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WHY SHRIMP TRAWLING SHOULD BE RECONSIDERED

The effects of shrimp trawling on the Dutch Natura 2000 network based on current literature

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< Brown shrimp on shell fragments and gravel (side view). Photographer: John Rundle

Abstract

Throughout human existence we have relied on the oceans as they provide multiple ecosystem services, including food provision through fishing. This has led to overutilisation and therewith depletion of fish stocks. As a reaction there has been a surge in Marine Protected Areas (MPA) in the past century. In Europe, most MPA's are part of the Natura 2000 (N2000) network. Their protection levels tend to vary between minimal to high protection, meaning that in many areas certain levels of extractions are allowed. In the Netherlands shrimp trawling happens more frequently inside N2000 areas, compared to outside. In this essay the aim is to research what the impact is of shrimp trawling on Dutch N2000 areas, based on current literature. The focus will be on the impacts on specific habitat types and therewith N2000 management goals. There are theories and models about positive indirect impacts of trawling when looking at ecological interactions or specific species, yet most studies tend to focus on the (direct) negative impacts. Some of which are a mortality in benthic invertebrate, leading to reduced benthic species richness, and reduced functioning of the benthic community. Most impacts depend on trawling gear and habitat type. In Dutch N2000 areas the focus is on improving and/or maintaining specific habitat types in combination with increasing endangered species abundance or boosting their habitat quality. There are two main habitat types in the Netherlands, which are in turn subdivided based on the dynamics (high or low levels of wave action). Habitats with natural disturbances (high dynamics) are less impacted by trawling pressure, while habitats with low disturbances can get permanently disrupted by frequent trawling. Trawling permits should therefore only be granted to habitat types that are naturally disturbed by wave action and should be prohibited in all other habitats.

Keywords: *Natura 2000 network, Natura 2000, Dutch coasts, shrimp trawling, trawling*, *trawling permits*

Introduction

Marine life has been an essential part of human existence for centuries. The oceans provide critical ecosystem services, among one of which is food provisioning through fishing (Liquete et al., 2013). At present, over 55% of ocean area is fished industrially, meaning it has a spatial extent more than four times that of agriculture (Kroodsma et al., 2018). Since the industrialisation of fishing in the early 20th century, a significant rise in commercial catch was observed (Kent, 1986), but decades later these increasing fishing efforts have resulted in landings declining due to overexploitation (Coll et al., 2008; Pauly et al., 1998; Perissi et al., 2017). Excessive utilisation leads to depleted fish stocks with mortalities higher than possible for sustainable recoveries (Gaillet et al., 2022). It also results in indirect implications for other species in the ecosystem (Guidetti, 2006; Pauly & Palomares, 2005), or even an entire ecosystem collapse (Jackson et al., 2001; Worm et al., 2006). Most fisheries impacts in coastal zones were already well described by the turn of the century and by then it was clear marine life was mostly negatively impacted (Jennings & Kaiser, 1998; Pauly et al., 1998; Roberts & Hawkins, 1999). This has led to worldwide efforts to restore marine ecosystems by applying a different management style and reducing harvests (Costello et al., 2016; Neubauer et al., 2013; Worm et al., 2009).

One clear example is the surge in establishment of Marine Protected Area's (MPA) (Grorud-Colvert et al., 2019; Juffe-Bignoli et al., 2014). This is mainly due to the Convention on Biological Diversity (CBD) and their initiative to halt further biodiversity loss (Spalding et al., 2013). While goals tend to vary per protected area, it is broadly accepted worldwide that the main aim is to conserve biodiversity and maintain natural ecological processes (Watson et al., 2014). Some studies state that this is done by increasing species abundance and biomass (Sala & Knowlton, 2006; Woodcock et al., 2017), while others focus on maintaining community stability (Pettersen et al., 2022). The International Union for the Conservation of Nature (IUCN) defines a protected area as "*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (IUCN & WCPA, 2018). This is a rather loose definition, which leaves a lot of room for interpretation on what constitutes 'managed'. As a result there has been speculation on the effectiveness of MPAs (Pickens et al., 2021; Rife et al., 2013). However, there are plenty of studies suggesting improvement in many different aspects, depending on the protection levels (Harasti et al., 2018; Leverington et al., 2010; Malcolm et al., 2015; Roberts et al., 2001; Zupan, Fragkopoulou, et al., 2018). Extraction in an MPA may reduce the positive impact it has on a marine ecosystem (Mazaris et al., 2019; Sala et al., 2021; Zupan, Fragkopoulou, et al., 2018), and tends to leave vulnerable species at continued risk (Dureuil et al., 2018; Giakoumi et al., 2017; Sala & Giakoumi, 2017). This indicates that the level of protection within an MPA affects its effectiveness (Sala et al., 2018). Therefore, a guide has been set-up to improve the chances of success by explaining the impact of different protection levels on several aspects of biodiversity (Grorud-Colvert et al., 2021). The MPA guide distinguishes four levels of protection based on the allowed activities (Table 1) and shows with peer reviewed studies how this might influence different attributes of the marine ecosystem (e.g., abundance of species, population age structure, biomass, species richness, etc).

Table 1. Different types of MPAs based on protection level. This table is based on the information given by the MPA guide (Grorud-Colvert et al., 2021).

Protection	Description	What is still allowed?
Full	No extractive or destructive activities are allowed; all abatable impacts are minimized	- Non-extractive low impact tourism, and cultural activities
High	Only light extractive activities with low total impact are allowed	- Small amount of small-scale fishing - Low-density, unfed aquaculture - Low-impact tourism, cultural and traditional activities
Light	Some protection of biodiversity exists but moderate to significant extraction and other impacts are allowed	- Fishing gears might be used (10 or fewer) or fishing occurs with less selective gear types (e.g., gill, trammel, or small-scale drift nets) - Semi-intensive aquaculture (unfed or low-density fed) - Moderate-impact tourism
Minimal	Extensive extraction and other impacts are allowed	- Many or high-impact gear types for extensive extraction - Medium- to high-density aquaculture, and/or large-impact anchoring - All types of tourism

In the European Union (EU) most MPAs are part of a larger network: the Natura 2000 network (N2000). All 27 EU Member States contribute to this coherent ecological network of protected sites, covering both land and sea, with the aim to create a haven for Europe's most valuable and threatened species and habitats (Sundseth & Creed, 2008). The 2030 Biodiversity Strategy states that the protection goals set by the CBD are insufficient to actually conserve and/or restore biodiversity (Maxwell et al., 2020; Visconti et al., 2019). Protected areas (designated by individual countries or part of N2000) will therefore continue to expand: a further 19% per Member State of sea surface has to become protected (European Commission, Directorate-General for Environment, 2021). Even though this sounds promising for reversing overexploitation by fisheries in Europe, only around 60% of the sites within the network have management plans, of which few are implemented (Sundseth, 2021). Yet for the ecological impact actual management is crucial (Bundy et al., 2017; Gill et al., 2017). As conservation measures and objectives are set per Member State (Dinerstein et al., 2019), they have the power to determine the level and type of management as well as extractive activities per site. As a result, almost all MPA's in Europe are considered lightly or minimally protected (Table 1), reducing the positive impact a fully protected MPA can have on the ecosystem (Sala et al., 2018). In almost all European MPA's, extraction in some form of fishing is allowed (Mazaris et al., 2019). The most common industrial fishing method in Europe is trawling (Kroodsma et al., 2018), which in several Member States actually happens with higher intensity in partially protected areas compared to non-protected areas (Dureuil et al., 2018; Zupan, Bulleri, et al., 2018). Shrimp trawling in the Dutch coasts is a clear example of this: 57-73% of the total legal shrimp fishing time is spent within N2000 areas instead of other areas (Hintzen, 2021).

The Netherlands has a total area of 15.033,6 km² contributing to the marine network of N2000 (Figure 1). There are different levels of protection and prohibitions set by the corresponding municipality, but none are fully protected MPA's. Even though the goals vary in specifics, the overall aim is to improve the completeness of an ecosystem by reconstructing/maintaining an ecologically important habitat or increasing/maintaining the abundance of specific endangered species (Ministerie van LNV, 2006). Yet, in several zones shrimp trawling is still allowed (Hintzen, 2021). To go shrimp trawling in these areas you need to get a permit as Article 2.7 of Nature Conservation Act of Dutch law states: '*it is prohibited to do any projects without a permit that is not directly related to or necessary for the management of a Natura 2000 site*' (Artikel 2.7 van Wet natuurbescherming). Before the start of 2023 the permits for shrimp fishing need to be renewed for shrimp trawling to continue. IUCN guidelines about commercial fishing in MPA's states: "*any fishing gear used should be demonstrated to not significantly impact other species or other ecological values*" (Day et al., 2019). For this reason, it is crucial to know if trawling has a significant impact on an MPA before new permits should be considered. The aim of this essay is therefore to answer the following question: '*What is the impact, according to current literature, of shrimp trawling on Dutch N2000 areas?'*. With a specific focus on the impact within different habitat types and the possible impacts on management goals set for each area.

Figure 1. All protected marine surface in the Netherlands.

Trawling

Trawling in general provides a quarter of wild marine landings worldwide (Amoroso et al., 2018), and is therefore substantial in its contributions to food and livelihood (FAO, 2018). Yet, there is a wide range of direct and indirect impacts on marine ecosystems and their ecosystem services (Collie et al., 2017). Some impacts can generally be considered positive when looking at ecological interactions or specific species (Collie et al., 2017; Van Denderen et al., 2013; Wolfshaar et al., 2020). However, trawling also leads to reduced benthic species richness (Tiano et al., 2020; Van Denderen et al., 2014), changes in seabed chemical composition (Tiano et al., 2022), mortality in benthic invertebrates and therewith functioning of the benthic community (Cook et al., 2013; Rijnsdorp et al., 2018; Sciberras et al., 2018), and it may reduce seabed habitat complexity (Buhl-Mortensen et al., 2016; Kaiser et al., 2006). The impacts are highly dependent on the type of gear, habitat type, and species composition (Kaiser et al., 2006; Lucchetti & Sala, 2012; Sciberras et al., 2018). For example: in sandy habitats deposit feeding macro-fauna were reduced by 20% by beam and otter trawls and 40% by scallop dredges, whereas suspension feeders were 70% reduced by beam trawls, 45% by scallop dredges, and 5% by otter trawls (Collie et al., 2000; Kaiser et al., 2006).

Direct impacts

Trawling physically disturbs the seabed by dragging fishing gear over the seabed to catch bottom-dwelling fish and benthic invertebrates. The direct impacts are the immediate effects this physical disturbance has on the habitat and on its organisms.

On habitats

Bottom trawling mobilises fine sediments from the seafloor to the water column due to mixing of the top layer of sediment (Lucchetti & Sala, 2012; Tiano et al., 2019). The amount of sediment mobilised is dependent on the penetration depth of the fishing gear (Hiddink et al., 2017; Sciberras et al., 2018), because it is a function of the hydrodynamic drag of the trawl (which increases with deeper penetration) in combination with the percentage of fine particles in the sediment (O'Neill & Ivanović, 2016). Heavier fishing gear or finer sediment particles therefore result in more mobilisation of sediment and higher disruption in the ecosystem (Eigaard et al., 2016; Hiddink et al., 2017; O'Neill & Summerbell, 2011). High hydrodynamic pressure from bottom trawling seems to resemble high levels of natural disturbances, which makes habitats that get naturally disturbed (e.g. by wave action) more resilient to trawling impacts (Hiddink et al., 2006; Jac et al., 2022). Habitats with low levels of natural disturbances on the other hand, tend to be composed of species which are more sensitive to disruptions as they are not adapted to them (Van Denderen et al., 2015). An increase in mortality of these species creates a detrimental switch in low hydrodynamic habitats (Cook et al., 2013; Van Denderen et al., 2015), while species in shallow wave-swept sandy habitats seem to be well adapted to high rates of disturbance-induced mortality (Diesing et al., 2013). Ecosystems with high levels of natural disturbances and coarse sediments are therefore typically considered to be less sensitive to direct impacts and to have a higher resilience compared to muddy ecosystems with low disturbance levels (Rijnsdorp et al., 2018; Sciberras et al., 2016; Van Denderen et al., 2014, 2015). Consequently, habitat type and species composition seem to be linked.

On organisms

Benthic taxa are in direct contact with the trawling gear and get therefore get disrupted directly by a single trawl (Tiano et al., 2020). However, benthic species have different degrees of sensitivity to bottom trawling depending on their biological characteristics and in particular their recovery rates (Kaiser et al., 2006; Pitcher et al., 2022; Rijnsdorp et al., 2018). Deep-sea areas, generally considered to be areas below 200 metres (Thistle, 2003), are a clear example. Many deep-sea invertebrates are exceptionally long-lived and grow extremely slowly, which makes their recovery capacity for fishing similarly long (estimated from decades to centuries) (Clark et al., 2016; Paradis et al., 2021). As this essay is focused on trawling in the Netherlands, further information will just be on trawling in shallow (< 200 metres) areas.

The five most important traits for benthic taxa to determine impact of trawling are position on the seabed, size, feeding strategy, fragility, and motility (Foveau et al., 2017). A single pass in a habitat with low natural disturbances may reduce the number of epifaunal organisms by at least 90%, with no evident recovery a year later (Cook et al., 2013). Deeply burrowed, large, infauna species seem more resilient (Drabsch, 2001; Tiano et al., 2022). In general, a large size seems to be indicative of a high sensitivity to trawling because they grow too slow to recover between frequent disturbance events (Buhl-Mortensen et al., 2016; Kaiser et al., 2006), especially large, sessile, emergent species (de Juan et al., 2009; Duineveld et al., 2007). Filter feeders tend to reduce in abundance in trawled areas most, compared to deposit feeders, burrowers and scavengers (Tillin et al., 2006; Van Denderen et al., 2015). Species that are mobile and/or reproduce at an early age are likely to recover more quickly after trawling, and will therefore dominate frequently trawled areas (Foveau et al., 2017; Tulp et al., 2020; Van Denderen et al., 2015). When species are long-lived and have low reproduction rates, the population recovers more slowly or not at all when trawling continues (Kaiser et al., 2006; Rijnsdorp et al., 2018). Therefore, if an area consisting of a benthic community with long-lived, epifaunal species is trawled frequently, it tends to shift to a composition comprising of infauna species with a shorter generation time, as they have a higher resilience after disturbance (Jennings et al., 2001, 2002; Tiano et al., 2020; Tillin et al., 2006). The epifaunal benthic community already starts changing with a trawling frequency of more than once every four years (Couce et al., 2020).

Benthic species are not the only organisms influenced by trawling. Bycatch, the incidental catch of unused or unmanaged species (Davies et al., 2009), leads to high mortality rates and constitutes a major ecological threat (Hall et al., 2000). While bycatch tends to be thrown back into the water, mortality rates are generally high (Berghahn et al., 1992; Temming, 2022). Globally, bycatch represents ± 40% of total catch (Davies et al., 2009), but in some places this can be up to 80% (Esmeralda Costa et al., 2008). It can therefore be very detrimental for the species caught, which range from algae species (Esmeralda Costa et al., 2008), to megafauna (defined as: cetaceans, pinnipeds, sirenians, large fish – such as sharks, rays, billfishes, etc.) (Komoroske & Lewison, 2015; Wallace et al., 2013). Just bycatch alone can therefore indirectly change trophic dynamics in marine ecosystems (McCauley et al., 2015). There has been a lot of research done in reducing bycatch by adjusting trawling gear (Fakıoğlu et al., 2022; Graham, 2002; Kynoch et al., 2015). A large amount of these studies come from European otter trawling, of which a high focus has been on reducing specific species as bycatch (Kennelly & Broadhurst, 2021). A common modification is to increase the mesh size of the netting, because smaller mesh results in less selective catch (Beutel et al., 2008; Campbell et al., 2010; Kynoch et al., 2011; Pol et al., 2016)

Indirect impacts

The direct impacts have consequences of their own, which are called indirect impacts. The indirect impacts of trawling highly depend on the intensity of trawling (Collie et al., 2017). Chronic and frequent trawling almost always leads to widespread change or even depletion of benthic invertebrate (prey) species and consequently reduce their predator abundance as well (Hiddink et al., 2011; Hinz et al., 2009). However, with less intense trawling pressure, a maximum of once or twice per year, there seems to be no effect on stomach fullness for generalist predators, only on diet composition (Dell et al., 2013; Johnson et al., 2015). Fish stomach content directly after trawling (20h) seems to increase, yet it is unclear if these short-term increases continue in the long-term (Collie et al., 2017). Bottom disturbance may even improve the feeding conditions for species that feed on small invertebrates (Hiddink et al., 2008). An example is flatfish species: there has been some discussion if one of the indirect effects of trawling may be an increase for target species such as flatfish due to higher food availability (Collie et al., 2017; Hiddink et al., 2008), as their abundance has risen in the North Sea (Millner, 1996; Rijnsdorp, 1996) and Wadden Sea (Beek et al., 1989). Even though this increase seems to have disappeared in recent years (Beare et al., 2013; Van der Veer et al., 2011), model-based research has indicated that these positive effects can indeed occur in bottom-up controlled ecosystems (Van Denderen et al., 2013). These modelled effects also seem to depend on habitat type as plaice in sandy habitats seemed to increase in length and age, while on gravel they showed a decrease (Shephard et al., 2010). Another model-based study highlighted that including ecological interactions within the ecosystem (e.g. food web effects) showed that trawling impact on benthos has indirect positive effects, besides the direct negative effects, and that it all depends on trawling intensity, habitat type, and trawling gear (Wolfshaar et al., 2020)

Europe

In European waters the trawling intensity in shallow areas varies between 0.02 to 8.5 times per year, depending on the location (Eigaard et al., 2017). There are four main demersal towed gear groups used: otter trawls, seines, beam trawls and dredges, which in turn can be subdivided into 14 categories based on target species (Eigaard et al., 2016). All categories and methods have distinct impacts on different habitat types (Pitcher et al., 2022; Rijnsdorp et al., 2020). While otter trawls are used most often in Europe, beam trawls are a close second in the northern parts (Eigaard et al., 2017). For *Crangon crangon* (brown shrimp) trawling a beam trawl with small rolling bobbin wheels is used (**Error! Reference source not found.**). Even though it is a beam trawl, compared to other beam trawls it is considerably lighter, has no tickler chains and is towed at a lower speed (Tulp et al., 2020). In theory, the only contact with the seafloor is with the shoes (**Error! Reference source not found.**) and the rubber bobbins. This method is therefore considered one of the least disruptive trawling methods (Rijnsdorp et al., 2020). However, the trawling net will still penetrate the subsurface at least two cm deep for each substrate type, especially when it is filled (Pitcher et al., 2022). This is corroborated by Schellekens *et al.* (2014), as they found live buried shellfish species as bycatch of shrimp trawling vessels. While the effect of general trawling methods on the benthic community has been studied thoroughly (Kaiser et al., 2006; Sciberras et al., 2018; Van Denderen et al., 2015), there are only few studies on the seafloor effects of shrimp trawl fisheries using bobbin wheels (Tulp et al., 2020; Vorberg, 2000). The impacts are therefore still not clearly defined.

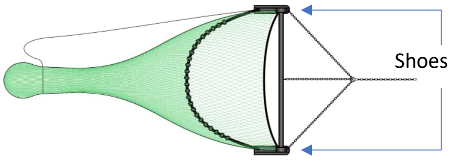

Figure 2. The beam trawl used for brown shrimp. This is an inshore beam trawl with small rolling bobbin wheels fitted to help the net travel over the seabed with minimal damage. This is a relatively undisruptive method and is still used within Natura 2000 areas. Picture is taken from: https://www.seafish.org/responsible-sourcing/fishing-gear-database/gear/beam-trawl-shrimp-beam-trawl/

Natura 2000 in the Netherlands

Natura 2000 regulations

The overall conservation objective of the Natura 2000 network is to "*. . . maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest*" (Article 2, Habitat Directive). A N2000 area can therefore get designated based on two things: habitat type or (bird-) species present. This means that all management goals, including the ones in the Netherlands, are set to maintain or increase the quality of specific habitat types or increase specific specie abundances. There are nine different marine habitat types that have special geographic, abiotic, and biotic features which makes them protected by the EU. Five of these are present on the Dutch coasts (Table 2). In the Netherlands, area appointment is done by the Minister of Agriculture, Nature, & Food Quality. Once an area is appointed it is obligatory by Dutch law to create a management plan within three years, where the goals for the area are set and a description of how these goals are supposed to be achieved are detailed. All current activities and the possible harmful effects they might have on the ecosystem should be taken into consideration and mentioned. When activities may be harmful, they might only be allowed with a permit. Creating a management plan is usually done by the province in combination with all the stakeholders, so everyone that uses or may use the area: from ecologists to fishermen. The province must take all suggestions and notes by the stakeholders into account. It is obligatory to renew a management plan after six years. There are guidelines set by the EU for creating these plans and each Member State is obliged to take these into consideration (Natura 2000, 2007). The province is also responsible for granting these permits.

Table 2. The marine habitat codes based on Natura 2000 regulations found in the Dutch coast

Habitat code	Description habitat type
H1110A	Sandbanks which are covered by sea water all the time, mostly shallow relatively flat areas (like gullies) which are influenced by the tides instead of wave action
H1110B	Sandbanks which are covered by sea water all the time, mainly deeper areas that are influenced by wave action instead of the tides
H1140A	Mud flats and sandbanks; the shallow coastal areas that fall dry and get flooded due to the action of ebb and flow. Consists largely of low-dynamic mudflats, which are shielded from wave actions
H1140B	Mud flats and sandbanks; the shallow coastal areas that fall dry and get flooded due to the action of ebb and flow. Mostly high-dynamic mudflats with low biodiversity of benthic organisms
H1160	Large creeks and bays; generally sheltered inlets where, depending on the size of the connection to the open sea, the influence of waves and tides is relatively small.

Areas with trawling

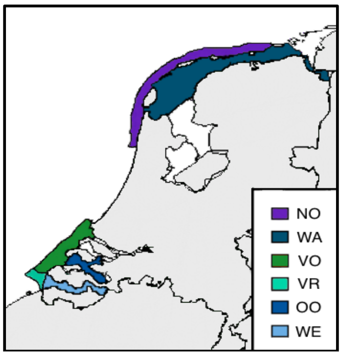

Figure 3. Natura 2000 areas in the Netherlands affected by shrimp trawling. The full names of these areas are: Noordzeekustzone (NO), Waddenzee (WA), Voordelta (VO), Vlakte van de Raan (VR), Oosterschelde (OO) and Westerschelde (WE)

In the Netherlands shrimp trawling for brown shrimp using motorised vessels and beam trawls started in the early 20th century (Lotze, 2007). There are six Dutch N2000 areas affected by shrimp trawling (**Error! Reference source not found.**): Noordzeekustzone (NO), Waddenzee (WA), Voordelta (VO), Vlakte van de Raan (VR), Oosterschelde (OO) and Westerschelde (WE) (Hintzen, 2021). For all areas except OO, designation was mainly done based on the presence of habitat type H1110 and H1140 (Table 2) and occurrence of certain endangered species. In OO designation was based on the degradation of the H1160 habitat and therewith a reduction in food source for shellfish consumers (Ministerie van LNV, 2006). Based on N2000 classification, each area (except OO) consists of mudflats and/or sandbanks with different depths and fluctuating wave and tidal impacts (**Error! Not a valid bookmark self-reference.**). However, within these classifications further differentiations can be made. For example, the sediment composition of the Wadden Sea (WA) varies in small spatial scales, which in turn leads to different macrofauna (organisms > 0.5mm) settlements and results in a mosaic of small habitats (Singer et al., 2016). These types of small fragmentations are not considered with N2000 designation. This could complicate achieving management goals. Especially because one of the goals with 'saline waters' is the restoration of the completeness of the ecosystem, and therefore to re-establish sub-literal and literal shellfish beds and seagrass meadows (Ministerie van LNV, 2006). Several shellfish species, however, are only able to settle successfully in sediments with specific characteristics (Tulp et al., 2020), which are not taken into consideration in N2000 area type designation. Another important goal is creating enough rest- and foraging areas for endangered species, which in some management plans is done solely by improving habitat quality (Anonymous, 2016b, 2016a). There are seven different endangered marine species within these areas, four of these are diadromous fishes and three are mammals. Several endangered bird species are also considered, including several fish eaters. For endangered species population size and habitat quality are taken into consideration: the aim is either to increase or maintain one or both aspects.

As it is necessary to keep various navigation destinations navigable and accessible, the maintenance of fairways and the dredging (and dumping) of (harbour) sludge is always allowed on Dutch coasts, (artikel 6.12 lid 2 onder c Waterbesluit). The same goes for shore face nourishments, in which sand is collected from areas offshore and placed as mounds near the shore to accommodate beaches in shallow waters (https://www.rijkswaterstaat.nl/water/waterbeheer/beschermingtegen-het-water/maatregelen-om-overstromingen-te-voorkomen/kustonderhoud/index.aspx). All kinds of fixed-gear fishing and all types of recreation are also allowed, except in certain designated rest sites. These sites are mostly assigned based on endangered bird species and therefore vary in size depending on the season. However, not all areas have rest sites, and in some of the sites many types of recreation are still allowed. The type of industrial size fishing that is allowed depends on the location. In NO, VO, and VR it is not possible anymore to obtain permits for fishing with tickler chains as this is too disruptive. For shrimp trawling, even with rolling bobbins (**Error! Reference source not found.**), the effects may be harmful as well, and therefore it is obligatory to obtain a permit.

Table 3. General information about the Natura 2000 areas in the Dutch coast affected by shrimp trawling

Area	Surface (ha)	Prominent habitat *	Habitat quality **	Type of MPA ***
Noordzeekustzone	144.475	H1110B, H1140B	> =	10% high protection, 90% minimal protection
Waddenzee	271.771	H1110A, H1140A	> >	100% minimal protection
Voordelta	83.534	H1110A, H1110B, H1140A, H1140B	= = = =	6-8 % light protection, 92-94% minimal protection
Vlakte van de Raan	17.521	H1110B	>	15% high protection 85% minimal protection
Oosterschelde	36.976	H1160	>	100% minimal protection
Westerschelde	44.052	H1110B, H1140B	= =	100% minimal protection

***** Habitat codes based on natura 2000 habitat type: Table 2
****** > means improving; = means maintaining habitat quality
******* Based on MPA guide: Table 1

Discussion

While the impact of trawling in general seems clear in current literature, the effects of shrimp trawling with rolling bobbins (from now on mentioned as shrimp trawling) is still inconclusive. It is expected that the effects of this method will resemble normal trawling, yet in a slightly dampened manner as the physical impact is less strong (Tulp et al., 2020). This indicates that the impacts depend on the habitat type and could impede some of the management goals of Dutch N2000 areas. All N2000 MPA's in the Netherlands are only lightly or minimally protected based on the MPA guide (Areas with trawling

In the Netherlands shrimp trawling for brown shrimp using motorised vessels and beam trawls started in the early 20th century (Lotze, 2007). There are six Dutch N2000 areas affected by shrimp trawling (**Error! Reference source not found.**): Noordzeekustzone (NO), Waddenzee (WA), Voordelta (VO), Vlakte van de

Raan (VR), Oosterschelde (OO) and Westerschelde (WE) (Hintzen, 2021). For all areas except OO, designation was mainly done based on the presence of habitat type H1110 and H1140 (Table 2) and occurrence of certain endangered species. In OO designation was based on the degradation of the H1160 habitat and therewith a reduction in food source for shellfish consumers (Ministerie van LNV, 2006). Based on N2000 classification, each area (except OO) consists of mudflats and/or sandbanks with different depths and fluctuating wave and tidal impacts (**Error! Not a valid bookmark self-reference.**). However, within these classifications further differentiations can be made. For example, the sediment composition of the Wadden Sea (WA) varies in small spatial scales, which in turn leads to different macrofauna (organisms > 0.5mm) settlements and results in a mosaic of small habitats (Singer et al., 2016). These types of small fragmentations are not considered with N2000 designation. This could complicate achieving management goals. Especially because one of the goals with 'saline waters' is the restoration of the completeness of the ecosystem, and therefore to re-establish sub-literal and literal shellfish beds and seagrass meadows (Ministerie van LNV, 2006). Several shellfish species, however, are only able to settle successfully in sediments with specific characteristics (Tulp et al., 2020), which are not taken into consideration in N2000 area type designation. Another important goal is creating enough rest- and foraging areas for endangered species, which in some management plans is done solely by improving habitat quality (Anonymous, 2016b, 2016a). There are seven different endangered marine species within these areas, four of these are diadromous fishes and three are mammals. Several endangered bird species are also considered, including several fish eaters. For endangered species population size and habitat quality are taken into consideration: the aim is either to increase or maintain one or both aspects.

As it is necessary to keep various navigation destinations navigable and accessible, the maintenance of fairways and the dredging (and dumping) of (harbour) sludge is always allowed on Dutch coasts, (artikel 6.12 lid 2 onder c Waterbesluit). The same goes for shore face nourishments, in which sand is collected from areas offshore and placed as mounds near the shore to accommodate beaches in shallow waters (https://www.rijkswaterstaat.nl/water/waterbeheer/beschermingtegen-het-water/maatregelen-om-overstromingen-te-voorkomen/kustonderhoud/index.aspx). All kinds of fixed-gear fishing and all types of recreation are also allowed, except in certain designated rest sites. These sites are mostly assigned based on endangered bird species and therefore vary in size depending on the season. However, not all areas have rest sites, and in some of the sites many types of recreation are still allowed. The type of industrial size fishing that is allowed depends on the location. In NO, VO, and VR it is not possible anymore to obtain permits for fishing with tickler chains as this is too disruptive. For shrimp trawling, even with rolling bobbins (**Error! Reference source not found.**), the effects may be harmful as well, and therefore it is obligatory to obtain a permit.

Table 3), despite the fact that this tends to leave habitat types vulnerable, and sometimes even leaves endangered species unprotected (Fortuna et al., 2018; Grorud-Colvert et al., 2021). Some management plans consider that a well-functioning habitat type consists out of a balanced development of biotic communities and a balance in life structure within the population of all species (Anonymous, 2016a). According to the MPA guide a well-balanced ecosystem would be difficult to accomplish based on the levels of protection, yet it might lead to achieving species-specific management goals (Grorud-Colvert et al., 2021). Impacts are only prohibited if there is proof there might be a negative impact on the set goals. Due to the lack of research on shrimp trawling, there is no conclusive proof. However, based on the similarity between shrimp trawling and trawling in general, the expectations are that the impacts are similar yet less strong (Tulp et al., 2020).

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Impact of trawling on goals concerning marine species

The limitations for the migratory fish are mainly due to their migratory route being impeded by locks and other upstream barriers (Anonymous, 2016b). This is not an issue addressed here and will therefore not be considered. The mammal species like *Halichoerus grypus* (grey seal) and *Phoca vitulina* (harbour seal), on the other hand, might indirectly be positively impacted by light trawling. Grey seals and harbour seals are considered as sympatric species in the North Sea, as they use the same areas on land and at sea, are mainly piscivorous, and have comparable life cycles (Brown et al., 2012). There are small differences in foraging behaviour: 1) Harbour seals tend to consume more inshore and focus on benthic species, while grey seals are more offshore and focus on pelagic species, and 2) grey seals mainly consume plaice and sandeels, while harbour seals are generalists and therefore consume a wider range of species, which include plaice and sandeels (Damseaux et al., 2021). On sand substrates, plaice are known to consume predominately polychaetes, which tend to proliferate at moderate trawling intensity resulting in more and longer plaice individuals (Hiddink et al., 2008; Shephard et al., 2010). As competition over food is most likely a strong contributor to the decrease in harbour seal populations (Russell et al., 2015), a higher abundance of longer individuals of plaice might reduce this competition and therefore increase harbour seal populations. An increase in harbour seal populations is one of the goals in areas WA, VO, OO and WE (Table 4), which indicates that in these areas light to moderate trawling (maximum of once or twice per year) might help reach their goals. These indirect positive effects are mostly based on models, however, and in practical cases it becomes clear that the positive effects are not with every plaice species (Hiddink et al., 2011) and depends on the type of ecosystem (Van Denderen et al., 2013).

The speculation of a positive impact on adult plaice species might get cancelled out when also taken bycatch into account. Brown shrimp generally grow up to nine centimetres long (Hayward & Ryland, 2017) and are marketable from 50 mm and upwards (Veiga-Malta et al., 2020). Optimal catch is therefore maintained with the smallest legal mesh size; 16 mm, although most vessels use 22 mm (Addison et al., 2017; Temming, 2022). Areas where shrimp trawling for brown shrimp is done, tend to correspond with nursery grounds of plaice species (Catchpole et al., 2008). Bycatch of brown shrimp trawling appears to be significantly reduced by adjusting trawl gear (Graham, 2002; Revill & Holst, 2004). However, these adaptations seem to be least effective with plaice species, despite them tending to make up the largest component of bycatch (Catchpole et al., 2008; Veiga-Malta et al., 2020). The indirect positive effects of promoting plaice populations by light trawling is therefore most likely cancelled out by the mortality rate of plaice as bycatch.

Table 4. Endangered marine mammals and the goals assigned to them per natura 2000 area. = stands for maintaining; > stands for improving population (pop.) or habitat (hab.) quality.

Areas:	NO		WA		VO		VR		OO		WE	
Marine mammals	Pop.	Hab.	Pop.	Hab.	Pop.	Hab.	Pop.	Hab.	Pop.	Hab.	Pop.	Hab.
Porpoise	=	>	=	=	=	>	=	=	=	=	=	=
Grey seal	=	=	=	=	=	=	=	=	=	=	=	=
Harbour seal	=	=	>	=	>	>	=	=	>	>	>	>

Phocoena phocoena (porpoises) are highly mobile species, with a diet comprised of high levels of sandeels (Leopold, 2015). Because of this, their distribution and abundance is highly linked to sandeel grounds (Gilles et al., 2016). The semi-burrowed lifestyle of sandeel species leaves them vulnerable to trawling, which makes their presence in the Dutch coasts negatively correlated with shrimp fisheries (Tien et al., 2017). For the sake of improving habitat qualities for porpoises, a goal in NO and VO (Table 4), it is therefore necessary to reduce shrimp fishing to a minimum to increase sandeel populations and thus boost food availability. This counts for porpoises as well as grey seals, because sandeels are also a main contributor to grey seal diets (Damseaux et al., 2021). Besides the indirect effect on food availability, there is also a direct negative effect of trawling on porpoise abundance as they tend to get tangled in the nets (Bjørge et al., 2013; Caswell et al., 1998). Therefore, for a direct increase in habitat quality of porpoises (NO and VO) and a possible indirect increase of harbour seal habitat quality and population size (WA, VO, OO, and WE), shrimp trawling should be reconsidered.

Impact of trawling on goals concerning habitat type

The two frequently occurring marine habitat types in the Dutch N2000 areas are: sandbanks (H1110) and mudflats (H1140), which are subdivided by level of dynamics: A; low in dynamics, and B; high in dynamics (Table 2). In habitats with high dynamics (H1110B, H1140B), species are well adapted to high rates of disturbances (Diesing et al., 2013), and are therefore less impacted by low frequent disturbances like shrimp trawling (Jac et al., 2022). For maintaining habitat quality of H1110B and/or H1140B shrimp trawling does not need to be completely prohibited. For improving habitat quality, however, it would probably be beneficial to reduce or prohibit shrimp trawling, as high frequencies can still cause disruptions (Hinz et al., 2009). Habitats with low natural disturbances (H1110A, H1140A and H1160) on the other hand, tend to naturally consist of species more sensitive to disruption (Van Denderen et al., 2015). In natural circumstances these habitat types have long-lived, larger, sessile species like mussels or other filter feeders (Foveau et al., 2017). For these habitat types an annual trawling intensity of 0.1 per year already starts to compromise the benthic community (Eigaard et al., 2017). When the habitat still consists of mussel beds or other biogenic areas, they threshold will have be even lower (Pitcher et al., 2016). In the entire North Sea trawling frequency varies between 1-10 times per year with beam trawlers (Eigaard et al., 2017), while in some places in the Netherlands shrimp trawling intensity can be > 30 times a year (ICES, 2018). Combine this with the fact that more than half of shrimp trawling hours in the Netherlands happens within the N2000 areas (Hintzen, 2021), and it creates a decent picture of the amount of disturbance these habitats have come to endure.

Benthic communities in areas like H1110A, H1140A and H1160 already start to change when the seafloor is trawled as little as once every four years, and with higher frequencies these changes become irreversible (Couce et al., 2020). On the Dutch coasts there have been hundreds of years of intensive bottom trawling, which makes it virtually impossible to find habitats that reflect historical conditions unaffected by human activity (Coolen, 2017; ICES, 2018; Lotze, 2007). Benthic communities with long-lived, epifaunal species have changed into communities of infauna species with a short generation time (Tiano et al., 2020). It is therefore hard to determine the level of disruption and possible (lack of) recovery in the coastal zones of the Netherlands. Maintaining the habitat quality of the current habitats means maintaining already affected conditions. Improving habitat quality could mean restoring to natural conditions, yet it is unclear to pinpoint what these might be and seems impossible with current protection levels.

Conclusion

To allow recovery of the entire ecosystem, high protection levels are strongly recommended (Grorud-Colvert et al., 2021; Sala et al., 2018). This seems advisable to better understand and predict the recovery trajectories resulting from a reduction or a ban of bottom trawling and dredging pressures, and to increase knowledge on the natural state (Jac et al., 2022). However, full, or high protection would not be economically viable to implement at all Dutch N2000 areas. It would mean no extraction of any kind, nor maintaining navigational fairways, which would impede waterways and would significantly reduce national shrimp landings. It is therefore advisable to start with selective prohibition based on probable impacts of shrimp trawling. My recommendations are made based on the assumption that shrimp trawling impacts resemble dampened general trawling impacts. They will mainly focus on habitat type, yet include the possible side effects on the goals of the endangered species (Table 5):

1) When improving habitat quality is a management goal, it would be recommended to reduce or even prohibit shrimp trawling. Trawling disrupts the seafloor, and with that the benthic community and the possible settlement of macrofauna (Couce et al., 2020; Kaiser et al., 2006; Tulp et al., 2020). Especially in areas without frequent natural disturbances (Jac et al., 2022; Van Denderen et al., 2015), like H1110A, H11140A, and H1160. It is therefore advisable to prohibit shrimp trawling in WA and OO altogether. As the impact of trawling will be less destructive in H1110B, prohibition might not be needed in VR and parts of NO. Nevertheless, it is not recommended when trying to improve habitat quality. Prohibition of trawling in WA and OO might also improve on the goal of increasing harbour seal populations and their habitat quality.
2) Maintaining habitat quality in habitats like H1110A and H1140A, as is the goal in VO, means maintaining an unnatural, interrupted state due to the history of intense trawling (Coolen, 2017; Lotze, 2007). As one of the aims of the N2000 areas is the restoration of the completeness of the ecosystem, maintaining the current state might not be advisable. If the aim is to restore the habitat to its natural state, trawling should be prohibited, yet if it is enough to maintain the habitat as is, trawling could continue. I therefore conclude that trawling is not recommended for H1110A and H1140A in VO. If trawling is prohibited there will most likely be an increase in habitat quality for both porpoise and harbour seal habitats. There will probably also be a positive effect on harbour seal populations. These goals will be impeded if trawling continues.
3) For maintaining habitat quality in dynamic habitats like H1110B and H1140B (NO, VO and WE) trawling can continue, albeit lower frequencies are recommended. Frequencies should be determined based on further research on benthic communities and their recovery rates in these specific areas. Allowing trawling to continue will most likely impede porpoise and harbour seal habitat improvements (goals in NO, VO, and WE), much like harbour seal populations (VO and WE).

Table 5. Recommendations for shrimp trawling permits based on habitat type. The probable risks on goals set concerning marine mammals are included. H1140 are unsuitable habitats for porpoises and risks of trawling on porpoises are therefore not considered in these habitat types

Area	Habitat type	Trawling permit	Risks on goals set concerning marine mammals
Noordzeekustzone (NO)	H1110B	not recommended	
	H1140B	allowed	Likely impedes porpoise habitat quality increase
Waddenzee (WA)	H1110A	prohibited	Might (indirectly) increase harbour seal populations
	H1140A	prohibited	Might (indirectly) increase harbour seal populations
Voordelta (VO)	H1110A	not recommended	
	H1110B	allowed	Likely impedes porpoise habitat quality increase
			Likely impedes both harbour seal goals
	H1140A	not recommended	
	H1140B	allowed	Likely impedes both harbour seal goals
Vlakte van de Raan (VR)	H1110B	not recommended	
Oosterschelde (OO)	H1160	prohibited	Might (indirectly) promote both harbour seal goals
Westerschelde (WE)	H1110B	allowed	Likely impedes both harbour seal goals
	H1140B	allowed	Likely impedes both harbour seal goals

To attain the set management goals and to improve on ecological values, shrimp trawling should be reconsidered in each individual area and only be permitted based on habitat type. Areas already vulnerable to natural disturbances should be left alone to recover and restore, while areas more resistant to disturbances can be trawled for shrimps without causing further changes to the ecosystem.

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