping industry and the government. These networks differ greatly in their perspectives on the project and therefore it will, upon occasion, be useful to interact with these stakeholders separately as the project continues. One recommendation would be to establish round table style discussions and workshops with these groups to ensure support is nurtured and worries are mitigated. This will also provide a setting where potential areas for mutual gains between stakeholders can be planned. An aspect that is particularly necessary when working with the stakeholders that currently stand in opposition to the project.

Finally, it is important to acknowledge the lack of primary evidence that was possible to gather over the short project timeframe. This means the stakeholder profiles and mappings are not as in depth as they could be. For this reason, we recommend that, if further research is undertaken, interviews should be undertaken with the remaining stakeholders as this could yield valuable information about the future of the project. Distributing the onion diagram to the relevant stakeholders and giving them a chance to provide feedback would also help to improve the validity of the findings and provide interesting insights into how the stakeholders will respond to the DTP-dam.

5. Location of the DTP-dam

5.1. Morphology & Flow Rates

Along the Dutch coast the driving forces for sediment fluxes are wind, tidal movement and density differences (Dronkers et al., 1990). The rivers Rhine, Meuse and Scheldt all flow into the North Sea, creating a salinity gradient across the shoreline. Due to the salinity gradient a northward flux along the coast is created (Rozemeijer et al., 1999). This northward movement is enhanced by the anticlockwise gyre which can be found in the North Sea (Ducrotoy et al., 2000). Also, Dronkers et al. (1990) stated that the flood sediment transport exceeds the ebb sediment transport, which enhances the movement of sediments in the northward direction. A northward sediment flow can be found, especially in the shallower parts, mostly along the coast (Ducrotoy et al., 2000). A so called 'coastal river' flows along the coast to approximately 1,5 km offshore, in which the most sediment is transported. Further off the coast the sediment transport is rather small (Hoitink, 2019; Rozemeijer et al., 1999).

With the current state-of-art models and knowledge on the driving forces for morphodynamics, the impact a large structure (like the DTP-dam) would have on sediment transport is difficult to predict (Luijendijk et al., 2017). Since the dam is an unprecedented construction in the area, there are no directly comparable studies. The most comparable study found is an ecological impact assessment about the development of an airport at sea, carried out by Rijkswaterstaat (Rozemeijer et al., 1999). The airport would be located on an island 10-16 kilometre of the coast and accessible by a dam or a tunnel. The effects on the ecosystem turned out to be very different when using a dam than a tunnel. The construction of the dam to reach the island can be regarded as a shorter version of the DTP-dam but attached to the coast. When using a dam, localised sediment deposition can be expected in the formation of sand and mud plates. These formations can then enhance the biodiversity around the dam, and as the sediments settle, there will also be an increase in visibility within the water.

Conversely, the Dutch coast north of the dam will receive less sediments, particularly the Wadden sea, since less muddy depositions are expected. With less sediments (mostly mud) reaching the Wadden sea the seabed will become sandier. Rozemeijer et al. (1999) found that this could result in a loss of biodiversity as important nursery areas for fish such as plaice are degraded. A loss of other species within the estuarine areas of the Wadden Sea may also occur, which could then change the total food web. Rozemeijer et al. (1999) expected that this would cause decreasing biodiversity in the Wadden sea.

After this, we think the effects of the dam attached to the coast are expected to be positive for the biodiversity around the dam, but negative effects on biodiversity further north might be expected. Also, the effects of the dam on coastal protection are difficult to predict.

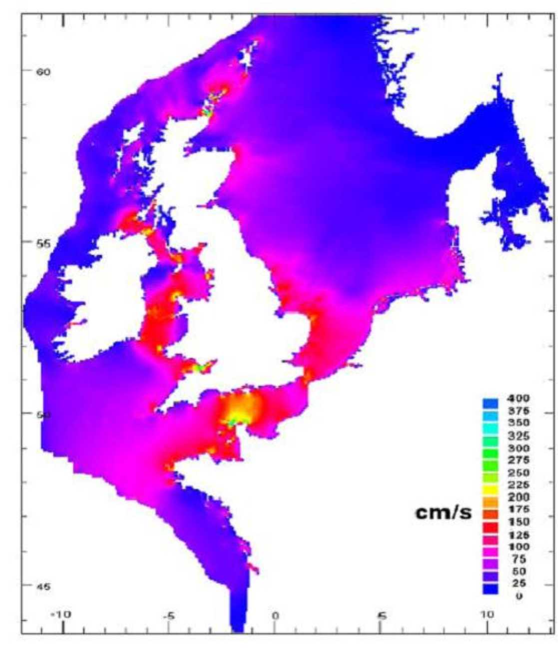


Figure 4: Peak tidal current velocities in North West Europe (Humsterland Energie).

Another important factor to consider when choosing the DTP-dam location is the maximum peak tidal current velocity which can be expected. A higher flow rate will cause a higher energy production which creates a cheaper kWh price for the energy baseload. According to Figure 4 the peak tidal current in the North Sea for the Dutch coast are expected to be in between 70 – 120 cm/s. Flow rates over 70 cm/s are found to be the lowest which can secure a sufficient baseload of energy production, which will make the project economical feasible (Humsterland Energie, 2019).

5.2. Location of the DTP-dam

After these findings, we decided to locate the dam further off the coast. No interfering with the coastal river will take place so sediment fluxes near to the shore will be unaffected. Considering current shipping routes, energy cable infrastructure and the possible synergy with wind energy, the location we picked for the dam is in the wind energy park IJmuiden Ver (Figure 5, area 6). Energie (2019). This location seems to be suitable since it is not interfering with the coastal river, and no shipping routes are going through. Also, since the dam will mostly be within a windfarm which is inaccessible to fishing boats, there will be not much additional limitations upon this sector. Additionally, the expected maximum tidal current velocity seems to exceed 70 cm/s, so the produced baseload will be economically feasible.

When the dam is located further offshore, we expect smaller impacts on sediment transport. As stated above, the sediment flux offshore in the North Sea is rather small. Erosion on the sides of the two V-shaped ends of the dam is expected. The sand which is eroded away might get deposited several 10's of kilometres behind the erosion spot (Bliek, 2019).

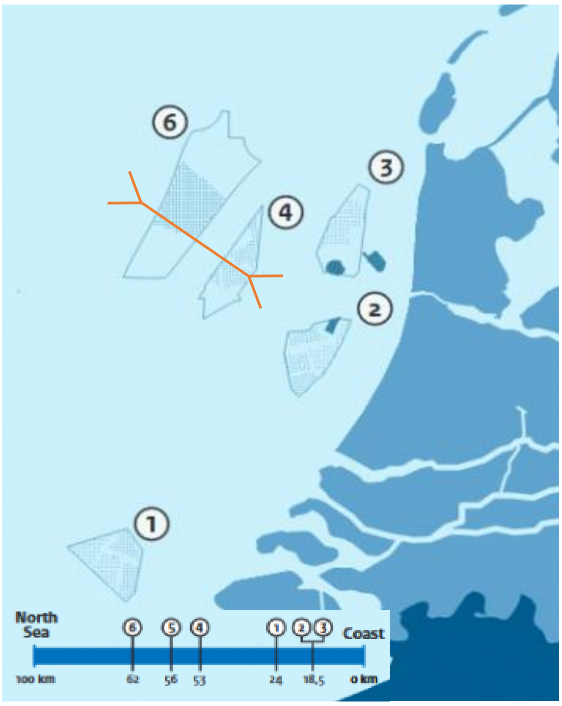


Figure 5: The DTP-dam location, through windfarm area 6 and 4.

We also expect sediment depositions on both sides of the dam, and a high probability of sediment build-up between the V-shaped areas since the water velocity will slow down over there. This is expected to occur based on expert-judgement. We recommend doing proper modelling studies on sediment transport in order to more accurately predict sedimentation flows Also, an accurate and more precise calculation of the expected maximum tidal current velocity at the proposed DTP-dam location needs to be executed in order to give a clear insight of the expected baseload on this location and to check the feasibility of the whole project.

6. Impact ecosystem North Sea

In this chapter we will investigate both the current status of the ecosystem of the North Sea at the location where the DTP-dam will be built and the expected impact of the DTP-dam on this ecosystem. Factors which we think are of importance are noise, light, flow dynamics and pollution. Through this evaluation we try to answer research question 2. Besides this, the hard structure of the DTP-dam will have a considerable impact for habitat provisioning, however, since this topic is extensive it is covered in Chapter 8.

6.1. Current ecosystem of the North Sea

In order to state anything about the ecosystem on which the DTP-dam might have an effect, the ecological zone of interest is needed. Ecosystems gradually change in all directions, especially in the open sea where biotopes overlap and interact. In this report we assume that the impact of the DTP-dam is related to the ecological system of the south-east North Sea below (green marked area), as defined geographically by Callaway (2002) and Stäbler et al. (2018). The south-east North Sea has depths mostly less than 50 m, but can reach depths over 100 m.

Figure 6: The green area in the North Sea depicts the ecological area of interest.

The biodiversity of the south-east North Sea is assumed to be distinct from the northern part, since considerable differences in salinity, oceanography and nutrient loads (ICES, 2008) occur there. Demersal fish stocks (Clark and Frid, 2001; Frelat et al., 2017) as well as catch compositions (Rätz and Mitrakis 2012; WGNSSK, 2016; HAWG, 2016) show that the structure and functioning of the south-eastern food-web and the impact of the DTP-dam on the latter should be expected to differ from that of the whole North Sea area.

Next to a north-south division of the North Sea ecosystem, the changes in seabed elevation are of importance to the ecosystem lay-out as well. Depth is a major determinant for the occurrence of varying species like e.g. juvenile flatfish and bottom-feeding bird species, such as diving ducks. From the Dutch coast onwards the bottom of the North Sea slopes gently. Three depth zones can be identified, the first is up until 5 kilometres of the coast, the second between about 5 and 20 kilometres and the third is 20 kilometres and onward. The NAP (new Amsterdam level) -10 m depth line is located 1 km of the coastline, the 15 m depth line at about 5 km from the coastline. The first 5 km off the coast is very rich in quantities of *benthic* (seafloor) animals (e.g. worms, shellfish, shrimps). At the ground level benthic animals represent an important link in the food chain. They are the main source of food for birds and fish. This benthic food availability enhances the coastal zone's function as a good breeding ground for young flatfish, which feed themselves with these benthic animals, enhancing the whole regional ecosystem in first zone. Between 5 and 20 km from the coast there is a transition zone that is less rich in animal life, and outside that- where the DTP-dam is placed- is zone 3, which is even more nutrient poor. The last two zones (2 and 3) are quite like each other and differ quite a lot mostly from the narrow coastal zone. Vertical zone 3 is where the DTP-dam is located. Stratification (the forming of different water layers due to changes in e.g. salinity and temperature) occurs slightly in the waters surrounding the DTP-dam, however due to continuous thermal mixing of the water this stratification is partly countered (Salomons et al., 2012). This natural stratification process decreases equal nutrient availability in the vertical water column surrounding the DTP-dam.

Generally, the composition of the benthos community living on varying depths in the North Sea, also shows a similar north-south structure as described before when defining the ecological research area. Benthic organisms can be mobile or sessile and live closely above/on the seabed (epibenthos), or below/in the seabed (endobenthos). We do not focus on endobenthos. Mobile epibenthos dominates south of the 50 m-line, while epibenthos in the northern North Sea is dominated by sessiles (Callaway et al., 2002).

The mobile epibenthos community in the area comprises mostly of species such as brittle stars (O. Ophiura), whelks (Buccinum undatum) and flying crab (Liocarcinus holsatus). The fish community structure at this defined part of the North Sea is shaped by high seasonality of bottom temperature and salinity and a relative productive phytoplankton regime compared to the northern part of the North Sea. Typical representatives of southern and south-eastern species are brown shrimp (Crangon crangon), Common sole (Solea solea), European flounder (Platichthys flesus), turbot (Scophthalmus maximus) and Thornback ray (Raja clavata). Fish like cod (Gadus morhua), haddock, herring, whiting and saithe are the main commercial species catched for consumption, with lesser quantities of flatfish like plaice (Pleuronectes platessa) and dab (Limanda limanda). Sand eel, mackerel (S. Scombrus f.e.), and sprat (sprattus) are caught to produce fishmeal.

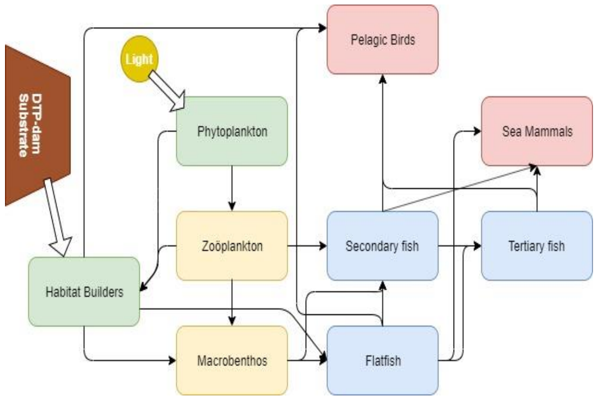


Figure 7: Simplified depiction of the North Sea food web. Arrows show directionality of biomass uptake.

The ecosystem can be divided into different trophic levels and functional groups within a general food web as visualized in Figure 7. A food web is a series of organisms (or functional groups in this case) within an ecosystem related by predator-prey and consumer-resource interaction. These different trophic levels are classified categories within a food chain. The first level of the food chain contains the primary producers, such as phytoplankton and seaweeds. Functional groups within this trophic level can be distinguished by different characteristics, for example, their structure or habitat. For our research, we chose to define nine different functional groups as follows: phytoplankton, zooplankton, habitat builders (such as sea-grass, bivalves and seaweeds like kelps), macrobenthos (visible organisms living at the sea floor, such as crustaceans, sea anemones and sea sponges), flatfish, secondary fish (such as mackerel), tertiary predatory fish (such as cod and sharks), marine mammals (such as sea lions and cetaceans) and pelagic birds. Normally habitat builders are not particularly defined as a functional group, however due to their important potential role in this project, they are separately outlined.

Between these functional groups several mutually reinforcing and opposing processes are going on. For example, early spring blooms of phytoplankton will not benefit zooplankton, which needs moderate water temperatures and so will be present later. A possible development of harmful algae blooms (which can be toxic) can hamper the success of zooplankton in algae consumption. An increase of tertiary predator fish or even marine mammals might enhance flatfish population or macrobenthos by keeping secondary fish populations within boundaries through hunting. This shows the continuous transmission of effects within the food web of the North Sea ecosystem and the interdependency of all functional groups. All these chain-reactions could be commenced through abiotic environmental factors the DTP-dam changes. Within the food-web as stated further research is needed to assess which species, or functional groups are most sensitive to anthropogenic effects that come in play due to the DTP-dam. This in-depth species-specific investigation is beyond the scope of this report, however.

6.2. Abiotic effects DTP-dam

Abiotic factors, like physical conditions and non-living resources, influence the ecosystem fundamentally since they play a central role in which type of organisms can thrive at certain places, enhance-or reduce primary production and may limit or exacerbate species reproduction. The constant mixing of waters in the shallow southern North-Sea basin provides a supply of nutrients and salts upon which lower forms of marine organisms, the basis of the sea's food-chain, depends. Phyto-and zooplankton that benefits from this nutrient mixing supports a varied and rich supply of fish. However, stratification occurs as well further offshore in the area of the DTP-dam, which limits overall nutrient availability compared to shallow waters. Furthermore, the availability of light in the water column and seabed determines the euphotic zone and constrains the type and the vertical distribution of algae species (Saulquin et al., 2013).

The total range of biotopes will likely increase around the DTP-dam. Through erosion and sedimentation, different environments are created that will accommodate different soil communities at the sides of the DTP-dam. The precise prediction of the change in bottom animals is difficult to predict. A lot of knowledge on possible effects on the micro-and macro communities at the seabed must be gained, as well as exact predictions within a certain timeframe of the sedimentation pattern. The living communities on the DTP-dam themselves, are likely to resemble those found on Dutch dikes and shipwrecks (Van Moorsel et al., 1999). To investigate different effects of the DTP-dam on its nearby environmental state, all abiotic factors that are likely to be influenced by the project are examined, except for substrate availability which is included as separate section in the chapter on nursery habitats. The abiotic factors which we believe likely to be influenced by the DTP-dam's operation and ancillary activities are mention in the next subchapters.

6.2.1. Noise

Noise is any unwanted or disturbing sound. In aquatic ecosystems, noise is intentionally produced for seismic exploration, harassment devices or sonar, or as an unintentional by-product such as industry, shipping, and recreational boating (Hildebrand, 2009). It can be damaging to marine species through individual's anatomy, physiology, and/or behaviour in several ways (Kunc, H., et al., 2016) (Figure 9).

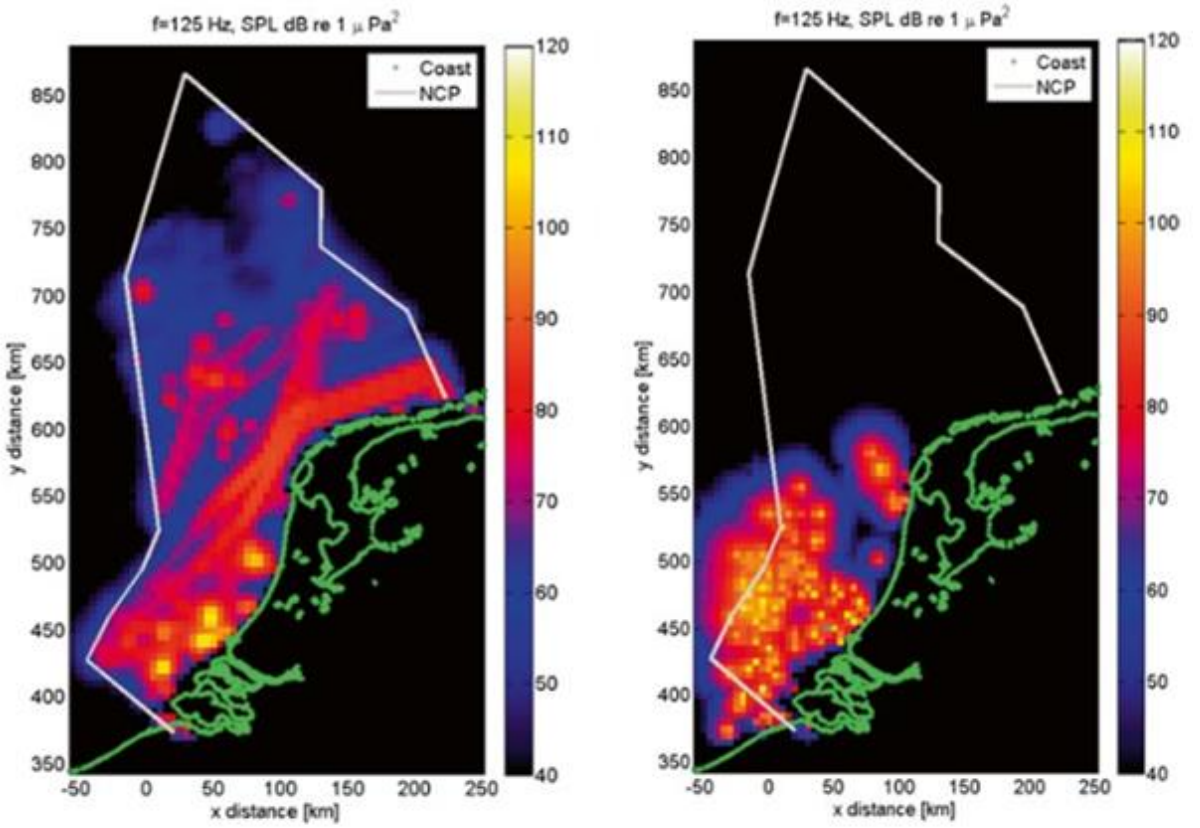


Figure 8: Sound maps for shipping (left and underwater explosions (right) at 125Hz over a period of 1 year in 2010. SPL sound pressure level, NCP North Sea Cawspian pattern, f frequency (Sertlek et al., 2016)

It is unclear whether the total amount of noise near the DTP-dam will increase or decrease compared to the current status. On the one hand extra activities, like maintenance, sea farming and will create noise, while on the other hand shipping routes and fishery activities will decrease since the dam will form a barrier. Shipping routes will alter geographically, but overall intensity of commercial shipping will not decrease in the North. From this follows the conclusion that more activities mean more noise in the North Sea. The question arises how much noise increase is considered acceptable in the surrounding area of the DTP-dam. This requires investigation, when project specifications have been concretized.

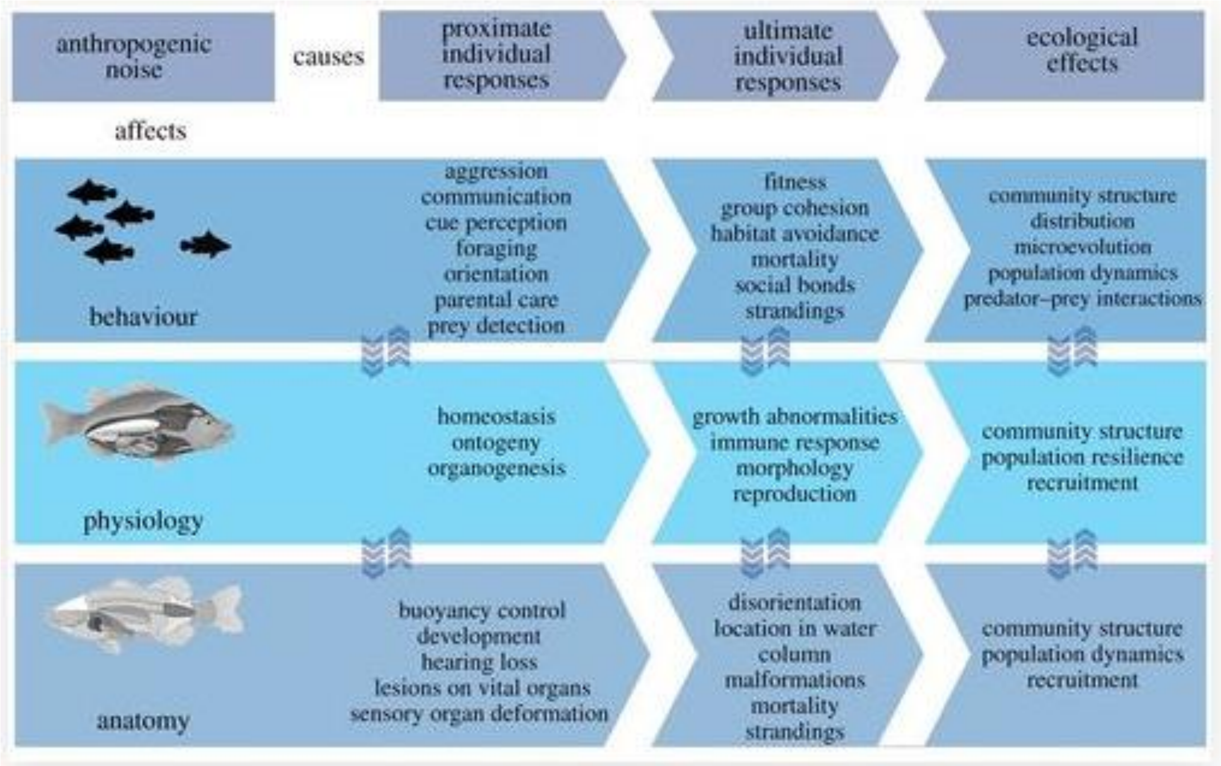


Figure 9: The effects of anthropogenic noise on individuals' anatomy, physiology, and/or behaviour. Changes in the acoustic environment through increasing noise levels can lead to immediate proximate responses, resulting in a variety of emergent responses.

The EU's Marine Strategy Framework Directive (MSFD; European Commission, 2010b) requires member states (MS) to achieve or maintain good environmental status (GES) by 2020. Specifically, the wording of Descriptor 11 requires "underwater noise to be at levels that do not adversely affect the marine environment." The MSFD further requires monitoring of "trends in the ambient noise within the 1/3-octave bands of 63 and 125 Hz (centre frequency)" (European Commission, 2010a). In Figure 8 the intensity and frequency properties of sound from anthropogenic (e.g., shipping, underwater explosions, seismic surveys, pile driving) or natural (e.g., wind, rain) sources are considered. As can be viewed in Figure 8 the consistent production of noise by shipping routes is relatively low in the suggested area of IJmuiden Ver. Combined construction and maintenance of windmills, as well as usage of the DTP-dam means that underwater noise is likely to increase compared to the current situation. Noise reduction can occur locally in spaces where busy shipping routes are interrupted.

6.2.2. Light

Light is an important inhibiting factor for primary growth. Phytoplankton and habitat builders such as seaweeds depend on it. The amount of light penetrating the water column depends on the water clarity and turbidity. As was mentioned in Chapter 6.1 the DTP-dam is expected to have an overall positive effect on water clarity, for sedimentation will occur near the dam, clearing the water of fine particles.

Furthermore, it is well known that nautical ecosystems with a high biodiversity-grade positively influence water clarity. In these systems different functional groups are balanced.

In a healthy ecosystem primary production by, for example, phytoplankton is not exacerbated up until the point that extensive phytoplankton dilution results in murky water, that becomes oxygen depleted due to the degradation process of these phytoplankton. This is because zooplankton feeds on phytoplankton and ensures no threshold is passed in which over-availability of the phytoplankton creates negative effects. The zooplankton production must, above all, be seen in the interest for the growth of (juvenile) fish. A similar balancing system is witnessed with herbivorous fish species, which keep seaweeds from overgrowing and shading lower parts of the vertical water column. Moreover, habitat builders such as oysters and mussels that may attach to the DTP-dam's walls are filter feeders. These species are known to clean the water column, decreasing turbidity (Timmermann et al., 2019). So, if the DTP-dam is able to enhance biological activity throughout all trophic levels, it is likely that a positive feedback loop is created in which the local ecosystem improves water clarity, which in turns increases light penetration, increasing biomass production at the first trophic level, which serves as foundation for further growth of all species within the local ecosystem (Figure 10).

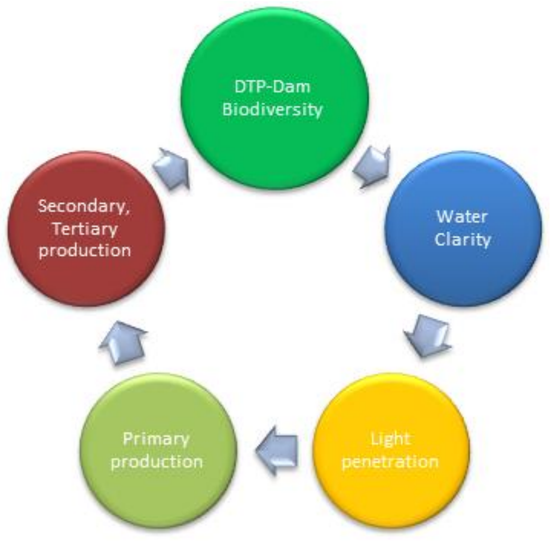


Figure 10: The general positive feedback loop of life attaching to the DTP-dam enhancing life associated with the dam. All these factors increase each other up until a stable state in the system is reached. Negative feedback-relations are also present but negligible in comparison.

Normally algae blooms in the North Sea begin at the end of April. The algae bloom rises to a clear maximum, followed by a summer minimum and a new algae bloom in the autumn (August, September October). In the coastal zone, these phenomena are most obvious, but they also occur further to the west, in less extreme matter. As a result of the reduction of the sludge concentrations in the water, spring flowering of phytoplankton could possibly start earlier, as was found by (Rozemeijer et al., 1999). However, the conclusions of Rozemeijer et al. (1999) were based on model calculations for the construction of a DTP-dam closer to the shore, in a significantly more turbulent flow-area. It is doubtful whether the DTP-dam at our proposed location will also affect the blooming period and consequent synchronicity of natural processes. This would require further investigation and modelling.

6.2.3. Flow dynamics

As explained in Chapter 5.1, the expected effect of the DTP-dam on currents and related sedimentation patterns further offshore is limited. It is possible that the absorption of tidal power from the North Sea, will result in a lessened dispersal radius of passive transporting marine larvae and spat to the shallower near-shore nursery habitats such as the Wadden Sea. The extent to which marine brood stock can reach settling grounds after placement of the DTP-dam should be the subject of further research. We expect placement of the DTP-dam would result in no immediate and sudden changes to the seafloor. Benthic life is generally able to adjust to minor changes occurring over time. The creation of a shallower seabed at the side of incoming tidal current is expected to have a positive impact on juvenile fish species as nursery habitat. This will be explained more in depth in Chapter 8.

6.2.4. Pollution

Different sources of pollution can be associated with the placement of the DTP-dam: complex chemical effluents like antibiotics (in aquaculture), organic matter (through feed, or feces in aquaculture), inorganic compounds such as nitrogen and phosphorous (through construction and feed) and plastics.

Chemical pollution can have serious negative effects on the marine ecosystem. For example, small concentrations of oil can have extensive detrimental effects on organism growth (Kinako, 1981). These chemicals are occurrent in waterbodies through anthropogenic influences such as shipping. The extent to which pollution negatively influences the ecosystem differs, impact of certain pollutants is species-dependent and life-stage-dependent. Early-life-stage organisms are in general considered to be more sensitive to toxicants than fully developed individuals from the same species (Hutchinson et al. 1988). Moreover, toxic compounds have the habit to build-up through the feeding cascade. When phytoplankton accumulates e.g. carbohydrate pollutants; these pollutants work their way up in the food-chain.

Two polluting sources of concern are organic matter and antibiotics. These mostly associated with aquaculture practices such as fish cages, where health practices, spillage of feed and excretion of faecal matter increase the amount of either complex chemicals or solved organic matter in the water. Eutrophication (the extreme increase of organic matter in water bodies) has adverse effects on the ecosystem since it shifts bottom-up processes in the food web, decreases PH and depletes oxygen reserves (Rozemeijer et al., 1999). When eutrophication occurs a shift in the species composition of phytoplankton can be expected. Increase of aquaculture associated antibiotics alters hormonal functioning of fish. When fish aquaculture would be practiced on a large scale, these two polluting factors form a risk. It should therefore be noticed that promoting active feeding of aquaculture species (be it fish, molluscs or other species) ought to be handled with care, because of negatively associated effects on the ecosystem.

However, in general it is found that many chemical pollution currently has low- or insignificant impact at current levels of influx from shore in the North Sea (Vethaak et al., 2005). The expected chemical input due to activities occurring around the DTP-Dam is expected to be low as well. The DTP-dam will have little impact on the ecosystem when viewed in relation to current impact of pollution in the North Sea by numerous pollution sources such as effluent wastewater, drilling platforms and shipping.

A similar conclusion can be drawn with regards to plastic pollution. Concerns that increased activity surrounding the DTP-dam might increase plastic pollution should be set against the background of the fact that currently relatively little plastic pollution has been found in fishes in North Sea, compared to what is found in other seas and oceans. Foekema et al. (2013) found that in the North Sea, 2,6 % of the fish contained plastic particles in their stomach, with the highest percentages (5,4 %) found in the southern North Sea. An increase use of nylon nets for aquaculture next to the DTP-dam might form a source of potential plastic pollution through wear and tear processes. However, we expect that with good regulation on for example aquaculture practices, plastic waste originating from the DTP-dam will not pose as a significant concern for marine life.

Even though possible adverse polluting effects that are posed by the placements of the DTP-dam are likely to be avoided easily, it should be realized that creating a structure of this magnitude will likely increase effluent of pollutants in the seawater of some sort. Further investigation into different possible pollutants associated with the DTP-dam's operation is therefore necessary to ensure no serious biological hazard is formed in this matter. A way in which the DTP-dam could cope with possible pollutants beforehand is to include some monitoring stations next to the structure that measure water quality parameters. In this way the scientific toxicological community is aided with data on the respective North Sea area and pollutants originating from activities on and near the DTP-dam are monitored too

6.3. Conclusions ecosystem North Sea

The key finding from the analysis of the effects of the DTP-dam on the North Sea ecosystem is that it will likely increase biomass and biodiversity in the food chain. Potential threats that the DTP-dam poses are from the impacts of noise and pollution in the form of organic matter and plastic, especially if large-scale aquaculture is incorporated. Knowing that the location of the DTP-dam is currently intensively fished and trawled it is expected that the ecosystem will gain more from the DTP-dam than that it will lose.

7. Migratory species

The placement of the DTP-dam could influence the migratory trajectory of certain types of migrating species. The question arises, if and how the DTP-dam would affect current routes or hamper active and passive transport of species. Two different migratory groups are identified as interesting to investigate for the impact the DTP-dam will have upon them: Cetaceans (whales and dolphins) and (pelagic) birds. We decided to not investigate the migratory roots of smaller fish or of fish larvae in the top layer since we assumed that these will simply fit through the turbines.

7.1. Cetaceans

Cetaceans are a group of aquatic mammals constituting mainly of whales- and dolphin species. There are about 89 known species of cetaceans (Ranneft et al., 2001) which include all whales and dolphins such as the minke whale, white-beaked dolphin and porpoise which are native to the North Sea area.

These species are known to migrate over distances extending hundreds of kilometres. In order to ensure conservation of migratory routes and protection of these marine species, the EU laid out several agreements in 'The Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas', shortly referred to as ASCOBANS (Nukamp & Nollkaemper, 1996) to protect this marine life. The agreements coastal EU states made in ASCOBANS are general and non-obligatory in nature but constructed in a political environment supportive to regional conservation practice (Nukamp & Nollkaemper, 1996) and therefore important to consider. The 60km length of the DTP-dam mean it may pose an obstruction to migratory routes. It is advised that the Netherlands should therefore conduct an effect study on cetaceans as they have agreed within the EU Marine Strategy Framework Directive (MSFD) and ASCOBANS. This involves the study of possible damaging activities to cetaceans by human activities in the North Sea. These sorts of studies have already been performed for cases such as fishing bycatch and pile driving for wind-turbines (Teilmann, 2015; Hamer, 2019).

Negative effects that the DTP-dam might pose for small cetaceans include increased pollution, noise nuisance and physical obstruction. Positive effects, however, like a build-up of an ecosystem to provide food for migrating cetaceans, possibly outweigh the negatives. One of the critiques posed by Nukamp & Nollkaemper (1996) and WWF on the ASCOBANS-agreement is the lack of an ecosystem approach within the European legislative framework. When the expected positive impact of the DTP-dam on the overall Dutch North Sea is quantified, this will likely override concerns about the protection of small cetaceans.

Moreover, concerns that the DTP-dam will obstruct the migratory corridor of small cetaceans can likely be neglected since the turbines used to produce energy will have a diameter of about 8 meters, meaning most small cetaceans can swim through the DTP-dam. It is unknown, from a behaviour-standpoint however, whether frequently recurring species in the area will do this. The location of the DTP-dam might conflict with overall habitat requirements of cetaceans as posed by Ross et al. (2011) and will have to be evaluated under ASCOBAR-guidelines as to see whether the area is a priority habitat to protect.

Concerns can be raised about the migratory routes of larger cetaceans like the sperm whale (Physeter macrocephalus), common minke whale (Balaenoptera). In a re-occurring study performed by the European Union Hammond et al. (2017), cetacean abundance in European Atlantic waters was estimated, based on the SCANS-III aerial and shipboard surveys in the summer of 2016. These aerial- and shipping surveys where performed to count and place different cetacean species. When zooming in on whale species indicated in this study, it can be viewed that almost no whales-species regularly occur in the waters surrounding the planned DTP-dam (Figure 11).

Based on these findings and other relevant data and parameters, Hammond et al. (2017) created a model to calculate the cetacean distribution per species type, per North Sea zone. No relevant species where calculated to occur near the IJmuiden Ver windfarm, except for the minke whale. The modelling output calculated an average of 0.015 minke whales. per square kilometres in our relevant area (Figure 12).

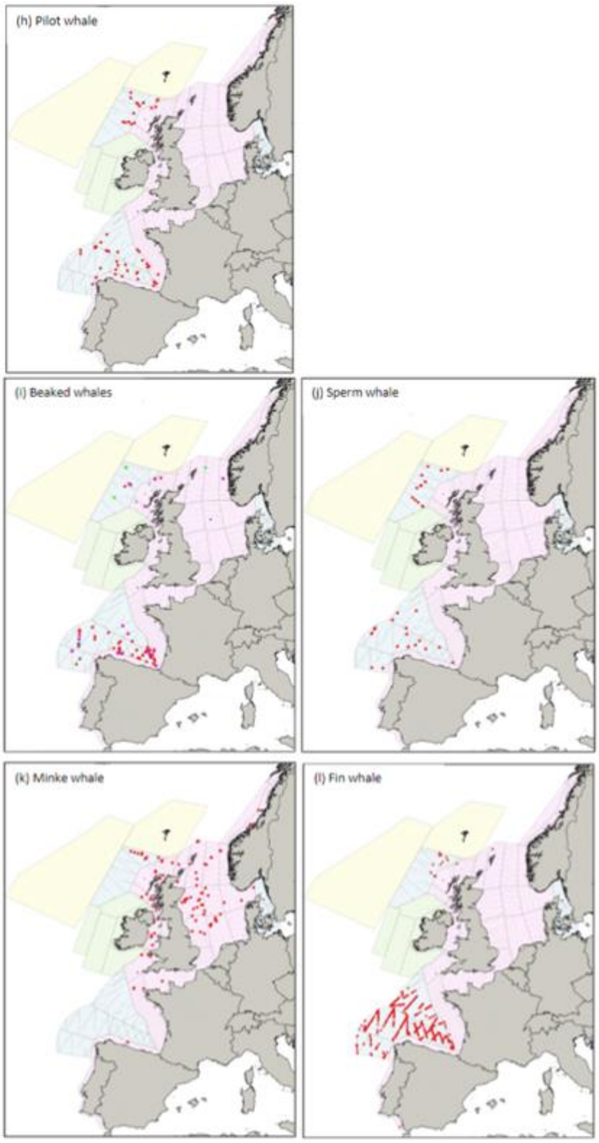


Figure 11: Locations (red dots) at which h) Pilot whales, i) Beaked whales, j) Sperm whales, k) Minke whales and l) Fin whales can be found (Hammond et al., 2017).

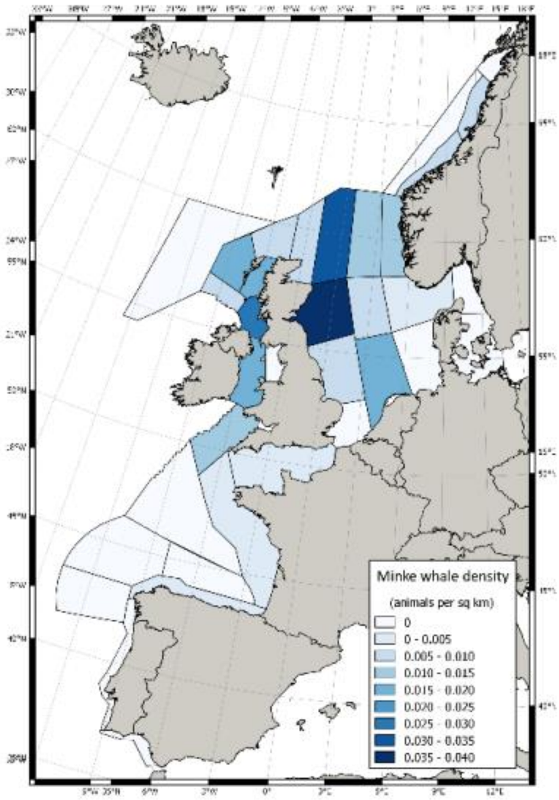


Figure 12: Average minke whale distribution as calculated by Hammond et al. (2017). Right below is a scale of the density of minke whales per square km.

Since minke whales grow up to about 7-8 metres with a max size of 9-11 metres, they will be unable to swim through the turbines. The question arises whether this poses a threat to this species, or whether the few minke whales in the area can adapt. When the DTP-dam steers these sorts of whales towards shallow waters of the North Sea, or Wadden Sea, it might pose as a threat. Expert knowledge and research may help reveal the extent of the 'problem' and help create possible mitigation solutions.

It is likely, however, that the few minke whales in the area swim around it or turn when they reach shallow waters. An option to steer minke whales around the dam is to use sonar, although this is yet not allowed since it will interfere with marine activity. Other comparable options are not yet investigated but should be given further consideration.

7.2. Birds

Birds in the North Sea can be subdivided into pelagic birds, which travel and migrate over long distances above sea, and coastal birds, which have a smaller action radius. Coastal and pelagic birds are not evenly distributed across the North Sea. The distribution is determined by abiotic factors such as depth (accessibility of food), distance from the coast and the presence and quality of food (Rozemeijer et al., 1999). Each season the need and therefore the distribution of a bird species changes. During the breeding season, the distribution is also determined by the presence of a suitable breeding area. The DTP-dam, a huge structure where birds could rest, could act as a breeding ground and a source of food.

The density of birds along the coast is relatively high almost the entire year, but especially in the summer period it is much higher than the density of births after the 20-meter depth line of the North Sea. The DTP-dam will be situated after the 20 m depth line. There is a chance the dam will alter the current distribution patterns of birds.

Since the DTP-dam is situated over 60 kilometre out of the coast, the question arises whether pelagic or coastal bird species will use the DTP-dam as a breeding place, as resting stop, or as feeding ground, or if they will simply ignore it. If the DTP-dam will function as a breeding ground depends not merely on the suitability of the location (e.g food availability), but also on the natal and breeding dispersal distance of certain bird species. This is how far birds are known to nest in relation to their birth ground (natal dispersal), as well as the movement from one breeding site to another (breeding dispersal). It is likely that more opportunistic pelagic species like the Great Comorant (*Phalacrocorax carbo*), that are known to breed far from their original place of birth (Vasile et al., 2001-2003). On the other hand, pelagic migratory species like the Arctic Tern (*Sterna paradisaea*) might simply ignore the DTP-dam or only use it as a resting/feeding place on their immense migratory route and not settle, whilst Dutch coastal species as the Velvet Scooter (*Melanitta fusca*) likely do not have the distribution range to even reach the DTP-dam (Jansma & van Ulzen, 2014).

However, new food areas further out to sea (e.g. fishing activities) can then be reached by birds through the aid of the DTP-dam. However, when the DTP-dam is situated in a windfarm-area, birds may be threatened by these turbines themselves as well through lethal hits and movement obstruction Aarts, B., & Bruinzeel, L. (2009). It should therefore be considered that there is likely to be a trade-off in birds that are drawn towards the DTP-dam for beneficiary factors as shelter and birds being threatened by windmills. Since the structure is only partly situated in a windfarm in our proposition, this problem doesn't account for the whole DTP-dam-area.

On the structure itself, moreover, birds will most definitely forage on grown vegetation, insects, waste, etcetera. The structure of the DTP-dam will also provide food in the form of benthic animals, fish and more. The DTP-dam might prove especially vital in the aid of the Wadden Sea sandbanks for species moving over the East Atlantic Flyway, one of the largest migratory routes on earth (Figure 13). Currently the Wadden Sea helps at least 36 migratory species on their route as feeding, breeding or resting ground (Van Roomen et al., 2017). Often numbers, of e.g. benthivore species, like Eurasian Oystercatcher and Black-headed Gull, have declined both in the Wadden Sea and in the overall flyway, with the rate of decline being faster in the Wadden Sea. Three other benthivore species; Common Eider, Pied Avocet and Common Ringed Plover, all declined in the Dutch Wadden Sea although they increased at the flyway level (Van Roomen et al., 2017).

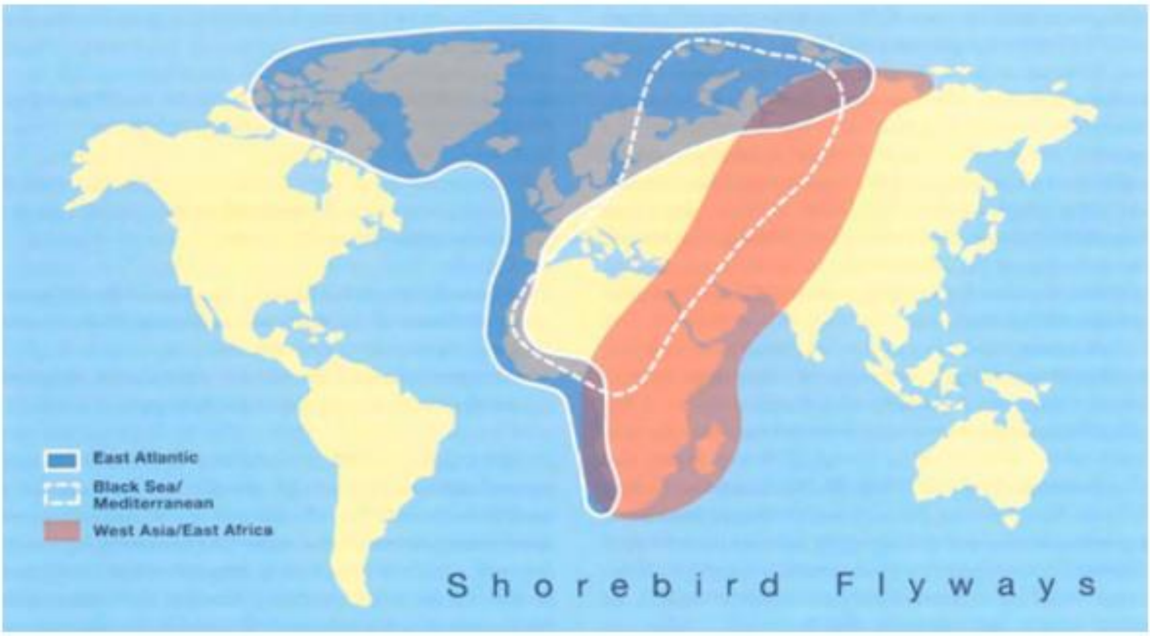


Figure 13: The three flyways in the African-Eurasian region as based on migratory shorebirds (Delany et al., 2009)

In conclusion, the DTP-dam could help counter the ongoing trend of some migratory bird species declining due to (among other things) urbanisation, fishery and wind farms, by providing extra resting, feeding and breeding space and could provide extra foraging and breeding area for local coastal species as well.

8. Nursery habitats

8.1. Current nursery habitats south North Sea

Nursery habitats are important marine areas where juvenile fish grow to maturity. They are typically shallow coastal waters of less than 10m in depth with sandy or muddy substrate seabed (Hufnagl et al., 2013). These areas support the recruitment and survival of a variety of species in the local ecosystem (Amara et al., 2007) therefore, when building the DTP-dam, it is important to minimise any disruption or degradation of them as this could negatively affect the important fish stocks within the North Sea.

The construction itself has the potential to disrupt the biological functions of the sea. These functions are influenced by changes in the sea's physical state, such as; temperature, salinity, wind and currents. It is important to understand how any changes in these states may affect important fish stocks in the area as they are all interconnected and will potentially be influenced by the introduction of the dam.

Overall, the North Sea has been experiencing a warming of temperatures since 1989. It is a deep sea with inflows from the Atlantic Ocean and to a lesser extent, the English Channel, resulting in deep waters with low temperatures. This has been changing in recent decades as a result of a warming climate (Teal et al., 2008). Temperature is a key factor which influences the development and location of both juvenile and mature fish. Increasingly there is a trend of fish moving away from shallow coastal nurseries due to an intolerable increase in temperature, and instead being found further offshore in deeper, cooler areas of water. Therefore, in previous years the offshore location of the dam could have been assumed to have little effect on nursery habitats, but as the nursery functions are now being sought in deeper waters, this may be a future concern.

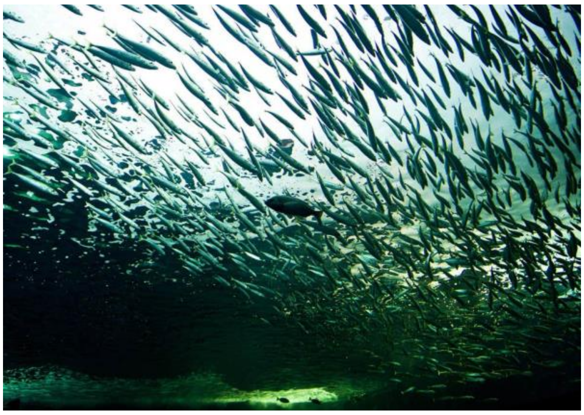


Figure 14: Soure Google images

8.2. Impact DTP-dam on nursery habitats

The different habitats are often far apart. Fish use several mechanisms to find and recognize those different areas. In general, there are three different mechanisms: - Imprinting (e.g. salmon) - Learning from older fish (e.g. plaice) - Genetically recorded information (e.g. plaice). In addition to the internal, basic mechanisms (which serve as a rough guide), the fish has incentives and signals from the environment that indicate that a certain habitat has been reached. These are often external stimuli: light, temperature, salinity, food availability, flow and turbulence or water pressure. Fish probably use the the variable with the steepest variable. Although this should be interpreted in a nuanced way: plaice, for example, does not use salinity as an incentive, while in the coastal zone there is a steep salinity gradient. In addition, bodily stimuli can also play a role (Rozemeijer et al., 1999).

When assessing whether the DTP-dam has effect on nursery habitats, it is important to review whether the exogenous stimuli are influenced with regards to abiotic factors such as temperature or nutrient availability.

As earlier mentioned, increasingly there is evidence of fish species being found in deeper waters than previously expected, this is thought to be the result of increasing temperatures in coastal waters. An example of an important fish stock moving away from its traditional locations can be seen with the North Sea cod (*Gadus morhua)*. This species increasingly been found in more north-eastern areas with deeper water and lower temperatures. The northward shift is thought to be related to increasing temperatures off the coasts of England and Scotland, while the Eastern movement is theorised to be in reaction to increased fishing pressure in these areas (Engelhard et al., 2013).

The cod has not only experienced changes in location, but also in abundance. The last few decades have seen a decline in this important species, with its lowest ever spawning biomass being recorded in the 2000s of just 50,000t (ICES, 2015). This was thought to be due to near equal level of fish mortality from fishing, resulting in the stocks being unable to recover sufficiently (Huserbråten et al., 2018).

In theory, the dam could offer a solution to the threat imposed by intense fishing in this area. Its construction in the western part of the sea, if no fishing is permitted along it, may allow some stocks to return to this area as they take advantage of this protection.

Figure 15: North Sea Cod (AP Images/European Union EP).

Currently, however, the stocks are fragile and any other possible disruption to their population should be examined carefully. One possible point for consideration which could be influenced by the dam would be the connectivity between their new nursery areas and their spawning grounds

A study undertaken by (Munk et al., 2009) found that the main spawning locations of fish are linked to hydrographic feature, such as salinity fronts, which may present favourable feeding conditions. Physical processes related to these fronts may then in turn confine egg and larval dispersal and transport them towards suitable nursery habitats (Munk et al., 2009). Cod eggs are predominantly found near the Fisher Bank area, and South of the Dogger bank. As the Dogger bank is in proximity to the proposed site of the dam, the potential for the dam and its construction to block the flow of eggs to northern nursery habitats should be considered.

Another important species of fish for North Sea fishing are flatfish such as sole (*Solea solea)* and plaice (*Pleuronectes platessa).* For sole, the temperature increase within the North Sea has been found to result in a positive growth trend. Combined with increased food availability, in the form of polychaetes exposed by intense bottom trawling (Rijnsdorp & Vingerhoed, 2001), the stocks of this species have not been grievously depleted by previous developments in the North Sea. Therefore, we could further assume the dam would also have limited negative effects upon them.

In the case of plaice, a negative growth trend is associated with rising temperatures. Since before the 1980's there has been an evident shift of younger plaice into deeper waters, similar to the cod. This is known as an offshore shift, evidence of which has been seen in the lack of success surrounding the introductions of plaice boxes along the traditional coastal nursery areas (Van Keekenet al., 2007).

Previously the nursery habitats of sole and plaice were found in the south-eastern coastal areas of the North Sea (van Beek et al., 1989), away from the dams proposed location. Today's movement away from these areas to deeper spawning waters may result in juveniles looking for areas to settle further offshore than before (Rijnsdorp & Van Beek, 1991). In this case, the addition of the dam with the associated creation of shallower waters could then provide nursery habitat to fulfil this function, mitigating any disruption the initial construction may have caused.

Lack of predators upon flatfish has also facilitated migration into deeper waters. As species which previously would have preyed upon the flatfish are caught through trawling, they now are able to further inhabit deeper waters. Upon introduction of the dam, there predators may return (Daan et al., 2005), ensuring there is not a monoculture of species in the surrounding area.

As habitats for juvenile fish are linked to three sets of physical features: nutrient rich areas as a result of upwelling and tidal mixing, (ii) convergence or frontal areas, and (iii) retention or drift areas around appropriate habitat (Munk et al., 2009), the dam has the possibilities to fulfil all of these. The placement of the dam in deep offshore waters with maximum tidal power would coincide with areas of upwelling and tidal mixing, while the dam itself with varied structures and materials could then provide a habitat for species. The additional benefit of the limited possibilities for fishing on and around the dam increase the positive impacts associated with its construction which seem to outweigh the current negatives.

To conclude, it could be assumed that despite the possible disruptions to tidal transport of larvae and juveniles, with suitable structures and habitat conditions created on and around the dam, most negative effects could be mitigated. The potential for the dam to provide habitat for a variety of species, if established correctly, has potential to improve the biodiversity of the area surrounding the dam.

8.3. Impact of hard structures

Since no DTP-dam has ever been built before and there are next to no analogous constructions, it is hard to compare the DTP-dam to similar developments. In this report, we chose to examine other hard structures, such as wind farms, offshore rigs and platforms for oil and natural gas extraction (hereafter called "rigs"), and artificial reefs. Although the DTP-dam scale mean is differing from these structures, we will look at similarities between hard structures put in the North Sea. All structures are solid, made of concrete or similar products, and provide similar services to the biodiversity. This section refers to research question 4 and explores the potential and threats of a hard structure of this scope in the North Sea and the effects on the design.

Figure 16: Abandoned oil rig hosting marine life (Bureau of safety and environmental enforcement).

8.3.1. Impact of hard structure on biotic environment

A hard structure will have an impact on the local food web in the area and the energy flow within this food web. This is because the hard structures attract species that settle on hard substrates. For example, habitat builders like oysters, seaweeds and mussels may attach. North Sea jellyfish like the moon jellyfish (Aurelia aurita) are likely to use the substrate to attach to when growing as planula towards polyp and jellyfish cyst. Macrobenthos species like starfish are likely to settle on the bottom of the structure, where sediment accumulation increases the benthic zone. These organisms fertilize the surrounding soil, thus increasing the organic matter in this area, which in his turn enhances the macrobenthos species again. In terms of biodiversity a higher abundance in infauna (animals living inside the seafloor), of bristle worms, bivalves (molluscs, including oysters and muscles) and crustaceans (Posey et al., 1994) is formed. Predatory species (usually fish) will be attracted by the increase in food. All of this together will greatly impact the local food web. This effect is called the artificial reef effect (Dannheim et al., 2018). An example of the enhancement of local biodiversity is found in Gabon where a non-functioning oil platform was used as a study site (Friedlander et al., 2014). The new fish species made up 34% of the recorded species and the total estimated biomass exceeded one ton at some locations. The dominant species on these locations were barracuda (Sphyraena spp.), jacks (Carangids), and rainbow runner (Elagatis bipinnulata).

An important aspect of the DTP-dam's structure is that it extends from the bottom of the sea to the water surface. A hard structure will attract in new species, because it provides a living opportunity for species that were previously restricted to coastal areas (Dannheim et al., 2018). In a research on the effects on hard structures in the North Sea it was found that Man Made Structures (MMS) can provide habitat for new species and connect species that were separated before. Furthermore, it can also connect populations of native species, which can now use the dam as a steppingstone. However, it fuels competition between native and exotic or invasive species too (Dannheim et al., 2018). At least one possible invasive species, snowflake coral (Carijoa riisei), has been witnessed in the area. They compete with the native species for space and food and can disrupt the food web. This indicates the high uncertainty with regards to how the expected increase in biomass in the ecosystem will result in positive and negative systematic changes.

8.3.2. Comparison with offshore wind farms

Wind farms and other hard structures in the North Sea are predominantly dominated by algae (Bouma and Lengkeek, 2012). In terms of fish the following species are found most: the semi-demersal whiting (Merlangius merlangus), the sand-dwelling dab (Limanda limanda), and sand eels (Ammodytidae spp.). In the research by Stenberg et al. (2015) these fish made up to 88% of the catch. Another animal that is sometimes found in wind farms is the invasive marine splash midge (T. japonicus). The splash midge can have advantageous and disadvantageous impacts on the ecosystem, influencing the food web either way. On the one hand they can be beneficial since they can be a food source for birds and other insects in winter. Migrating water birds use the splash midge as an important food source. On the other hand, a too wide distribution of this midge may cause harm to native species. The splash midge has high capacity in colonizing new areas and thrives well in harsh environments. The splash midge was, among others, an alien species of which was thought that it had disappeared. But around Man-Made structures in marine environments they are again observed (Kerckhof et al., 2007). The main reasons for the reoccurrence of those species were shipping and aquaculture (Brodin and Andersson, 2008). It will be of interest to monitor this species around the DTP-dam.

Since wind farms and the DTP-dam both have a structure which extends from the seafloor up to the surface the underwater communities around it can develop on the same depth levels. However, an important difference is that windmills stick out in the air quite high. Concerns have risen around possible influences on migrating birds. In contradiction, the DTP-dam might be able to serve as a rest place for migrating birds. Another huge difference between the DTP-dam and a wind farm is the connectivity. It has been observed by Stenberg et al. (2015) that in OFWs (Offshore Wind Farms) new communities are emerging in very close proximity to the individual turbine foundations. Between the turbines, the sandy areas were similar to the sandy areas outside the wind farms (Stenberg et al., 2015). When the DTP-dam is implemented this will be totally different. Since the dam will be a very large connected structure a lot of movement and spreading along it is possible. This has a positive impact on species that need the area as a steppingstone, such as kelp and jellyfish. However, it can also mean that invasive species are not dammed and could potentially spread faster and further.

8.3.3. Comparison with other offshore hard structures

Different offshore infrastructure projects have shown that there are environmental benefits in having hard structures offshore. For example, old oil rigs are not towed away completely but are used to enhance the ecosystem, enhancing local biodiversity and providing reef habitat. Also, leaving the rigs in place protects the location from trawling and the seabed from being disturbed (Fowler et al., 2018). Beside structures which ended up in the North Sea for a non-ecological purpose there are also artificial reefs implemented in order to enhance biodiversity. A small-scale example of this is the fish hotel designed by Tinka Murk (Murk, 2019). These fish hotels consist of pipe like structures of different sizes with several holes in it. The structures can be connected to each other so they form some sort of reef. It is an innovative and interesting design which can also be created using for example old rain pipes or roof tiles. Biodiversity is best enhanced when there are different shapes and sizes present so a lot of different species can find shelter (Murk, 2019).

The question arises whether these structures can function as steppingstones for native and non-native species. Bouma (2012) found that several non-native species were found on the hard substrate north of Scotland. The species Japanese skeleton shrimp (Caprella mutica) and the marine midge (Telmatogeton japonicus) were found in the highest abundances (MBA, 2019). In the Dutch North Sea, the most abundant species on hard structures were Japanese skeleton shrimp and the crustacea species Jassa marmorata (Bouma, 2012).

An often-heard argument in the debate around artificial reefs is the production-attraction hypothesis (Bohnsack, 1989). These are two opposing hypotheses (see Figure 17). The attraction hypothesis states that the fish in artificial reefs are merely being attracted away from natural reefs, depleting those. This is expected mostly to happen at the stage of larvae through settlement redirection. Movement for fish in older age-classes is less usual. The production hypothesis advocates the other way around and states that artificial reefs increase production by providing alternative habitats for fish which were normally living in habitats that are saturated (Wilson et al., 2001).

If suitable habitat is the main limitation for a fish species to flourish, bringing in artificial reefs can be beneficial. In a research conducted by Polovina and Sakai (1989) the catch per unit effort of the Pacific giant octopus (Octopus dofleini) increased when artificial reefs were put in the Japanese waters, but the catch per unit effort of the flatfish (Pleuronectidae) stayed the same. This suggests that the octopus population was habitat limited, and the flatfish population could have been recruitment limited. This was also thought because the year-class strengths fluctuated a lot each year regardless of the available habitat (Macreadie et al., 2011).

The graphs in Figure 17 visualise that with the attraction hypothesis the total amount of production does not increase since the animals are drawn from one location to the other. In the production hypothesis, the artificial reef merely provides extra habitat and the total production increases with a larger artificial reef.

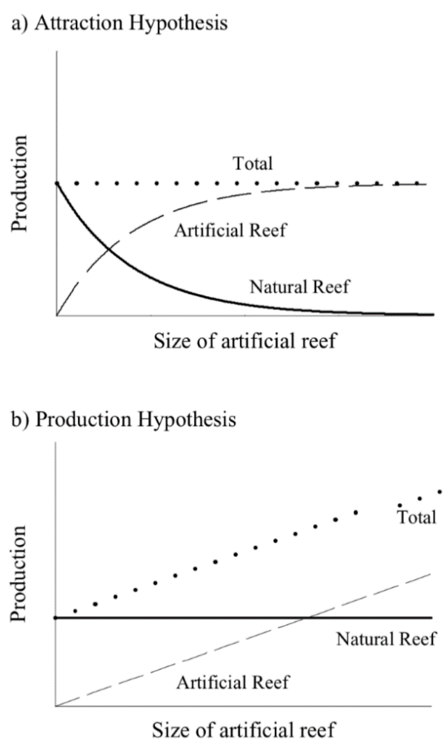


Figure 17: The attraction hypothesis (a) and the production hypothesis (b). With the attraction hypothesis the amount of production stays the same. With the production hypothesis, however, the total production increases.

In the case of a DTP-dam in the North Sea, we expect that the production hypothesis is in place. The DTP-dam will provide habitat which will increase biomass and certain fish populations will grow. The North Sea is fished quite heavily at this moment, as only 0.6% of the North Sea is not being trawled at least once a year (Vrooman et al., 2018). Due to all the bottom trawling the seafloor is empty and no habitat provision is present anymore.

8.3.4. Conclusion and recommendations on impact of hard structures

The DTP-dam will have a huge impact on biodiversity. As a very large hard structure, it can be a safe haven for a large amount of native and non-native species. This can have positive and negative influences. The enhancement of the biodiversity will be a great advantage, but non-native species can pose a threat. They can take over a large part of the newly formed ecosystem. Still, this does not have to be a bad influence from every point of view, it can be positive from a fishery perspective. However, it is advisable to keep track of what species increase in number and what their effect on the food web is. How much the DTP-dam can enhance biodiversity will greatly depend on the design of the dam (Murk, 2019). To create living spaces for different animals the dam should have a varied structure. Differently sized coves can offer hiding places for different kind of fish. Also overhanging structures are recommended to implement to offer a hiding place for the bigger fish species. A sufficient and cost-effective example to provide shelter is to place (old) existing structures such as pipes and roof tiles on the seabed floor and attached to the dam. Another important aspect of the design of the dam should be sheds, because under these different fish and benthic species can make shelter.

A difference between wind farms and the DTP-dam will be that the DTP-dam can function as a steppingstone for species that cannot migrate between the turbines of the wind farms, which are far apart from each other. The dam will create the possibility for them to migrate. This is of beneficial value to e.g. lobsters (Murk, 2019).

9. Aquaculture

The area around the DTP-dam might be suitable for multi-use with other marine activities. In this chapter we will identify the possibilities for aquaculture and investigate its economic potential. Since offshore wind farms are growing in the North Sea and take over a substantial area, a multi-use of wind farms with other maritime activities is of high interest these days. The research done on multi-use of wind farms is comparable with the multi-use of the area around the DTP-dam, also since the DTP-dam will be in a wind farm. After a literature study and several pilot studies for the possibilities of aquaculture in wind farms, it is shown that mussel cultivation has the highest potential in the future. Seaweed cultivation also appears to be promising, but currently faces some processing related challenges. Finfish culture is found to be limited in the North Sea (Jansen et al., 2016). Since mussel and seaweed cultivation seem to have the highest potential offshore, we decided to mainly focus on the possibilities for these around the DTP-dam. Aside from these two species, we also investigated oyster cultivation and possibilities for sea ranging around the dam.

Since the dam will function as an artificial reef it will attract several species and enhance the biodiversity, as was discussed in previous chapters, and then may provide options for regulated sea ranging or passive fishing activities.

9.1. Mussels

9.1.1. Current mussel cultivation

Currently in the Netherlands mussel cultivation takes place in the Wadden sea and Eastern Scheldt. Mussel cultivation starts with catching seeds with a so-called mussel seed capture installation. A mussel seed capture installation consists of nets or ropes which are suspended in the water. Mussel larvae attach to the nets and ropes and juvenile mussels will then mature. The mussels will grow to about one to two centimetres before they are harvested and transported to a different location where they can grow to their full size and are ready for consumption. After the mussels have reached one to two centimetres there are two options for further cultivation: bottom culture and suspended culture. With bottom culture the mussels are moved to a sand bank where the mussels can further develop. When growing on the seabed the mussels will develop a thicker shell and grow at a slower rate than those in suspended culture. When using the suspended culture (also called hanging culture) the mussels are hung on lines. When measuring one to two centimetres, they will be thinned out to create space for other individuals to grow further by being transferred to new ropes. In the hanging culture the shell will remain thinner and the mussels will contain some more meat. Also, no cleaning is needed after harvesting as the mussels are not in contact with the seabed. In both the bottom and suspended cultivation, the mussels totally rely on natural resources for food, spat and space and are expected to reach market size in 15 months (Buck et al., 2010).

9.1.2. Offshore mussel cultivation

In the North Sea several pilots for offshore mussel cultivation within a wind farm have been executed. As the North Sea can be quite rough (wave height up to 12 m), it turned out that only the hanging culture is suitable for mussel cultivation offshore (Jansen et al., 2016; Buck et al., 2010). The dam can provide a somewhat quieter place in between the two V-shaped areas which will create better circumstances for maintenance and harvesting. Van den Burg et al. (2017) and Buck at al. (2010) found that a simple, semi-submerged (5-7 m below the surface) longline structure will be suitable for offshore use, but with the restriction that the water depth should be at least 20 m (Figure 18). At a depth of 5 –7 m the system will be below the strongest wave activity. The system will consist of floating buoys/cylinders, below which continuous looped lines will hang on which the mussels grow. The whole system will be anchored to the seabed. Buck et al. (2010) suggest that it is best to not restock the mussels once they reached one to two centimetres, but to just thin them out. The mussels which are removed by thinning out can be used for further cultivation in the Eastern Scheldt or Wadden sea. The mussels which remain on the lines will grow until they reach market size and can be harvested.

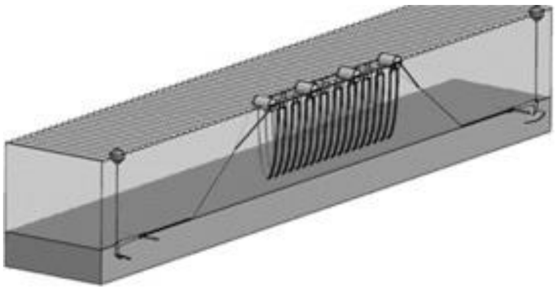


Figure 18: Visualization of a semi-submerged longline structure for offshore mussel cultivation (Buck et al., 2010).

When using longlines for mussel cultivation it can provide shelter for other invertebrates. Several species might be able to find refuges from predation which will increase the biodiversity around the cultivation areas (Jansen et al., 2016). When the mussels are on the semi-submerged longlines at 5 - 7 m depth predation by birds or starfish will be reduced and mussel larvae will be able to settle (Buck at al., 2010). Furthermore, mussels are found to be able to clear the water of their surroundings. While feeding, they filter the water of contamination, in this way they can then enhance the visibility which can increase biodiversity. A downside of the high filtration capacity of mussels is that if the water around the DTP-dam is very polluted for whatever reason, the mussels will also be polluted and may not be suitable for consumption anymore (Riisgård, 1991; Timmermann et al., 2019). However, the DTP-dam is not expected to produce contamination.

9.1.3. Recommendations

So far, only pilots for mussel cultivation within windfarms have taken place and no big mussel cultivation project is started yet. The wind industry is not taking the lead in creating multi-use areas and the mussel industry is significantly smaller which makes it questionable if they can finance such a project (Jansen et al., 2016). The DTP-dam creates new opportunities for multi-use with mussel cultivation, but a pro-active attitude of both parties involved is needed. We also expect that mussel cultivation in between the V-shaped areas of the DTP-dam will be favourable compared to in between a windfarm. In between the V-shaped areas the water will be less rough which will make maintenance on the mussel cultivation area easier. Also, the V-shaped areas will provide protection against stormy conditions, so the risk of losing mussels during storms is decreased. In order to point out the exact benefits of mussel cultivation in between the V-shaped areas a modelling study on flow dynamics and wave height around the DTP-dam is suggested. The depth of the sea seems suitable in the current situation, although the DTP-dam might influence sediment transport. Erosion and deposition spots might form in the dam's surroundings. The outcomes of the modelling study on sediment transport (as suggested in the chapter about morpho dynamics) will be needed as well, in order to see what can be expected concerning water depth in the V-shaped areas in the years after implementing the DTP-dam.

9.2. Seaweed

Seaweed cultivation is a new development, with ongoing investigations to identify which species are best suitable for cultivation. Seaweed cultivation is very popular in Asian countries, of the worldwide produced seaweed 75 – 85 % is used for human consumption in Asia. Seaweed comes in a variety of different species. Some research has been done on the possibilities of seaweed cultivation. The first pilots were run in basins on land, later moving into the Eastern Scheldt and then offshore. Seaweed cultivation is beneficial for the environment. It removes excess nutrients from the sea, attracts marine live and increases biodiversity. It also has the capacity to capture heavy metals. A negative associated with seaweed cultivation could be the potential for shading, turbidity and sedimentation. A challenge will be the competition with Asian seaweeds on the market which can be heavy, but if seaweed produced in the North Sea can claim to be more sustainable this can create a beneficial value. Seaweed produced in Asia has a high environmental impact since a lot of fertilizer is used (Jansen et al., 2016). Sea weed is very useful in making a shift from dairy products towards plant-based proteins. It can be a very interesting product in becoming more sustainable (Jansen et al., 2016).

New markets are coming up, in the Netherlands already some seaweed-based products are on the market. Seaweed is high in protein and is now increasingly used in pastas, mayonnaise, seasoning mixes, cheese and burgers. The Dutch Weed Burger is on the market since 2012 and produced from seaweed grown by a Dutch farm in the Eastern Scheldt. Also, some Dutch companies are creating hybrid burgers which consist of meat and seaweed (Jansen et al., 2016). Seaweed becomes increasingly important when thinking about the growing world population and the ongoing climate change. It can be produced at sea which saves a lot of space on land, and when produced in windfarms in which fishing is prohibited it will not be affecting any other marine activities. Seaweed is healthy, a good source of proteins and iodine and low in calories.

9.2.1. Recommendation

Seaweed cultivation seems a promising business since it can fulfil the upcoming need of being more sustainable and at the same time it increases biodiversity and cleans the sea water. But not enough is known yet to be able to implement a seaweed cultivation field within the V-shaped area of the DTP-dam right away. Currently it is not known yet which species, for example, are the most beneficial in terms of ecology and economy. In the current situation offshore seaweed cultivation is not yet economically feasible, but there is a promising future for it (Van den Burg et al., 2016). Since the DTP-dam is supposed to be ready around 2030, there are some years left in which more research to the feasibility of offshore seaweed cultivation can be done. We recommend investigating the opportunities for seaweed cultivation since it can become an important ingredient of our future food system.

9.3. Oysters

Oysters are, beside mussels, an interesting shellfish species for cultivation. In the Netherlands the oyster cultivation has always been present but on a much smaller scale than mussel cultivation. Most oyster cultivation takes place in the Eastern Scheldt but due to a predator in the Eastern Scheldt and a disease the oyster business is not doing well currently. Bottom culture is not as successful as it was in the past. Growing mussels on tables in shallow water is taking over (Balkenende, 2019).

9.3.1. Wild oysters

In the past in the North Sea the European flat oyster (Ostrea edulis) occurred over quite extensive areas in natural bottom cultures. Since almost the whole North Sea is bottom trawled (Vrooman et al., 2018) only very few areas in which the flat oyster can be found are left. However, the fact that still some flat oysters can be found suggests that growth reproduction and dispersal in the North Sea are still possible (Kamermans, 2018). The existence of flat oysters in the North Sea is mostly on hard structures, which are mostly artificial, for example shipwrecks and windfarms. Recently a new natural oyster reef with flat oysters and Japanese oysters formed near Brouwersdam. Wageningen University and Resource (WUR) is investigating how this could happen and if this reef can sustain by itself (Kamermans, 2018). Furthermore, WUR is working on oyster reef restoration. Oyster reefs form when oyster spat settles on hard substrate, for example stones, shipwrecks or oyster shells. Oyster shells in existing beds are a preferable settling substrate for oyster spat. Due to this process oyster beds sustain themselves. Oyster beds are important for the overall functioning of the ecosystem. They create reefs with 3D structures which give shelter to up to 250 different species (Smaal et al., 2015) and create nursery habitats, spawning places, food sources and a substrate on which other species can attach. For example, a soft coral species (dodemansduim) can attach to oyster beds. Furthermore, oyster beds enhance fish production, water quality, seabed stability and coastal protection (Kamermans, 2018). Oysters feed themselves with plankton.

Once the oysters were removed from the North Sea it is difficult for them to return. The small number of oysters make the chance for reproduction very small. Since 2016 WUR has two projects in which they implement artificial reefs with flat oysters attached to it. Besides this several thousands of kilos oysters are dropped around the artificial reef combined with shell material which can be used as a substrate to attach to as well. This project is executed in the Gemini windfarm and in the Voordelta (Sas et al., 2016). After the first results it turns out that the oysters are doing well, the reef is growing and reproducing, and the biodiversity in the Voordelta is increasing. These results look promising and show that there might be opportunities for oyster restoration around the DTP-dam. The DTP-dam can function as a hard structure to which oysters can attach.

9.3.2. Oyster cultivation

Since flat oyster is known as a high-value product, Pogoda et al. (2011) investigated the possibilities for offshore oyster cultivation within windfarms. They also researched the difference between the growth rate of the native European flat oyster and the introduced Pacific oyster. Oyster doesn't require artificial feeding and can even improve water quality in marine systems. The oysters were reared in small oyster lanterns (Figure 19) which were connected to the hard structures of windmills or the piles of a former research platform. All oysters showed a positive growth rate and very high survival rates were found (>99%). The native European oyster showed slightly better results than the Pacific oyster. The high survival rates show that it is no problem for the oysters to be in the deeper waters of the North Sea. In the deeper waters less plankton is expected, but the higher hydrodynamic flow can compensate this. This study concludes that the offshore cultivation of flat oyster will be possible.

Figure 19: Oyster lanterns.

9.3.3. Recommendations

Around the DTP-dam there might be possibilities for oyster restoration as well as for oyster cultivation, although the later needs more research to find out how feasible it exactly will be. Oyster cultivation in lanterns might be possible in between the V-shaped areas of the DTP-dam. As described above the growth rates are good offshore and the oysters will clean the water. This seems positive but the exact costs for maintenance offshore needs to be investigated. Regardless if oyster cultivation will be executed or not, we recommend restoring natural oyster beds. The possibilities for oyster restoration seem to be good since the dam will function as an artificial reef to which the oysters can attach. It might also be worth to overthink the possibilities of putting some hard structures or shelf material on which oysters are attached in between the V-shaped area as is done in the Gemini windfarm by WUR. This might enhance the restoration of oyster beds even more.

9.4. Sea ranging around the DTP-dam

Besides the possible cultivation of mussels, oysters and seaweed there might be possibilities for regulated fishing, or so-called sea ranging, around the DTP-dam. Since the dam will enhance the ecosystem and create a larger biodiversity, a growth in biomass around the dam is expected. For example, lobster and crab fishing can be a possibility. These fisheries are not practiced by using nets, but by using pots. These pots are placed on the bottom of the sea in order to trap lobsters or crabs. Lobsters and crabs are baited to enter the pots, where they will be trapped once they enter. After a certain time, the pots are hauled out of the water by means of a line that connects the different pots (Waterdance Ltd., n.d.). Since lobsters and crabs move in between sheltered areas, the DTP-dam might turn out to be a beneficial structure for lobster and crab populations. As has previously been described in this report, the DTP-dam could provide possibilities for habitat (in combination with fish hotels) for these species. This might potentially benefit lobster and crab populations around the dam. This shows that the dam could potentially enhance possibilities concerning lobster and crab fisheries.

Since the dam will provide habitat for more species than only lobster and crab regulated fishing around the dam for certain species can become a possibility. Regulations need to be strict and a safe space around the dam in which fishing is not allowed is recommended in order to minimalize disturbance which will favour biodiversity. Further research to which species can be expected and are suitable for fishing is needed. Also, an investigation on how to make regulations which make sure the biodiversity will not be affected by fishing and overfishing of a certain species will not happen needs to be done.

9.5. Economic potential

Three potential different kinds of aquaculture are discussed. These are mussels, oysters, and seaweed. Mussels and oysters seem to be the most profitable options. Van den Burg et al. (2016) state that it is not economically viable to produce seaweed offshore in the North Sea yet. Doing a sensitivity analysis, they showed that revenues have to increase by approximately 300% to make a profit. Further research should investigate possibilities to profitably produce seaweed offshore in the North Sea.

We propose to perform aquaculture in the V-shaped area of the dam. Since the exact size of the DTP-dam is not yet known, we assume that the V-shape tails are both 20 kilometres. The degree of this angle is assumed to be at least 60 degrees and at maximum 90 degrees. This corresponds to a surface range of approximately 4,8 km^2 inward + outward. In the estimation of the economic potential of each of the different aquaculture practices, we assume that the whole area is used for a monoculture of this particular practice. The goal of this analysis is to show the potential of different species for aquaculture in the V-shaped area of the DTP-dam.

9.5.1. Mussels

Van den Burg et al. (2017) researched the possibilities of a business case for mussel aquaculture in offshore wind farms in the North

Sea. They state that mussels have the potential to be commercially cultivated in offshore wind farms in the North Sea. Since there is no data on mussel cultivation on and around the DTP-dam, we assume that their results also apply to mussel aquaculture on and around the DTP-dam. In this analysis, we focus on the harvest of consumption-sized mussels only, so neglecting the seed and half-grown mussels harvest. Van den Burg et al. (2017) state that the consumption-size harvest of mussels after 21 months is 37.504 kg/ha. Since the range that we use for the surface of the V-shaped area is 4,8 km2, which is 480 ha, this corresponds to a total harvest of 18 million kilograms around the V-shaped area. The average mussel price is €1,12 (Wageningen Economic Research, 2019). So, this results in a total harvest value € 20 million. This is a large number. However, this is not a realistic estimate, since we assume the V-shaped area to be fully used for just mussel cultivation, which leads to large numbers. Whereas in reality, for example, space for boats for maintenance will be needed.

9.5.2. Oysters

As has been described in this report, oysters could potentially be a viable option for aquaculture in the V-shaped area. Besides the wide array of services oysters provide, they are also a valuable resource to harvest. Grabowski et al. (2012) estimated the harvest value of oysters in North Carolina. Even though this setting is, of course, not exactly the same as it is with the DTP-dam, we assume that it is. They divided oyster harvest values in two categories, a pristine reef and a degraded reef. As a matter of comparison, we extrapolate the values concerning a degraded reef since this resembles the situation around the DTP-dam more than a pristine reef. They found that the average oyster harvest value of a degraded reef is €2.375 ($2.6391) per ha, corresponding to a net value of €792 ($880). The net value of course depends on the characteristics of the company executing the cultivation. Since the range that we use for the surface of the V-shaped area is 4,8 km2, which is 480 ha. Using the numbers for a pristine reef, you would obtain a large result again. Namely a value of €46.095 ($51.217) per hectare, corresponding to a total harvest value of € 22 million. Again, this is not a realistic estimate due to the assumption that the total V-shaped area will be used for oyster cultivation.

It turns out that mussels and oyster both have potential to be an economically viable option for aquaculture in the V-shaped area of the DTP-dam. However, further research about practical issues should indicate the exact amount of space that can and/or should be used for aquaculture.

10. Effect DTP-dam on fisheries

10.1. Dutch fisheries

The Dutch fisheries sector consists of several subsectors. These consist of (1) great sea fisheries; (2) cutter fisheries; (3) other small sea fisheries; (4) mussel culture; and (5) oyster fisheries (Wageningen Economic Research, 2019). Table 1 provides an overview of each subsector's total revenue and corresponding net profit in 2018.

Table 1: Overview of economic performance of different Dutch fishery subsectors over 2018. Based on Wageningen Economic Research (2019).

Economic performance / Sector	Total revenue (in million euros)	Net profit (in million euros)
Great sea fisheries	128	16
Cutter fisheries	310	54
Other small sea fisheries	14.09	5.52
Mussel culture	51	4
Oyster fisheries	-	-

10.1.1. Great sea fisheries

Great sea fisheries represent the fishing activities executed by trawlers. Trawlers are fishery ships that fish using a funnel-shaped net. The Dutch great sea fisheries currently consist of seven trawlers. The main fish species being fished by the great sea fisheries are blue whiting, herring, mackerel, horse mackerel, sardine, sardinella. In 2018, the total amount of fish caught by the great sea fisheries was about 317 million kilograms. This corresponded to a total revenue of €128 million and a net profit of €16 million (Wageningen Economic Research, 2019).

10.1.2. Cutter fisheries

Cutter fisheries represents the fishing activities executed by so-called cutters. Cutters are ships that have a relatively low stern. In 2018, there were 289 active Dutch cutters in the cutter fisheries. The main fish species being fished by the cutter fisheries are plaice, sole, brill, turbot, tub gurnard, goatfish, squid, mackerel, cod, shrimps, langoustines. In 2018, the total amount of fish caught by the cutter fisheries was about 71 million kilograms. This corresponded to a total revenue obtained by the cutter fisheries was €310 million and a net profit of €54 million (Wageningen Economic Research, 2019).

10.1.3. Other small sea fisheries

Other small sea fisheries consist of fishing activities using a fishing rod, gill nets, fish pots, small trawls and shellfish fisheries. This is a small subsector, consisting of 225 ships. The main fish species being fished by the other small sea fisheries are razor clams, sea bass, sole, shrimps, mullet and other sea fish. In 2018, the total amount of fish caught by the other small sea fisheries was 9 million kilograms. The total revenue of the other small sea fisheries amounted to €14.09 million and a net profit of €5.52 (Wageningen Economic Research, 2019).

10.1.4. Mussel culture

As its name already indicates, mussel culture focusses on the exploitation of mussels. Currently, there are 53 Cutters in the Dutch mussel culture. Dutch mussel culture takes place in the Wadden Sea and the Eastern Scheldt. In the 2017/2018 season, the total amount of mussels caught by the (at that time) 52 Cutters, was 44 million kilograms. This corresponded to a total revenue of €51 million and a net profit of €4 million (Wageningen Economic Research, 2019).

10.1.5. Oyster fisheries

The Dutch oyster fisheries are a relatively small subsector. The subsector focusses on two different kinds of oysters, these consist of the Japanese oyster (Zeeuwse creuse) and the flat oyster, which are produced in the Oosterschelde and in Grevelingen respectively. In the 2017/2018 season the oyster fisheries caught 20.7 million Japanese oysters and 7.5 million flat oysters. This clearly shows that the Japanese oyster amounts for the major share of oysters. Since there is no reliable data concerning the cost and revenue structure of the oyster fisheries, there are no estimates concerning the total revenue and net profit of this subsector, as can be seen in Table 1 (Wageningen Economic Research, 2019).

10.2. Potential effect of DTP-dam on fisheries

As has previously been stated in this report, it is assumed that the dam will be built in the wind energy area "IJmuiden Ver'' in the North Sea, which has a surface of approximately 1.170 km2. The area is supposed to be ready for usage in 2027 (Rijksoverheid, 2018). According to Dutch law, it is not allowed for ships to pass through these wind farms (only for maintenance), thereby automatically excluding fishery activities in that area. However, since the construction of the wind energy area has not yet started, there are fishery activities taking place now. The major fisheries activities taking place in IJmuiden Ver are cutter fisheries. The gross added value originating from IJmuiden Ver as a share of the total gross added value by the Dutch cutter fleet on the Dutch continental shelf accounts for 0.60%. In 2017, 191 tons of fish was caught. The yearly average gross added value of the cutter fisheries in the area was €350.000 over the period of 2010-2017. This corresponds to an average gross added value of €853 per km^2 (Mol et al., 2019). For our reference case, it is assumed that there are no fishery activities taking place because it is not allowed according to Dutch law. Therefore, we assume that building the DTP-dam will not have a direct effect on fisheries.

On the other hand, the DTP-dam could have some indirect effects on fisheries. As the results in this report show, the DTP-dam could potentially positively benefit the marine ecosystem which may lead to an increase in fish stocks in the area around the DTP-dam. This might provide some spill-over effects. Spill-over effects are effects that unintentionally occur in another area than the treated area, which in this case is the area around the DTP-dam. Since fish stocks in the area of the DTP-dam might be positively affected by the DTP-dam, this could lead to an improvement of fish stocks in the surrounding areas outside IJmuiden Ver. Since these surrounding areas will be accessible to fishing ships (providing that these areas are free of regulation concerning fisheries), fishing activities could benefit from this situation. However, when discussing such potential effects, the ''Plaice Box'' scenario pops up. In 1995, a certain area in the Northern North Sea was closed for large trawlers in order to reduce the discarding of plaice. It turned out that this decision had adverse effects, since plaice landings and biomass declined (Beare et al., 2013). This situation therefore shows that there is no guarantee that such decisions are effective, it is possible adverse effects occur. Therefore, such potential adverse effects are something that should be considered when researching the effects of the DTP-dam on fisheries.

Furthermore, the DTP-dam could potentially enhance possibilities concerning lobster and crab fisheries in the surrounding area. For the dam to provide additional benefits for the fisheries sector, it could be useful to research possibilities for lobster and crab fisheries to be allowed in the area, even though it is a wind energy area. Since lobster and crab fisheries are less detrimental for the marine ecosystem because it does not harm the sea bottom as much as trawling does, it could potentially be possible for these fisheries to exist in the area without having significant negative effects on the marine ecosystem. However, regulation of these fisheries is necessary to ensure the ecosystem is not to be negatively affected. Further research should indicate what types of regulation are most suitable for this situation. Note that lobster and crab fisheries are two different kinds of fisheries, but the fishing methods are quite similar.

11. Ecosystem Services Assessment (ESA)

11.1. Background to ecosystem services

This section will involve an overview of the ecosystem services provided by marine ecosystems. Furthermore, certain ecosystem services that are most relevant to this project are assessed.

Alcamo et al. (2003, 53) define ecosystem services as "the benefits people obtain from ecosystems''. These 'services' include both tangible and non-tangible benefits. MEA (2003) divided the ecosystem services into four categories, consisting of (1) supporting services; (2) provisioning services; (3) regulating services; and (4) cultural services.

Alcamo et al. (2003, 59) define that "supporting services are those that are necessary for the production of all other ecosystem services". The impacts of supporting services on human well-being are indirect, whereas changes in the other services have a more direct effect on human well-being. Provisioning services are the tangible products that people obtain from ecosystems, examples of these are timber, food, medicines. This makes provisioning services relatively easy to identify as compared to other services. Regulating services are the benefits that people obtain from the regulation of certain ecosystem processes. Examples of regulating services are biological control, water regulation, climate regulation. At last, Alcamo et al. (2003, 58) define cultural services as "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences''. Cultural services are closely related to human values and behaviour. This in turn impacts how people value these different services.

11.2. Relevance for the DTP-dam

The North Sea is one of the busiest seas in the world, leading to considerable risk of further ecosystem damage (Vogel et al., 2018). Fishing, shipping, military, raw material exploitation and nature protection all utilize the area. Growing demand for renewable energy usage will only intensify this, an effect currently demonstrated by the expansion of offshore wind farms (Beaumont et al., 2007).

Increased spatial demand is a ramification of this growth and in turn necessitates well informed marine spatial planning. Awareness of the ecosystem services that an area provides supports this planning and allows plans to be drawn up that effectively guide (policy) decisions. Identification of these services and whom benefits from them can reduce the risk of conflict arising between ecological, social, and economic interests (Vogel et al., 2018). Neglecting services that an area provides could potentially lead to environmental damage, increased management costs and social unrest.

There are many similarities between large scale infrastructure developments and the construction of the DTP-dam in the North Sea. Offshore windfarms are of particular interest. Many questions have arisen around the long-term effects of these projects. Whilst construction disrupts ecosystems and the services they provide, it has been found that the long-term effects can vary, with some areas, processes, properties and services being more sensitive than others (Burkhard et al., 2011). It is thought that the foundations of these wind farms can provide habitats for biodiversity and increase the associated services. However, there is still uncertainty around this due to a sparsity of data (Burkhard et al., 2011).

Many of the services provided by the wind farm can be related to the DTP-dam whilst the scale of the project means many additions impacts and synergies are possible. This necessitates an analysis of the broad effects the construction will have, and which services will be most affected. An ecosystem service assessment provides a concise and easily communicable summary of these impacts upon the ecosystem services. This has the potential to be a useful tool in portraying the repercussions of the development to policy makers and stakeholders. In addition, it provides a framework for summarizing ecological and social impacts.

11.3. Ecosystem services present in the area

A paper on the ecosystem services in the North Sea identified 23 ecosystem services that were present (Vogel et al., 2018). Another paper identified 13 related services that were provided by marine biodiversity, the article went on to identify which were present at seven case study sites (Beaumont et al., 2007). Although the sea off the coast of the Netherlands was not studied, the Belgian part of the North Sea was, and is, in most relevant ways, analogous to the area we are focusing on during this study (Beaumont et al., 2007). The services identified in these studies were summarized and condensed into the following list (Table 2) that formed the basis for our ESA.

Table 2: Overview of ecosystem services provided in the North Sea. Based on Vogel et al., (2018); Beaumont et al., (2007)

Ecosystem Service	Description
Food Supply	The marine flora and fauna extracted from unmanaged environments or aquacultures that are used for human consumption.
Water Supply	The marine water (i.e., saline, brackish, and freshwater) that is abstracted from the water column and aquifers for human consumption and for use in industrial and economic activities.
Genetic Resources	The genetic material from marine organisms that is extracted for nonmedical, nonfood purposes.
Medicinal Resources	The material that is extracted from or used in the marine environment for its ability to provide medicinal benefits.
Raw Materials	The marine material that is extracted for human nonfood uses.
Fossil Hydrocarbon Resources	The fossil organic materials exploited from marine subsurface reservoirs.
Renewable Energy	The use of the marine environment for the generation of renewable energy.
Storage	The use of marine subsurface natural fractures and pores and artificial structures for storage purposes.
Condition for Infrastructure	The use of marine environments for the foundation and protection of infrastructure.
Transportation	The use of waterways for commercial shipping.
Weather Regulation	The regulation of local weather conditions by marine ecosystems.
Air Purifications	The regulation of the concentration of physical and chemical substances in the lower atmosphere by marine ecosystems.
Climate Regulation	The regulation of the concentration of climate-active gases by marine environments.
Water Purification	The removal of physical, chemical, and biological substances from seawater by marine ecosystems.
Nutrient Cycling	The natural cycling processes leading to the availability of nutrients in seawater that produce organic matter.
Coastal Protection	The protection of humans and the built environment against extreme events, such as storm floods and coastal erosion.
Regulation of Water Flows	The contribution of marine ecosystems to the maintenance of localized coastal current structures.
Biological Self-Control	The contribution of marine ecosystems to the maintenance of population dynamics, resilience through food web dynamics, disease and pest control.
Lifecycle Maintenance	The habitat that marine organisms and communities provide for a healthy and diverse environment, including viable gene pools.
Recreation and Tourism	The opportunities that marine ecosystems provide for relaxation and leisure or amusement.
Aesthetic and Cultural Perceptions and Traditions	The individual and societal associations with and emotional responses to the marine environment itself in traditions, art, and religion.
Cognitive Development	The generation of knowledge and technological development resulting from researching marine environments.
Sea Scape	The emotional benefit attached to the marine environment without physical use.

This table gives an overview of the diversity of services provided by the marine environment. Although many are not relevant for this project, it is important that an understanding of this range of benefits is maintained when approaching large scale infrastructural projects such as this. For example, if future developments for DTP were planned closer to the coast the ramifications for recreation and tourism, cognitive development, sea scape, aesthetic and cultural perceptions and traditions, and the regulation of water flows could be significant. Looking further into the future, continued development of these kind of marine projects could have substantial influence on our conception of the ocean, carving up the commons for human management and privatization. Acknowledging these implications will be important for future success.

11.4. Key Ecosystem Services

11.4.1. Food provisioning

Beaumont et al. (2007, 256) define the ecosystem service food provision, related to marine ecosystems, as ''the extraction of marine organisms for human consumption.'' This corresponds to fisheries and activities such as aquaculture and sea ranging. This ecosystem service is relevant to this project, since as we have described in our report, there are some possibilities for sea ranging since the DTP-dam could enhance the marine ecosystem, for example by providing nursery habitat. Thereby also having an indirect effect on fisheries. Furthermore, the design of the dam allows for potential possibilities for sea ranging as well.

In the reference case, we assume that no fishing activities or other activities are taking place in IJmuiden Ver. This means that the food provision is zero. However, as we have described, there are fishing activities taking place at the moment. In 2017, 191 tons of fish was caught in IJmuiden Ver. Furthermore, over the period 2010-2017 the average gross added value of fishing activities in IJmuiden Ver was €350.000 per year. This corresponds to an average gross added value of €853 per km2. The differences between the different years were substantial, leading to a standard deviation of €50.000 per year. The corresponding highest and lowest value were €670.000 and €220.000 per year (Mol et al., 2019).

As has been mentioned in the report, the DTP-dam could provide possibilities for aquaculture sea ranging. Van den Burg et al. (2017) researched the potential of mussel cultivation in offshore wind farms in the North Sea. They state that after 21 months, 37.504 kg/ha of consumption-size mussels can be harvested. With a mussel price of €1,12 per kg, this corresponds to €42.004 per hectare. For oysters, Gabrowski et al. (2012) researched the harvest value of oysters and the ecosystem services they provide. They state that the harvest value of oysters is €2.375 ($2.639) per ha for a degraded reef, and a value of €46.095 ($51.217) per hectare for a pristine reef. Besides aquaculture, sea ranging can also contribute to the amount of food the ecosystem provides. Therefore, the ecosystem service food provision will probably increase compared to the reference case, if the DTP-dam will be built.

11.4.2. Genetic resources

There is currently no seed stock or genetic resources gathered in the area. Trawler fishing means biodiversity is negligible and spawning species have no hard structures to settle upon. This lack of hard structures also prevents the area from being used for nursery habitats.

As previously highlighted the dams structure provides an opportunity for mussel aquaculture. The proposed technique would involve frequent thinning of the mussel lines and therefore more consistent revenue. Part of this process is the harvesting and selling of seed stock that can then be sold to other aquaculture projects. The is the only quantifiable genetic resource from the development, however, it is likely that other species that settle on the structure could provide value. Oysters and seaweed species may also offer similar services, but these have not been quantified. Although bioprospecting can yield genetic resources of commercial and academic value in the deep sea (Leary et al. 2009), it is unlikely that significant value will be gained from the establishment of hard structure habitat around the dam.

11.4.3. Renewable energy

The ecosystem service renewable energy is relevant to this project, since the main purpose of the DTP-dam is to generate renewable energy. Furthermore, IJmuiden Ver is an area that will become a wind farm, generating wind energy. This shows that renewable energy is an important ecosystem service in our project.

In the reference case, the expected production of renewable energy by means of wind turbines in IJmuiden Ver is 4 gigawatts (Rijksoverheid, 2018). Once the DTP-dam is built, it will contribute to the amount of renewable energy that is generated in the area. We assume that the dam will be 50 kilometres long and that the current flowrate in IJmuiden Ver is 0.9 meter per second. This corresponds to a generation of approximately 11 gigawatts per year (Humsterland Energie, 2019). Both the wind energy and tidal energy combined will then amount for 15 gigawatts per year.

11.4.4. Water purification

Locating the DTP-dam offshore means pollution will be minimal in comparison to coastal areas where runoff from agriculture and other industrial activities would be an issue. In addition, the water depth and strong current prevent the accumulation of chemical and particles. There is, however, evidence that concentrations of organic chemicals in the sediment are above the permissible threshold (Klamer et al., 2005). Evidence of the water quality in the location is lacking, however, and presumably difficult to quantify because of the currents. In order to accurately quantify the filtration services provided, further research in the location is necessary.

Certain shellfish, namely mussels and oysters, are filter feeders and purify water by feeding on the contained sediments and nutrients. Mussels ability to remove nutrients contained in particles, predominantly phytoplankton, and convert them to tissue growth is well documented (Timmermann et al., 2019). A study modelled this effect on Danish coastal waters and found that mussels could potentially lower chlorophyll concentration by 30% and light attenuation by 14% (Timmermann et al., 2019), meaning the water transparency is increased, this can be beneficial to photosynthetic species. Whilst sediment concentration was 6% lower surrounding the farm, it was 14% higher within the farm due to the excrement that gathered below the mussel lines (Timmermann et al., 2019). This may have additional benefits to the primary production around the dam and is discussed further in the section on nutrient cycling. Despite the efforts to quantify this service the wider effects of mussels upon the surrounding environment are complex and difficult to assess (Timmermann et al., 2019).

Additionally, seaweed can lower the levels of nitrates in, and extract carbon from the water body, thereby reducing the effects of eutrophication and sequestering carbon (Kim et al., 2017). Average nitrogen content of the five most commonly farmed seaweed species is 3.26% (Kim et al., 2017). The average carbon content is 31.8% (Kim et al., 2017). Whilst purification services supplied by the aquaculture species are the most quantifiable, in theory these services are also provided by any increased biodiversity that the structures support. All flora will sequester carbon and filter feeders will consume particles.

11.4.5. Nutrient cycling

The process of stratification in the area limits the availability of nutrients for phytoplankton. This reduces the overall productivity of the ecosystem. The presence of the DTP-dam will influence nutrient availability. There is evidence that it will increase the overall productivity of the surroundings. Bivalves will feed upon particles in the water and the nutrient rich sediment they excrete will provide food for a variety of organisms and potentially increase nutrient availability for primary production (Jansen et al., 2018). There is a high level of uncertainty around this claim, however, as filtration from bivalves can both depress and stimulate phytoplankton production (Jansen et al., 2018). Ecosystem dynamics are hard to predict, but the increased biodiversity predicted from the presence of the hard structure is likely to reduce stratification and increase nutrient cycling from the sediment.

11.4.6. Biological self-control

Biological control is the service organisms provide by reducing the population density of other organisms (Lenteren, 2006). The absence of biological control can lead to the proliferation of pest species and therefore, by definition, damage to either the environment or surrounding structures (Lenteren, 2006). In a natural ecosystem the risk of this happening is dramatically reduced by the presence of high numbers of species that prey upon natural pests, this is referred to as natural biological control and helps maintain abundant and diverse ecosystems (Lenteren, 2006). This can be further described as "The contribution of marine ecosystems to the maintenance of population dynamics, resilience through food web dynamics, disease and pest control" (Hattam et al., 2014). Suitable habitat increases the production of predators and competition which increases biodiversity and strengthens biological communities (Hattam et al., 2014).

Human activities in the marine environment can influence this natural biological control in many ways. Transport, fishing and aquaculture can spread invasive and pest species (Atalah et al., 2014). They can also reduce populations of predators and competition thereby creating an environment that is more exposed to pest proliferation. By this logic, trawler fishing can remove and destroy habitat and leave an environment that is largely devoid of biodiversity and exposed to exploitation by only select generalist species. This kind of practice can therefore be said to leave the ecosystem dangerously fragile. This is the state of the area planned for the construction of the dam, it offers little in the way of natural biological control.

Given the sparse habitat currently provided by the area there is little chance that the DTP-dam will significantly damage important habitat. It is, however, likely to provide structure for a variety of species. As is the case with artificial structures such as marinas, ports, and piers, mussels and other sessile organisms will proliferate on the DTP-dam (Atalah et al., 2014). These shellfish then provide food and refuge for small crustaceans and macroinvertebrates (Draget, 2014), such as lobster. Proliferation of these species then provide a food source for a greater diversity of species, including valuable fish species. Drawing analogies from other hard structures, an estimated 7.4 tons of mussels and 100 kilograms of small crustaceans and polychaete worms had developed on the Egmond aan Zee offshore wind farm (Draget, 2014). The planned incorporation of mussel and seaweed aquaculture with the DTP-dam would increase these effects by providing increased habitat and food for prey and predator species, these, in turn, will feed upon pest species that may otherwise thrive within the farms. In short, the DTP-dam may bolster the natural biological control around it. On the other hand, there is a risk that the structure may provide a stepping-stone for pest species to grow (Atalah et al., 2014), ensuring diverse habitat is provided within the structure will reduce the risk of this.

11.4.7. Lifecycle maintenance

Vogel et al. (2018, 4) define lifecycle maintenance as "the marine habitat that marine organisms and communities provide for a healthy and diverse environment, including viable gene pools". This ecosystem service is of relevance to this project, since the DTP-dam will contribute to an overall enhancement of the ecosystem due to the different functions it provides, such as habitat provisioning for several species. For example, mussels are found to attach to the hard structures, such as the DTP-dam. This in turn does also affect the ecosystem and different species in the particular ecosystem, like small crustaceans and macro-invertebrates. In an offshore windfarm at Egmond aan Zee, a significant development of hard substrate species was found. This contributes to the overall food availability and habitat provisioning (Draget, 2014).

So, as compared to the reference case, the ecosystem service lifecycle maintenance is expected to increase after the construction of the DTP-dam.

11.5. ESA Table

Ecosystem Service	Indicator	Identified in area	Value (€)	DTP-dam	Value (€)
Food Provision	KG Catch per Ha	Current fishery activities are focussed on flatfish. (191 tons in 2017)	Average of €21.72 per ha yearly	The area will provide a certain amount of food through aquaculture. This is in place of the previous fishing activity taking place. In addition, sea ranging activities will take place leading to an increase in harvest of species such as lobster and crab.	Mussels: €42.004 per ha. Oysters: €2.375 - 46.095 per ha.
Genetic Resources	No. caught per Ha	There is no seed stock currently caught in the area.	Not present	Seed stock will be supplied if mussel aquaculture is implemented in the area.	€21,500 per ha.
Renewable Energy	KW per Ha	The area is used for wind power production. Currently 4 GW are extracted from the wind farm per year.	4 GW * electricity price	The area will be used for producing tidal energy as well and wind, resulting in generation of 15 GW per year.	15 GW * electricity price
Water Purification	Particle removal per Ha	Pollution in the area is minimal as string currents and deep waters minimise accumulation. Concentration of certain organic chemicals, however, may be high in the sediment.	Not currently quantifiable	Mussels (and other bivalves) have multiple effect on the water purity. They are likely to lower chlorophyll concentration and light attenuation but increase the amount of sediment.	Not currently quantifiable
Nutrient Cycling	Nutrient conc.	There is only limited availability of nutrients in the area due to high levels of stratification. Nutrients and sediment remain in the benthic layer.		Difficult to predict due to a confluence of different factors. It is, however, likely to increase due to greater overall productivity and nutrient availability from mussels.	
Biological Self-Control	Occurrence of pest species Species diversity	Present only in very minimal amounts due to the denuded nature of the ecosystem.	Not currently quantifiable	Likely to increase, particularly around the hard structures where bivalves can settle. Additional sediment can stimulate increased biodiversity and resilience. On the other hand, proliferation of pest species around mussel farms and hard structures is a risk and should be observed and minimised.	Not currently quantifiable
Lifecycle Maintenance	Species abundance Nursery habitat Populations of larvae or juveniles	There is some minor transport of larvae and genetic material such as cod eggs in the area, but the location does not contain any particular features for lifecycle maintenance.	Not present	The habitat provisioning from the hard structures is likely to increase the number of lifecycles maintained in the area. This will predominantly be for bivalves, but other invertebrates may also inhabit the surrounding areas and use them to breed and spawn.	Not currently quantifiable

12. Discussion

In the discussion, the overall findings and conclusions are evaluated. Assumptions that were made are highlighted and underlying reasoning substantiated. The discussion can be read as an overall evaluation of the outcomes, as well as in-built self-criticism when necessary.

In the first part of the report a range of stakeholders were identified. Emails were sent out asking relevant actors if they would be willing to discuss the DTP-dam with us, in order to understand their interests in a more detailed way. Unfortunately, following some follow up phone calls, we received only two replies and subsequent interviews. Visned and Good Fish Foundation were the stakeholders interviewed. This gave a limited view of the actual opinions of the stakeholders, but it did provide us with some valuable insights into two differing points of view upon the project. Therefore, though our primary information was limited we did get some understanding of a strongly opposed actor and strongly supportive actor.

For examination of the environmental and socio-economic impacts, a location was first determined by analysing the expected impact of the Dam on sediment transport and coastal protection. The current sediment transport routes in the North Sea are quite well known, but how these would be impacted by such a large is difficult to predict. We selected a reference case we deemed to be as reliable and comparable as possible, but as it was published in 1999, it may have some limitations.

The reference case used found that there may be negative effects associated with a large structure extending from the coast, therefore in the case of the Dam we decided an offshore location would be more suitable. Having decided this, we then further determined that the DTP-dam should be placed in IJmuiden Ver windfarm. From this location the dam will cause the least disruption to shipping and fisheries activities.

Upon identifying a suitable location for DTP-dam we began by identifying possible effects upon the ecology of the North Sea. The current status of the ecosystem of the North Sea was examined, and a general overview created. Subsequent effects associated with the introduction of the dam could then be determined. Some key functional groups and their key species were identified.

However, since a thorough ecosystem description of the area would require a separate report, our examination should be viewed as a general overview. Our limited timeframe justifies the generalization of functional groups but, for the future of this project, further identification of vulnerable key species in the ecosystem is recommended.

We expect, from literature research and expert consultations, that the ecosystem's primary production will increase due to the placement of the DTP-dam and its associated impact on light and nutrient availability. Increases in substrate, nutrient and light availability will most likely promote the settlement of habitat builders such as seaweeds, filter feeders and benthic species, which form a fundamental base layer for a healthy ecosystem.

Noise and chemical pollution were found as possible threats to the local ecosystem. It is expected local noise pollution will occur, but when regulated sufficiently may not cause extensive harm to the systems functioning. A similar conclusion can be drawn for the pollution by organic, chemical, or plastic compounds from construction materials used for the DTP-dam. Furthermore, in order to mitigate this issue further, a monitoring station for water quality could be added to the DTP-structure to help to counter any current or future pollution.

The ecosystem investigation and the impact the DTP-dam will have on it is closely related to the chapter about nursery habitats and hard structures. We found that no nursery habitats are currently found in the proposed area for the DTP-dam, but it could become important in the future as species seek deeper, cooler waters in which to inhabit. From consultation with Tinka Murk we gained information about the functioning of artificial reefs and their impact on biodiversity, which we then further researched. It was determined that the DTP-dam could provide extensive habitat for a variety of species. For this to be possible, the structure of the dam is very important. Sheds, pipes and coves should be placed in and near the dam to provide this habitat. Though this is in general a positive development, native species may find themselves out-competed by non-native invasive species, therefore monitoring of this habitat may be necessary.

The report also assesses the dam's effects upon migratory species. The migratory patterns of smaller cetacean species were found to cross the location of the DTP-dam, but since the turbines are very big (8 m) we think the dam will not be a problem. The small cetacean species will be able to swim through the turbines; therefore, it will not be a lethal threat to them. Bigger species such as Minke whales, which are often found in the waters around the proposed location, may face some difficulty so this should be monitored to ensure they do not become stranded in shallow waters.

It was then decided to explore the possibilities for aquaculture upon the dam. Given the findings of increased biodiversity to be expected, we decided it would be best to look for native species for aquaculture practices. Mussel and oyster cultivation were deemed to be the most suitable, due to the pollution associated with fed finfish systems, and the current pilot studies being run with these species in windfarms. These pilot studies on offshore cultivation of oysters and mussels show good results and we expect that the results within the V-shaped area of the DTP-dam have potential to be more positive. The water will be sheltered which will allow easy maintenance and decrease losses due to storms creating conditions not only suited to the raising of shellfish, but also seaweed. As we recommend the DTP-dam to be built in the wind farm where fishing is currently prohibited it was concluded that there will be no current direct effect upon North Sea fisheries. However, this conclusion may be presumptuous, as there are currently discussions to allow certain fishing activities within wind farms.

The possibility that the entire DTP-dam will not fit in a wind farm should also be considered, requiring possible revision of the dam's design to allow fishing and/ or fit within the parameters of the windfarm.

Concerning the ecosystem service assessment, studies were used that examined the ecosystem services in the North Sea. Due to a lack of specific information about the area in which we wanted to place the dam, the ecosystem service assessment created is a general overview, instead of an in-depth assessment. Most of the ecosystem services are qualitatively assessed, with some quantified using data which we selected as applicable within our study site too. Therefore, in order to do a more specific ecosystem service assessment, more research is needed on the actual ecosystem services in the area and how these will be affected by the DTP-dam.

Overall, we created a broad overview of the impacts of the DTP-dam on the North Sea's ecology and fisheries, and the potential of aquaculture within the dam itself. This report can therefore provide a base from which more in-depth analysis can be done in order to gain a deeper understanding of the impact such a construction will have.

13. Conclusion

To conclude, we have summarized the main findings in order answer to our research questions. The overall main research question was: "***What are the potential environmental impacts of the DTP-dam and its socio-economic consequences?",*** further divided into eight sub questions.

1. *Which location will be best suitable for the DTP-dam concerning sediment transport in the North Sea?*

It is advised to place the DTP-dam partially within the 'IJmuiden Ver' –windfarm. Here the negative expected impacts on coastal protection and a biodiversity loss in the Wadden Sea are mitigated, almost no sedimentation transportation will be altered.

2. *How will the current state of biodiversity in the surrounding area of the DTP-dam be affected by the DTP-dam?*

The total biodiversity surrounding the DTP-dam is expected to increase, due to cascading positive effects created by the provision of substrate and shelter for varying functional groups in the ecosystem and a small expected increase in light availability. Expected negative impacts like chemical- and noise pollution are limited in comparison to the positive effects.

3. *What will the influence of the DTP-dam be on patterns of migratory fish and other animals in the North Sea?*

The DTP-dam will have limited impact on migrating small cetaceans (dolphins and whale species), since they can swim through the submerged turbine vents. However, the movements of the larger species (minke whale) should be investigated, since they are observed to appear in small numbers in the nearby area and might be limited in movement once the DTP-dam is built. Migratory birds that move over the migratory route of the East Atlantic Flyway are expected to be positively affected by the DTP-dam through provision of a resting- as well as feeding grounds and possibly a breeding spot. The impact on migratory birds is bird species specific.

4. *What is the potential of the DTP-dam to provide nursery habitats through, among other things, hard structure design?*

Fish maturing in shallow coastal waters are increasingly being found further out to sea, meaning that the DTP-dam may find itself utilized as a nursery habitat as species seek deeper, cooler waters. The DTP-dam will mostly provide space for varying local marine species to mature, shelter, and generally inhabit. This effect is exasperated due to the extensive size of the construction which can connect different biotopes and function as steppingstone for species such as lobsters. The enhancement of the biodiversity will be a great advantage, but non-native species can pose a threat as they might become too dominant. It is advised to monitor species development. Hence, it is important that the dam is designed to include structures to accommodate the changing need for nursery habitat and to provide new habitat for species already found in the area.

5. *Which ecosystem services are provided and influenced in the surrounding area of the DTP-dam?*

There are a few main ecosystem services that are currently provided in the area. *Food provisioning* already occurs through fishing but can be enhanced through the positive effects the DTP-dam has on the environment and through possible aquaculture practices. However, assuming that fishing is not allowed, there will be

changes in the volume and species. *Renewable energy* is provided in large amount by the DTP-dam. The local output will be increased immensely. This can be added up with the energy already provided by the wind farm. *Water purification* in the area can be enhanced when filter-feeders like mussels and oysters attach to the DTP-dam. *Nutrient cycling* can be enhanced, as the increased biodiversity predicted from the presence of the hard structure is likely to reduce stratification and increase active redistribution of nutrients in the area through the food web. *Biological control* that naturally occurs through balancing processes within healthy ecosystems, may be bolstered by the DTP-dam through its positive effects on highly fish species like cod.
On the other hand, there is a risk that the structure may provide a stepping-stone for pest species to grow. The ecosystem service *Life Cycle Maintenance* obtains contributions through the DTP-dam's positive impact on overall food availability and habitat provisioning.

6. What are the main stakeholders involved within the frame of the DTP-dam project's influence on marine life?

The main stakeholders identified that operate within the domain of the marine ecosystem are: The government of the Netherlands, Humsterland Energie, the EUCC International Secretariat in Leiden, the Netherlands Wind Energy Association, Stichting de Noordzee, VisNed, the Good Fish Foundation, the Marine Stewardship Council, the Aquaculture Stewardship Council and the organization Sportvisserij.

7. What fisheries take place in the area where the DTP-dam will be built and how will these be affected by the DTP-dam?

The major share of the fisheries that take place in the area are cutter fisheries. The yearly average gross added value of the cutter fisheries in the area was €350.000 over the period of 2010-2017. However, since the DTP-dam will be built in a wind farm area, the direct effect on these fisheries is assumed to be zero. Indirect effects could be positive in the outside areas due to spillover effects.

8. What types of aquaculture systems would be best suited to the conditions of the DTP-dam and the local ecosystem, what are the economic potentials?

The best suited species for aquaculture are mussels and oysters. Both species are native species in the North Sea and research has shown that offshore cultivation is economically feasible. Furthermore, sea ranging for lobster and crab is possible as the dam will enhance their presence. Creating strict regulations for all types of cultivation and fishing around the dam is recommended to prevent overexploitation.

Overall, the report tentatively concludes that the negative ecological impacts of the dam will be minimal, whilst the potential for improving ecosystem health in the surroundings is high and could provide considerable conservation benefits. In addition, with well-planned management, there is scope for stimulating economic growth through the provisioning of space for aquaculture and the increase in high value stocks for passive fishing of species such as crab and lobster.

Looking towards the future and the realization of this dam, it is evident that the project impacts a wide spectrum of actors. It currently lacks powerful support and has economically and politically influential opposition. Planning how development can be adapted to find mutual gains between different forms of energy production, powerful industry and investment will be key for the future of the DTP-dam. Mapping out the interests of these parties and ensuring they are considered is imperative.

Round tables, workshops and discussions with the networks who support and oppose the project will aid future developments and enable conflicts to be minimized early on.

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Appendix

A. Stakeholder interview questions

Interview questions -

Below are some examples of questions that we may ask during an interview.

1. Before we approached you, had you heard of Dynamic Tidal Power?
2. Describe your attitude towards the project?
3. Could you identify any positives you associate with this project?
4. Could you identify any areas of concern?
5. What, in your opinion, are the key impacts the DTP-dam could have upon your sector?
6. What are your opinions on the following projects?
   - Intensive Aquaculture Projects – For example, The Barbé Mussel Farm, produces 10% of Dutch mussels from an area of beds along the Dutch coast.
   - Gemini Wind Park Netherlands - The largest offshore wind park in Europe, built 85 km off the coast of the Netherlands. This park produces sustainable energy for 800.000 households.
   - Doggersbank – Natura2000 area. 473.500Ha of sand banks in the North Sea that protects a wealth of biodiversity and species such as stingray and anchovy.
   - The Maasvlakte 2- An extension of the original westward extension of Rotterdam Port known as the Maasvlakte. It creates a new port and supporting infrastructure on reclaimed adjoining land. Approximately 2000Ha will be reclaimed, with 1000Ha to be used by port related industries.
   - Afsluitdijk- a dam and causeway in the Netherlands. It is 32 kilometres in length and a width of 90 metres. It is part of the larger Zuiderzee Works, which dammed off the Zuiderzee. This saltwater inlet of the North Seas was then turned into the freshwater lake of the IJsselmeor which now provides flood protection.
7. Have you had any previous experience with similar developments? Please describe if so?
8. Have you ever had interactions with government at any level? If so, could you describe the reasons for the interaction?
9. Could you please identify any actors from the following sectors with whom you have interacted?
   - Humsterland Energie
   - Rijkswaterstaat
   - European Union
   - Energy companies (NUON, ENECO, ESSENT, VATTENFALL or Other)
   - Shipping sector
   - Aquaculture sector
   - Wind energy lobby (NWEA)
   - Fisheries
   - (Environmental) NGO's (Nordzee Schichting , EUCC, or Other)
   - TenneT
   - Local communities
   - Electricity consumers (Industry, Public)
   - Ministry of Defense
   - Construction companies (Cleantech Holland, Bluestream Offshore etc)
   - Ecologists
   - Dam engineers (technical researchers)
10. Could you please name the specific actors (organization, company etc.) and describe the interactions?
11. How often do you communicate with this party? (daily, weekly, monthly etc.)
12. Could you please identify other parties that you think will be affected by this project?

B. Stakeholder longlist

- Commissioner
- Dutch government
- European Union + Britain
- Fossil fuel industry
- Tourist sector
- Shipping sector
- Aquaculture sector
- Wind energy lobby
- Fisheries

- (Environmental) NGOs
- TenneT
- Local communities
- Electricity consumer
- Ministry of Defence
- Construction companies
- Rijkswaterstaat
- Ecologists
- Dam engineers (technical researchers)
- Investors

B. Logical Framework

	Summary	**Indicators**	**Evidence**	**Assumptions**
Commissioners Goal	To realise the construction of a DTP-installation in the North Sea that is economically viable and has an overall positive effect upon the environment.			
Team's Purpose	To provide unbiased advice about what the impacts of the dam will be and how the dam can create opportunities for the ecosystem and economy.			
Outputs	**Main:** A report and presentation **Intermediary**: experts and stakeholder interviews, literature summary, stakeholder analysis, economic analysis of affected fisheries and potential of aquaculture.	**Main:** Complete report answering all research questions and PowerPoint presentation summarising main findings. **Intermediary:** Stakeholder Matrix, description of fisheries before and after dam construction, aquaculture potential.	All data used in each section will be in the corresponding folder in OneDrive.	There will be sufficient current literature, fisheries within the North Sea will be affected by the dam.
Activities	Literature research on ecological and socio-economic effects. **If time allows;** identification of food webs, ecosystem services analysis, and spatial-visual representation of a possible location for the dam.	Literature reviews complete from each section. Interview questionnaire created. Visualisation of food webs, Map in ArcMap.	All data used in each section will be in the corresponding folder in OneDrive.	The North Sea ecology, and economic activities have been researched in current literature, stakeholders will be interested in talking with us. There is enough data about the chosen location to create the spatial-visual representation.