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Well-founded and supposed negative effects of cockle dredging on tidal-flat sediment and fauna: A review of contributions of ecological research

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ABSTRACT

Published studies on effects of mechanical dredging on tidal flats for cockles (*Cerastoderma edule*) are critically reviewed, with special emphasis on studies in the Dutch Wadden Sea. The evidence on fishery-caused changes in sediment composition is contradictory, but some loss of silt and coarsening of the sediment was found in part of the fished areas. However, the part of the tidal flats touched annually in the Wadden Sea was invariably small (mostly only a few percent) and recovery was rapid. Generally, negative effects on bivalve recruitment following fishing were not established. Negative effects on non-target fauna were always present but variable. Recovery of the fauna was generally rapid. The stocks of adult cockles were thinned, but high proportions were caught only in a small minority of the years when cockle abundance was low. Food supply for shellfish-eating birds on the tidal flats, notably Oystercatchers, was reduced in fished areas, but not seriously so in most years. Evidence for negative effects of mechanical cockle fishing on bird condition and survival was present, but scarce. Such effects depended on the availability of alternative food, particularly mussels (*Mytilus edulis)*. Overall-negative reports on consequences of cockle fishery were published only by a group of Dutch ecologists. These reports are judged questionable. Though the effects of mechanical cockle dredging appear to be not all so bad as sometimes supposed and the reasons to close this fishery are partly open to question, resumption of this (since two decades forbidden) fishery in the Wadden Sea is not recommended.

1. Introduction

Apart from catching the intended fish or shellfish, any bottom disturbing fishing activity causes collateral damage, such as altering the sediment or killing non-target species. Several review papers (among others: Hiddink et al., 2017; Pitcher et al., 2022) about effects of bottom fishery appeared, but none with an emphasis on hydraulic fishing for cockles or on tidal flats. Though mechanical cockle fishery is now forbidden nearly everywhere (for instance in the Dutch Wadden Sea ever since 2003) where it flourished in earlier years, there are some reasons to review the studies on its possible negative effects. The fishery was controversial for a long time and a lot of studies on its effects were executed. However, an exhaustive review of results and conclusions of these studies is not available so far.

Cockle dredging causes serious disturbance of the upper layer of the sediment. The suction dredges (width 50–115 cm) are towed by ships with a shallow draft (of about 0.5 m), allowing them to fish for several hours per day on tidal flats. In front of the dredge, the sediment is loosened by strong spouts. The dredge ploughs through the sediment to a depth of about 5 cm. It catches everything with a diameter of over 1.5 cm. The catch is sucked up and washed onboard.

The Piersma et al. (2001) publication appears to have decisively influenced the closure decision in the Netherlands, because it suggested a long-lasting negative effect of mechanical cockle fishery: a long-term decline of bivalve recruitment. This paper was favorably received, so far gaining almost 300 citations according to Google Scholar. However, it was recently subject of severe criticism (Beukema and Dekker, 2018, 2020b; Van der Meer and Folmer, 2023). These three papers conclude that there is no evidence for any reduction of bivalve recruitment after cockle fishing. In contrast, because the success of bivalve recruitment is negatively related with the size of the adult cockle stock (Beukema and Dekker, 2018), rather a positive effect might be expected of thinning of stocks of adult cockles on their recruitment success. In the present paper, particularly the evidence presented by Piersma et al. (2001) and his followers (Van Gils et al., 2006; Kraan et al., 2007; Compton et al., 2016) will be critically reviewed.

An earlier review of the effects of cockle fishery on sediment and benthic life (Nomden et al., 1999) concluded that there was no evidence

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for lasting negative effects of cockle dredging on sediment composition nor on the benthic fauna. However, this report was published exclusively in the "grey" literature and it hardly attracted attention (Google Scholar reports only 3 citation in >2 decades). A report by Ens et al. (2004b) received more attention (about 100 citations). It elaborately discusses the effects of shellfish fishery on Dutch coastal ecosystems, particularly on the base of results of extensive research in the early 2000s in the framework of the EVA-II program. A recent, but unpublished (only available as a pdf) review by Haupt (2022), dealing in particular with the cockle fishing in the Thames estuary, concluded that this restricted fishery does not have long-term impacts on the stock of bivalves and has little impact on the environment.

After 2004, several additional relevant papers on effects of mechanical cockle dredging appeared and the discussion on the possible damaging nature of this fishery is still controversial and active, reasons enough to present an updated review. Such a review might shed some light on the role of science in adding arguments pro or contra the continuation of the fishery and on the quality of these arguments.

2. Methods

The literature on effects of mechanical cockle fishery (dredging for cockles) was surveyed. Literature was searched by using Google Scholar, including the first 100 entries on the terms "impact of hydraulic cockle dredging", "tidal mudflat cockle dredging", and "Wadden Sea cockle dredging". We evaluated the papers for correctness of methods and for relevance. Many reports in the grey literature were included, because these reports are open access and in the case of the EVA-II research program they were critically reviewed by an audit committee of three distinguished professors in marine ecology (Carlo Heip and Wim Wolff) and sedimentology (Poppe de Boer). All selected papers reported negative effects on stocks of adult cockles, some also on the sediment, on bivalve recruitment, on survival and recovery of non-target fauna, and on the availability of bird food and effects of fishery-influenced food abundance on bird condition and dynamics. Several papers, however, reported (apart from temporarily reducing the fished cockle stocks and thus the abundance of bird food) an absence of any significant long-term side-effects.

3. Results

3.1. Effects on sediment composition

An immediate effect of hydraulic cockle dredging is that the upper sediment layer is brought into suspension, followed by sedimentation. The sandy part sinks quicker than the silty fraction. Meanwhile, a higher part of the silt than of the sand fraction may be transported away from the fished area by tidal currents. The result would be a sandier sediment after than before the dredging. How long this would last is unpredictable. A sediment too poor in silt or with too much shell material might have a negative effect on subsequent bivalve recruitment and thus on speed of recovery of the fished cockle population.

Apart from changes in sediment composition, cockle dredging results in the creation of a visible maze of tracks with a depth of 3–5 cm (see a photograph in Ens et al., 2004b: their fig. 25). These tracks remain visible for highly variable periods, from 1 day to 1 year (Nomden et al., 1999). Recovery of sediment composition appears to be a variable process, dependent as it is on biotic (such as faeces production by bottom animals) as well as abiotic processes (seasonally variable sedimentation and erosion, as affected by weather conditions and shelter). It may take some months to more than a year (Ens et al., 2004b).

The evidence for sediments being significantly sandier after cockle dredging is contradictory (Table 1). Zwarts et al. (2004) studied at length sediment characteristics and changes therein in the Dutch Wadden Sea for the 1950–2002 period. He concluded that substantial changes took place in sediment composition at several places during that

Table 1
Observed changes in sediment composition (mean grain size, proportion of silt and amount of shell debris) attributed to mechanical cockle fishing.

Grain size	silt content	shells	reference
coarser	lower	more	Piersma et al. (2001)
no change	no change	no change	Leopold et al. (2004)
coarser	lower		Zwarts et al. (2004)
no change			Wijnhoven et al. (2011)
no change	no change		Clarke and Tully (2014)

period and that among the various causes cockle fishery did probably contribute to lower silt contents. This was so for the short as well as the long-term (a full year) changes in silt content of the sediment. Examples are shown in figs. 27 and 28 of Ens et al. (2004b). After dredging for cockles, Piersma et al. (2001) found an increase in median sediment grain size of the sediment and amounts of shells at the surface (and some statistically non-significant loss of silt) near the island of Griend (western part Dutch Wadden Sea). No <8 years later, the initial sediment characteristics were re-attained there. Leopold et al. (2004), however, found no relationship between foregoing dredging intensity and changes in sediment composition, nor in proportion of "tarra" (debris of shells that might have been brought to the surface by dredging). Neither did Clarke and Tilly (2014) find significant changes in sediment composition 8–9 days after hydraulic dredging for cockles in Dundalk Bay (Ireland). Nor found Wijnhoven et al. (2011) an effect of cockle dredging in the Oosterschelde on median grain size. An indirect effect of cockle dredging on the sediment is the decrease of pseudofaeces production in areas with thinned cockle stocks. However, whereas bio-stabilizers, like mussel beds and seagrass beds, reduce tidal currents, wave action and sediment resuspension, the cockle appears to be a bio-destabilizer, that increases sediment erosion/resuspension due to bioturbation and bed roughness (Widdows and Brinsley, 2002; Ciutat et al., 2007).

The part of the tidal flats that was annually touched during the 1992–2002 period by cockle dredgers amounted on average to only 1 to 2% and was even less (0.7%) for the sublittoral part of the Wadden Sea. In the Oosterschelde these percentages amounted to 6.5% and 0.2% (Ens et al., 2004b). Kraan et al. (2007) mention a cumulative 15% of the intertidal flats of the Dutch Wadden Sea affected by cockle dredging for the 10-year period 1992–2001. This higher percentage resulted from the variable locations of the cockle beds. In view of the generally rapid recovery of the sediment composition, such a cumulative percentage appears to be hardly relevant (the exception being the results reported in Piersma et al., 2001).

3.2. Effects on cockle stocks

A direct and undeniable effect of cockle dredging is reduction of the stock of adult cockles. On Wadden Sea tidal flats, the abundance of cockles has always been highly variable. During the 46 years of the 1973–2018 period, cockle biomass as observed on Balgzand (a 50-km^2 tidal flat area in the westernmost part of the Wadden Sea) in late winter varied from 0.1 to 15 g AFDM (ash-free dry mass) m^{-2}, with 34 annual values of <5 g m^{-2} and 12 values of even <2 g m^{-2} (Beukema and Dekker, 2019a). Two environmental factors contributed particularly strong to this large between-year variability. Cockle survival was <10% in severe winters (mean Jan/Feb water temperatures <2^{o} C), occurring 6 times in this 46-year period (Beukema and Dekker, 2020a). The other factor was the high variability in annual recruitment: from <10 to >1000 recruits m^{-2} in August (Beukema and Dekker, 2014). Variability in annual growth rates was more restricted, except for one year with very low growth rates at an extremely high cockle abundance (Beukema and Dekker, 2015, 2019b). Wadden Sea-wide estimates of abundance of cockles and of cockles + mussels (all expressed in flesh weight) are shown in Brinkman and Smaal (2003: figures 24 and 27, respectively).

The intensity of mechanical cockle fishery strongly increased in the

1970s and was maximal in the 1980s. Total annual yields from all Dutch coastal waters increased from around 10 million kg fresh weight (including shells and water) in the 1970s to around 60 million kg in the 1980s (maximum about 80 million kg), to decline to an average of about 30 million kg in the 1990s (Ens et al., 2004b). Amounts fished in the western Dutch Wadden Sea varied in the 1984–1999 period from 0 to 10 million kg fresh weight of flesh (Brinkman and Smaal, 2003: their fig. 28).

On average (for the 1992–2002 period), the removed proportions of the stock amounted to 6.5% of the numbers present in the Wadden Sea (Kamermans et al., 2004), being about one tenth of the total mean annual mortality (Ens et al., 2004b). In the less important fishery area Oosterschelde this percentage was higher (10.7%). When expressed in a more relevant way in units of biomass, the percentages of stocks removed annually by fishery were larger: on average in the Wadden Sea 11%, and in the Oosterschelde 15% for the 1990s (Kamermans et al., 2004). For the 13 years of the 1990–2002 period, Kamermans et al. (2003) found an average catch of 19% of the calculated September stock weight in the Wadden Sea. In this period, extremes in the Wadden Sea varied from 0% (3 years when fishery was forbidden by the government to reserve sufficient food for birds in years with very low stocks) to 100% (1 year: 1990). Before 1990, these percentages were lower. De Vlas (1987) estimated a mean yield of <5% of the biomass for the 1970s and about 10% for the 1980–1985 period (with high values of about 20 and 40% at small stock sizes in 1984 and 1985). Ens et al. (2004b: their figure 23) show calculated September stock sizes and yields for the years 1971–2004. In nearly all of these years, catches were < 10% of the stock biomass. Wadden Sea-wide surveys of the cockle stock started in 1990, so the data for earlier years were based on extrapolating the data from Balgzand. Wadden Sea-wide estimates of cockle stocks for these early years may be unreliable. Since 1990, stock estimates for the fishing month September were based on extrapolations from samplings executed in May. These extrapolations were not very certain (by lack of data on rates of growth and survival between May and September). In fact, these estimates of September biomass values were invariably overestimating the true biomass (Kamermans et al., 2003), resulting in consents for too high catches. Maybe, in some more years fishery should have been forbidden to reserve sufficient food for birds.

3.3. Effects on bivalve recruitment

In the Wadden Sea, recruitment in bivalves is highly variable from year to year (Beukema and Dekker, 2005, 2014, 2020b). It depended in particular on the abundance of predators on small spat (Beukema and Dekker, 2014). It was generally higher in years with low than in years with high abundance of adult cockles (Beukema and Dekker, 2005, 2018). In an elaborate study, using long-term (decades) data from the twice-annually sampled cockle populations on the tidal flats of Balgzand, they found this negative relationship for recruitment of cockles, but also of *Limecola (Macoma) balthica* and *Mya arenaria*. The negative relationship in cockles between spawning stock and recruitment was also observed by Hancock (1973), Van der Meer et al. (2001), Kamermans et al. (2004), and Callaway (2022). Only Magalhaes et al. (2016) did not find any relationship (positive nor negative) between adult stock and recruitment in a cockle population in Arcachon Bay. The usually observed negative relationship might mean that thinning of stocks of adult cockles (for instance by cockle dredging) would result in more successful rather than in reduced recruitment in bivalve populations.

The evidence that thinning of adult cockle stocks by fishing might promote rather than reduce subsequent bivalve recruitment is fourfold: an increased cockle recruitment after cockle harvesting in a Scottish lagoon (Mendonca et al., 2008), a (non-significant) difference in the recruitment success in years following years with and without fishing (Beukema and Dekker, 2018), a long-term (1993–2004) increasing trend in cockle recruitment in frequently fished areas as observed by Kamermans et al. (2004) (see also fig. 34 in Ens et al., 2004b) and an on average higher recruitment in areas open to fishery than in closed areas (Ens et al., 2004b: their fig. 35).

All of this evidence contradicts findings published in Piersma et al. (2001), the only paper found that suggests a reduction in bivalve recruitment caused by cockle dredging. According to Piersma et al. (2001), recruitment of cockles (and non-significantly also of *Limecola balthica*) was reduced in the years after dredging (as compared to non-dredged nearby areas), to recover only after some 8 years. However, their conclusions were effectively countered by Van der Meer and Folmer (2023). Compton et al. (2016) suggested an even longer period till high recruitment was restored in L. *balthica*. Apparently, they had not been aware of the paper by Beukema and Cadée (1996), who reported a recruitment in this species in 1991 that was higher than ever in 50 years and occurred immediately after the mechanical fishery on the tidal flats executed in 1990 that was more intensive than ever. Van der Meer and Folmer (2023) also show a higher recruitment in this species in 1991 than in seven subsequent years in dredged areas around Griend and north of Groningen and a one-but-highest recruitment on the Piet Scheveplaat. They found little difference in recruitment success between dredged and reference areas. Like in L. *balthica*, recruitment in cockles was relatively high in 1991 (as compared to other years of the 1990–1999 period) and even slightly higher in dredged than in reference areas near Griend as well as on Balgzand (Van der Meer and Folmer, 2023). Relatively high recruitments in cockles were observed also in 1990, immediately after a period with intensive fishery.

Franklin and Pickett (1978) found cockle spat fall levels in dredged areas to be similar to those in adjacent unfished areas. De Vlas (1987) did not find a difference in cockle recruitment between a fished and an undisturbed part of a cockle bank. Cotter et al. (1997) found hardly any differences in cockle recruitments after tractor dredging for adult cockles. They conclude that delayed effects of the dredging on cockle stocks were negligible. Hiddink (2003) observed that the suitability for 0-group *Limecola balthica* and *Cerastoderma edule* was not affected by cockle dredging. There are some indications of reduced mussel recruitment in areas where cockles were dredged (Hiddink, 2003; Leopold et al., 2004), but there is no evidence that cockle dredging negatively affected mussel recruitment at the scale of the Wadden Sea (Ens et al., 2004b).

The effects of the very intensive fishing for mussels and cockles on Balgzand in the summer of 1990 might indicate causes of relatively high bivalve recruitment after cockle fishing. This fishery in 1990 resulted not only in an area poor in biomass (no cockles nor mussels were left in early 1991), but also to highly successful recruitments observed in the summer of 1991 in an unusually high number of species (Beukema and Cadée, 1996). These overshoots may have been due to a plenty of space, plenty of food by elevated algal concentrations (by low grazing activity of bivalves: Beukema and Cadée, 1996), a reduced mortality of larvae of various species by an absence of inhaling activity of bivalves (André and Rosenberg, 1991), and low disturbance of sediment by activities of adult bivalves, enhancing survival of early bottom stages in several species (Flach, 1996). It is unknown which of all these known factors were the most important for the observed high recruitment successes immediately after intensive dredging. All in all, there is a lot of evidence that fishing for bivalves on tidal flats might promote rather than reduce bivalve recruitment.

3.4. Effects on non-target fauna

Clarke et al. (2017) reviewed impacts of invertebrate harvesting on intertidal benthic communities. Invariably, they found negative effects of harvesting. Recovery rates were highly variable, with near-recovery within two months in many species. Several publications reported on influences of cockle dredging on abundance of other species than cockles (Table 2). Generally, they reported serious immediate negative effects on numbers of non-target benthic fauna. Much less has been published on recovery times. In the following, the numerous relevant papers will

Table 2
Observed changes (abundance after some months, immediate mortality, speed of recovery) attributed to mechanical cockle fishing in non-target fauna (small worms and small bivalves).

abundance		immediate mortality		recovery	reference
worms	bivalves	worms	bivalves		
	no change				Hiddink (2003)
incr/decr	decline (2 sp.)				Leopold et al. (2004)
	no change				Kamermans et al. (2004)
no change	no change				Wijnhoven et al. (2011)
no change	decline (1 sp.)				Clarke and Tully (2014)
	Increase				Sinclair et al. (2018)
		5–50%	30%		De Vlas (1987)
		25–100%	45–50%		Ens et al. (2004a, 2004b)
				rapid	Hall and Harding (1997)
				rapid	Beukema and Cadée (1996)

be discussed in chronological order.

De Vlas (1987) was probably the first to study effects of cockle dredging on bottom fauna. Cockle dredges wash out all animals in the top layer of the sediment. Only animals larger than about 1.5 cm (i.e. almost exclusively adult cockles) are retained. Smaller animals remain in the water jet and part of them survive. Larger animals, such as lugworms *Arenicola marina* and adult clams *Mya arenaria* live too deep to be touched. Immediate mortality in small worms amounted to 5–50%, in small bivalves to about 30%. Ens et al. (2004a) found somewhat higher percentages (the comparison is shown in table 7 of Ens et al., 2004b). Due to the relatively small part of the tidal flats fished (a few percent per year), De Vlas (1987) estimated the loss of the non-target animals to be <1% of the entire Wadden Sea populations of these species. This estimate was for years when fishing intensity was still rather low.

Hall and Harding (1997) did field experiments and compared small fished with undisturbed plots. They found high levels of mortality in non-target benthic species, but observed rapid (within 2 months) recovery of the faunal structure in the disturbed plots. They conclude that the overall effects on populations of non-target species were probably low. Such rapid recovery of several species of the benthic fauna after serious disturbance by fishing on mussels and cockles was also observed by Beukema and Cadée (1996). In a high proportion of the species, this was attributed to increased rates of recruitment and growth.

Ferns et al. (2000) found substantial mortality in some worm species after tractor dredging on tidal flats. Some of these species had not yet completely recovered after 2 or 3 months.

Hiddink (2003) compared the fauna before and after cockle dredging in non-fished plots of about 1000 m^2 with that of surrounding dredged areas. He found little differences, but the dredged areas appeared to be less suitable for settlement of *Mytilus edulis* and *Limecola balthica.* On the other hand, Sinclair et al. (2018) found a significant increase in numbers of *Limecola balthica* after cockle dredging, in particular after suction dredging.

Leopold et al. (2004) made an extensive Dutch Wadden Sea-wide study of relationships between cockle dredging intensity in foregoing years and changes in the fauna. They found negative effects on the abundance of *Cerastoderma edule, Mytilus edulis, Limecola balthica* and *Lanice conchilega*, but non-consistent effects on abundance of other worms (in one species, *Hediste diversicolor,* even positive abundance changes in the years after fishing). The decline of mussels in earlier fished areas may be explained by a lack of cockle shells serving as substratum for mussel spat.

By comparison of fished and unfished areas and of areas closed and open to fishery, Kamermans et al. (2004) did not find significant differences in the dynamics of populations of *Limecola balthica.*

Kraan et al. (2007) compared the fauna of dredged and surrounding non-dredged areas on the base of samples taken at thousands of stations. Contrary to the express statements of the authors, these two area types were in fact not really similar as to environmental conditions (Beukema and Dekker, 2009). As opposed to the dredged areas, the non-dredged areas included both very high and very low tidal flats where the fauna included species such as *Macomangulus (Tellina) tenuis* and *Ensis leei* that hardly occurred in the dredged areas (Beukema and Dekker, 2009). Therefore, this study could not really establish an effect of dredging in such species. The statements by Kraan et al. (2007) that A. (*T.*) *tenuis* increased and *E. leei* declined in the fished area are therefore unjust. In most of the other species, occurrence before and after dredging hardly changed. Apart from cockles, only the abundance of *Mytilus edulis* and *Heteromastus filiformis* was negatively affected. Kraan et al. (2011) found a strong decline in the abundance of in particular molluscs (but also in crustaceans and to a lesser extent in polychaetes) between 1956 and 2005 in two areas in the western Dutch Wadden Sea. As in both areas mussels as well as cockles had intensively been fished and most mussel beds had disappeared from the area, the declines could not with any certainty be ascribed to cockle dredging. The (almost) complete disappearance of mussel beds may have exerted a stronger negative influence, as with the disappearance of mussel beds extensive more or less silty areas had turned into sand flats, showing an impoverished fauna.

By a BACI study, Wijnhoven et al. (2011) compared the fauna at dredged and non-dredged parts of a tidal flat in the Oosterschelde (SW Netherlands) 2 months and 1 year after fishing. They found no effects on macrofauna density, diversity or biomass. The loss of weight of fished adult cockles was almost compensated by the increases of biomass of non-target species.

Likewise, Clarke and Tully (2014) studied the effects of hydraulic dredging for cockles in Ireland by monitoring sediment and benthos. They could not detect significant differences in community structure nor in non-target species as a consequence of dredging, with one exception of a short-lived effect in a bivalve living close to the surface: *Macomangulus (Tellina) tenuis*.

3.5. Effects on food supply of birds

Numbers of birds that are dependent primarily on bivalves (Oystercatchers, Knots, Herring gulls, Eiders) showed a declining trend in the Wadden Sea area, starting around 1990 (Ens et al., 2004b). These trends were opposed to those for worm-eating birds (Van Roomen et al., 2005), which numbers increased in most of these species since around 1990. The declining trend in shellfish eating birds continued after the closure of the mechanical cockle fishery. No clear positive effect on bird numbers was observed when cockles were exceptionally abundant around 2012. Thus, it remains doubtful whether cockle abundance and cockle fishery were a main cause for the ongoing decline of numbers of shellfish eating birds in the Wadden Sea.

There are important differences in prey selection among the four shellfish-eating bird species. Eiders and Oystercatchers prey on adult cockles that are also targeted by fishermen (Leopold et al., 2004). Hence, these two species may suffer most from cockle fishery. Eiders swallow shellfish whole, so that the thick shells of cockles make them less profitable as prey (Ens and Kats, 2004). Mass mortality of Eiders in the winter of 1999/2000 was linked to fishery caused shortage of principal (mussels and cockles) and secondary (*Spisula subtruncata*) prey, but the contribution of fishery on these three species to bird mortality could not be assessed (Camphuysen et al., 2002). Directly relating Eider mortality to shellfish stocks for the period 1979–2002 showed that high mortality was primarily due to shortage of sublittoral mussels, which are the preferred prey due to their high flesh to shell ratio (Ens and Kats, 2004; Ens 2006). Furthermore, by linking detailed Eider counts to detailed shellfish surveys, it was found that the distribution of Eiders wintering in the Dutch Wadden Sea was primarily determined by the density of medium and large-sized mussels on the sublittoral culture plots (Cervencl et al., 2015). For the Danish Wadden Sea, it was concluded that availability of blue mussels may have a key role in building up and maintaining body condition in Eiders during winter (Laursen et al., 2009). Summarizing, there is no evidence for a direct effect of suction dredging for cockles on survival of wintering Eiders.

In contrast, two papers report clear evidence for a negative effect of cockle fishery and of low cockle abundance on Oystercatchers. In early 2001, Verhulst et al. (2004) found a lower condition (a body-weight measure that predicts mortality rate) in Oystercatchers found dead in areas where cockle fishery was allowed as compared to protected areas. From this difference, they estimated a 43% higher annual mortality in fished areas (where densities of adult cockles were lower and Oystercatchers had less shellfish in their diets). Such an elevated rate of mortality might explain the declining trend of Oystercatcher numbers, but not the ongoing decline of these numbers after the total closure of the fishery in 2003 and the gradual recovery of mussel beds. Beukema (1993) and Beukema and Cadée (1996) observed that in early 1991, when mussel and cockle densities were exceptionally low, Oystercatchers shifted to prey on alternative bivalve species (*Limecola balthica, Mya arenaria*) and as a result these species then showed elevated death rates. Apparently, these alternative food sources, which only Oystercatchers can reach by their long bill, provided insufficient food and Oystercatchers left the area earlier in winter than in other years. Although the 1990/1991 winter was not really severe, Oystercatchers showed elevated death rates in 1991 (Camphuysen et al., 1996). Earlier dispersal in spring of Oystercatchers away from tidal-flat areas when cockle abundance was low there was also observed in the Burry Inlet (England) by Norris et al. (1998). The events in 1991 will have been a consequence of too intensive fishery in 1990 for both mussels and cockles. Kamermans et al. (2003) calculated an estimated yield of 100% of the weight of the Wadden Sea cockle stock in 1990 (in the other 12 years of the 1990–2002 period this percentage varied from 0 to 29%). Nearly all mussel beds in the intertidal of the Dutch Wadden Sea were removed completely in that year (Beukema, 1993).

It took more than two decades before the intertidal mussel beds that were removed in 1990 had fully reappeared. However, this return was accompanied with the establishment of the exotic Pacific oyster (*Magellana gigas),* so that an increasing number of beds are a mixture of mussels and oysters (Troost et al., 2022). Such beds offer little food to Oystercatchers (Waser et al., 2016). Modeling the birth, growth and death of the intertidal shellfish beds on the basis of data spanning the 1999–2013 period and taking mixed beds into account, Van der Meer et al. (2019) predicted that from 2020 onwards the area of intertidal shellfish beds would fluctuate between 2000 and 5000 ha, as was the case (Troost et al., 2022). It was estimated that before the nearly complete removal of intertidal mussel beds, more than half the population of wintering Oystercatchers depended on mussels (Smit et al., 1998). Hence, the establishment of the Pacific oyster is a permanent and major reduction in the carrying capacity for wintering Oystercatchers.

Declining numbers of shellfish eating birds appear to be largely due to this near-disappearance of mussels (Smit et al., 1998). Oystercatchers are particularly sensitive to low cockle abundance at times that mussel stocks are also low (Atkinson et al., 2003, 2005). It was estimated for the years 1990–2001, that suction dredging for cockles reduced the carrying capacity of the Dutch Wadden Sea by 12%, but that the removal of the intertidal mussel beds was the primary cause of the decline in the wintering population of Oystercatchers (Rappold et al., 2003). A salient detail is that the removal of intertidal mussel beds was executed mostly by cockle fishers, as only their ships had a sufficiently shallow drought to be able to fish on the flats for several hours per day.

In 1990, when fishing pressure on mussels and cockles was exceptionally high, stocks of the main shellfish species were relatively small due to failing recruitments in the preceding years 1988 and 1989. At that time, there was insufficient legislation to prevent overfishing on tidal flats. The destructive fishery for shellfish in 1990 compelled the government to restrict this fishery in the Wadden Sea. Starting from 1993, the government decided that substantial parts of the tidal flats were closed for cockle fishery and that a certain amount of bird food should be reserved. The biomass values of bird food to be expected in the fishing season (August–October) were calculated from wide-scale sampling in May, but unfortunately this procedure often resulted in overestimates (Kamermans et al., 2003). The reservations led to a closure of the cockle fishery in 1996 and 1997 (low stocks after severe winters). The policy of food reservation applied between 1993 and 2003 was welcome, but students of bird dynamics judged the threshold value as too low (Ens et al., 2004b). On the other hand, seriously enhanced mortality rates in Oystercatchers were not observed in the years after 1991 (Camphuysen et al., 1996). It is difficult to assess a minimum cockle stock that should be reserved for birds, because stock size of alternative shellfish species (mussels in particular) is a complicating factor in assessing a lower limit to food supply. Starting from 2003, mechanical cockle fishing in the Dutch Wadden Sea was completely closed, solving the problems that were met in detailed regulation.

Like Eiders, Herring gulls and Knots swallow their bivalve prey whole, so that the thick shells of the cockles reduce their profitability as a prey item. Cockles are generally not an important food source for Herring gulls (Camphuysen, 2013), but when they do take them, they take young age classes that are not targeted by fishermen (Spaans, 1971). Knots can only swallow cockles that are well below the lower size limit of fishermen. Hence, any impact of suction dredging cockles on Knots (and Herring gulls) must be through its possible effect on the recruitment of bivalve prey. According to Van Gils et al. (2006), the gradual destruction by suction dredging cockles of the necessary intertidal resources explained both the loss of Red Knots from the Dutch Wadden Sea and the decline of their European wintering population. By reanalyzing the data in this paper, Van der Meer and Folmer (2023) show that this conclusion is false. In fact, dredging may even benefit Knots. There is no doubt that feeding conditions for Knots deteriorated between 1998 and 2002 in the western Dutch Wadden Sea, but there is no evidence that this was due to suction dredging cockles.

4. Discussion

Several studies brought forward a variety of negative effects of mechanical cockle fishery on the tidal-flat ecosystem. However, not all of the results and conclusions of these studies can be considered as equally firm. For a proper evaluation of the effects, it should be kept in mind that the fishery affected annually only a minor fraction (a few percent) of the tidal flats. It appears questionable whether the reworking of the small proportions of the bottom could exert a large-scale influence on the bottom structure of the fished and surrounding areas. Natural events such as gales and floating ice might be much more drastic and, moreover, might wipe out the changes caused by dredging. Maybe, effects of silt suspension had some negative effect by coarsening the sediment in areas already poor in silt. The low mussel stocks from late-1990 (caused by the large-scale removal of mussels that took place around 1990) continuing for a long period thereafter (the mussel beds only slowly recovered) might have coarsened the sediment over much larger areas than cockle fishery could do and might have had a more serious effect on sediment composition.

Cockle fishery thins the stocks of adult cockles on tidal flats, though for a high proportion so only in years with low cockle abundance. Fishery thus reduced the food supply for Oystercatchers to a varying extent. Apart from Verhulst et al. (2004), hardly any direct effects of bivalve abundance on abundance of birds or their survival has been established. The events in 1991 appear to be a unique exception: extremely small stocks that occurred simultaneously in both cockles and mussels resulted in early disappearance of Oystercatchers from the tidal flats in late-winter 1991 and in reduced survival of these birds in that period.

The effects of cockle dredging on non-target infauna were investigated best by the two BACI studies (Wijnhoven et al., 2011; Clarke and Tully, 2014). In both studies, serious long-term effects on non-target fauna proved to be absent. The short-term effects hit only minor parts of the total populations because only small parts of the tidal flats were touched by the fishery. Other studies (Hall and Harding, 1997; Hiddink, 2003) reported rapid recovery or little differences between dredged and non-fished areas. Reports on the effects on the abundance of *Limecola balthica* were inconsistent.

Except for the paper by Piersma et al. (2001), none reported a negative effect of cockle fishing on cockle recruitment, The Piersma et al. (2001) study, however, was exposed as flawed by Van der Meer and Folmer (2023). This late unmasking is regrettable, because the Piersma et al. (2001) paper played an important role in the coming about of the decision to close the cockle fishery in The Netherlands. Moreover, it is the most cited paper on effects of cockle fishery and it will have strengthened the view that cockle fishery causes irreparable damage to the tidal-flat ecosystem.

Only the reports published by members of the Piersma group (Piersma et al., 2001; Van Gils et al., 2006; Kraan et al., 2007, 2011; Compton et al., 2016) suggest serious and long-lasting negative effects of cockle dredging on non-target fauna and on bivalve recruitment. However, the reliability of the conclusions drawn in the papers by members of the Piersma group may be questioned, because all of these papers show serious shortcomings. The conclusions of Kraan et al. (2007) were based on the false starting-point of similarity between the compared (fished and non-fished) areas. In the control areas, the biomass values of benthos showed a higher variance (see Beukema and Dekker, 2009: 290–291). Kraan et al. (2011) blame the cockle fishery for the impoverishment of a large sandy area in the western Wadden Sea, but this could at least equally well have been a consequence of the near-disappearance of mussel beds from this area. The presence of mussel beds positively affects a wide area around the beds (Zwarts et al., 2004; Van der Zee et al., 2012). The conclusion of Piersma et al. (2001) on a long-delayed (8 years) recovery of bivalve recruitment was based on a data series that started no <2 (Balgzand) to 4 (Griend) years after a large-scale cockle dredging. It included only one comparison of recruitment rates observed in successive periods (1992–1994 versus 1996–1998), chosen out of a number of possible comparisons (see Beukema and Dekker, 2018: 85; Beukema and Dekker, 2020b: 9). Piersma et al. (2001) had omitted data for 1991 and 1995; a reason was given only for the latter omission (lack of suitable data at 1 out of the 5 sampling places). Particularly the omission of the 1991 data (the first year after intensive fishing for which data were available) was crucial. The inclusion of the 1991 data would have reversed or annihilated any increasing trend in recruitment after fishing. Van der Meer and Folmer (2023) recalculated the differences in recruitment success between fished and control areas for the 4 sampling places with a full data set (1990–1999) and found not any indication for the suggestion by Piersma et al. (2001) of a delayed recruitment recovery. This suggestion in Piersma et al. (2001) was thus entirely due to the particular selection of years they had made and it completely vanished when all available data are considered. In conclusion: all five papers on effects of cockle fishery by members of the Piersma group are in one way or another flawed.

It is remarkable that the members of the Piersma group were connected with the action group “De wilde kokkel” (“wilde” can be translated by wild as well as by savage). This group agitated against all fishery for cockles in the Wadden Sea. Though presented as objective science the above papers of the Piersma group create the impression that they selectively published evidence to discredit the fishery. In the short term, such attitude might serve nature conservation (and it did), but in the long term its one-sidedness inevitably will be noted. The most serious consequence is that it harms the credibility of ecological research and advice. At the very least, scientist should clearly state what position they take: either as independent researchers or as connected to a stakeholder. Because of their noisy and public advocacy to stop suction dredging cockles, those researchers were excluded from the EVA-II evaluation (Ens et al., 2004b) of the effects of mechanical cockle fishery in Dutch waters by the two ministries funding the research program (Swart and Van Andel, 2008).

5. Conclusion

Although in the above the evidence underlying the closure of mechanical cockle fishery in the Dutch Wadden Sea is criticized and partly found insufficiently founded, it is not intended to advocate a re-introduction of this fishery after its buy-out in 2004. In a nature reserve, any large-scale activity such as mechanical fishery simply is not appropriate. In such areas, the precautionary principle always should prevail.

6. Epilogue

The attentive reader will have noticed that the present author was one of the co-authors of the above criticized paper Piersma et al. (2001). His role was modest: he provided part of the data, but never saw the complete data set and was not really involved in the writing of the paper. In hindsight, he regrets his acceptance of co-authorship. Without success, he later tried to achieve that the Piersma et al. (2001) was retracted or at least that his name would be removed from the list of co-authors.

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The author has no conflicts of interest to declare.

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References

André, C., Rosenberg, R., 1991. Adult-larval interactions in the suspension-feeding bivalves *Cerastoderma edule* and *Mya arenaria*. Mar. Ecol. Prog. Ser. 71, 227–234.

Atkinson, P.W., Clark, N.A., Bell, M.C., Dare, P.J., Clark, J.A., Ireland, P.L., 2003. Changes in commercially fished shellfish stocks and shorebird populations in the Wash, England. Biol. Conserv. 114, 127–141.

Atkinson, P.W., Clark, N.A., Dodd, S.G., Moss, D., 2005. Changes in fishery practices and oystercatcher survival, recruitment and body mass in a marginal cockle fishery. Ardea 93, 199–212.

Beukema, J.J., 1993. Increased mortality in alternative bivalve prey during a period when the tidal flats of the Dutch Wadden Sea were devoid of mussels. Neth. J. Sea Res. 31, 395–406.

Beukema, J.J., Cadée, G.C., 1996. Consequences of the sudden removal of nearly all mussels and cockles from the Dutch Wadden Sea. PSZNI. Mar. Ecol. 17, 279–289.

Beukema, J.J., Dekker, R., 2005. Decline of recruitment success in cockles and other bivalves in the Wadden Sea: possible role of climate change, predation on postlarvae and fisheries. Mar. Ecol. Prog. Ser. 287, 149–167.

Beukema, J.J., Dekker, R., 2009. The intertidal zoning of cockles (*Cerastoderma edule*) in the Wadden Sea, or why cockle fishery disturbed areas of relatively high biodiversity. Helgol. Mar. Res. 63, 287–291.
Beukema, J.J., Dekker, R., 2014. Variability in predator abundance links winter character and bivalve recruitment: correlative evidence from long-term data in a tidal flat. Mar. Ecol. Prog. Ser. 513, 1–15.
Beukema, J.J., Dekker, R., 2015. Density dependence of growth and production in a Wadden Sea population of the cockle *Cerastoderma edule*. Mar. Ecol. Prog. Ser. 538, 157–167.
Beukema, J.J., Dekker, R., 2018. Effects of cockle abundance and cockle fishery on bivalve recruitment. J. Sea Res. 140, 81–86.
Beukema, J.J., Dekker, R., 2019a. Is food supply for shellfish-eating birds in the western Wadden Sea affected by the between-species synchrony in year-to-year fluctuations of bivalve population parameters? Helgol. Mar. Res. 73, 8.
Beukema, J.J., Dekker, R., 2019b. The carrying capacity of a tidal flat area for suspension-feeding bivalves. Mar. Ecol. Prog. Ser. 629, 55–65.
Beukema, J.J., Dekker, R., 2020a. Winters not too cold, summers not too warm: long-term effects of climate change on the dynamics of a dominant species in the Wadden Sea: the cockle *Cerastoderma edule* L. Mar. Biol. 167, 44.
Beukema, J.J., Dekker, R., 2020b. Half a century of monitoring macrobenthic animals on tidal flats in the Dutch Wadden Sea. Mar. Ecol. Prog. Ser. 656, 1–18.
Brinkman, A.G., Smaal, A.C., 2003. Onttrekking en natuurlijke productie van schelpdieren in de Nederlandse Waddenzee in de periode 1976–1999. Alterra rapport 888. Alterra, Wageningen, pp. 1–238.
Callaway, R., 2022. 50 years of estuarine cockles (*Cerastoderma edule*L.): shifting cohorts, dwindling sizes and the impact of improved wastewater treatment. Estuar. Coast. Shelf Sci. 270, 107834.
Camphuysen, C.J., Ens, B.J., Heg, D., Hulscher, J.B., van der Meer, J., Smit, C.J., 1996. Oystercatcher *Haematopus ostralegus* winter mortality in the Netherlands. The effect of severe weather and food supply. Ardea 84A, 469–492.
Camphuysen, C.J., Berrevoets, C.M., Cremers, H.J.W.M., Dekinga, A., Dekker, R., Ens, B. J., van der Have, T.M., Kats, R.K.H., Kuiken, T., Leopold, M.F., van der Meer, J., Piersma, T., 2002. Mass mortality of common eiders (Somateria mollissima) in the Dutch Wadden Sea, winter 1999/2000: starvation in a commercially exploited wetland of international importance. Biol. Conserv. 106, 303–317.
Cervencl, A., Troost, K., Dijkman, E., De Jong, M., Smit, C.J., Leopold, M.F., Ens, B.J., 2015. Distribution of wintering Common Eider Somateria mollissima in the Dutch Wadden Sea in relation to available food stocks. Mar. Biol. https://doi.org/10.1007/s00227-014-2594-4.
Ciutat, A., Widdows, J., Pope, N.D., 2007. Effect of *Cerastoderma edule* density on near-bed hydrodynamics and stability of cohesive muddy sediments. J. Exp. Mar. Biol. Ecol. 346, 114–126.
Clarke, S., Tully, O., 2014. BACI monitoring of effects of hydraulic dredging for cockles on intertidal benthic habitats of Dundalk Bay, Ireland. J. Mar. Biol. Assoc. U. K. 94, 1451–1464.
Clarke, J.L., Hughes, K.M., Esteves, L.S., Herbert, R.J.H., Stillman, R.A., 2017. Intertidal invertebrate harvesting: a meta-analysis of impacts and recovery in an important waterbird prey resource. Mar. Ecol. Prog. Ser. 584, 229–244.
Compton, T.J., Bodnar, W., Koolhaas, A., Dekinga, A., Holthuysen, S., ten Horn, J., McSweeney, N., van Gils, J.A., Piersma, T., 2016. Burrowing behavior of a deposit feeding bivalve predicts change in intertidal ecosystem state. Front. Ecol. 4 (2016), 00019.
Cotter, A.J.R., Walker, P., Coates, P., Cook, W., Dare, P.J., 1997. Trial of a tractor dredger for cockles in burry inlet, South Wales. ICES J. Mar. Sci. 54, 72–83.
De Vlas, J., 1987. Effects of cockle fisheries on the macrobenthos in the Wadden Sea. In: Tougaard, S., Asbirk, S. (Eds.), Proceedings of the 5th international Wadden Sea Symposium, Esbjerg, pp. 215–227.
Ens, B.J., Kats, R.K.H., 2004. Evaluatie van voedselreservering Eidereenden in de Waddenzee - rapportage in het kader van EVA II deelproject B2. Alterra rapport 931, pp. 1–155. Wageningen. https://edepot.wur.nl/30669.
Ens, B.J., De Jong, M.L., Ter Braak, C.J.F., 2004a. Resultaten Kokkelvisexperiment Ameland. Alterra Rapport 945, Alterra, Wageningen. https://edepot.wur.nl/28504.
Ens, B.J., Smaal, A.C., De Vlas, J., 2004b. The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde. Alterra-rapport 1011, RIVO-rapport C056/04, RIKZ-rapport RKZ/2004.031, 1-212.
Ferns, P.N., Rostron, D.M., Siman, H.Y., 2000. Effects of mechanical cockle harvesting on intertidal communities. J. Appl. Ecol. 37, 464–474.
Flach, E.C., 1996. The influence of the cockle, C*erastoderma edule,* on the macrozoobenthic community of tidal flats in the Wadden Sea. PSZN I. Mar. Ecol. 17, 87–98.
Franklin, A., Pickett, G.D., 1978. Studies on the indirect effects of fishing on stocks of cockles, *Cardium edule*, in the Thames estuary and wash. Fish. Res. Tech. Rep. Lowestoft 42, 9.
Hall, S.J., Harding, M.J.C., 1997. Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna. J. Appl. Ecol. 34, 497–517.
Hancock, D.A., 1973. The relationship between stock and recruitment in exploited invertebrates. Rapports et Proces-verbaux Réunion 164, 113–131.
Haupt, P., 2022. Review of Environmental Impacts of Hydraulic Suction Dredging for Cockles in Kent and Essex IFCA District. Cocklereview.kentandessex-ifca.gov.
Hiddink, J.G., 2003. Effects of suction-dredging for cockles on non-target fauna in the Wadden Sea. J. Sea Res. 50, 315–323.
Hiddink, J.G., Jennings, S., Sciberras, M., Kaiser, M., 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. Proc. Natl. Acad. Sci. 114, 8301–8306.
Kamermans, P., Kestelo, J., Baars, D., 2003. Evaluatie van de geschatte omvang en ligging van kokkelbestanden in de Waddenzee, Ooster- en Westerschelde. In: RIVO Rapport C054/03, pp. 1–88. https://edepot.wur.nl/26995.
Kamermans, P., Bult, T., Kater, B., Baars, D., Kestelo, J., Perdon, J., Schuiling, E., 2004. Deelproject H4: Invloed van natuurlijke factoren en kokkelvisserij op de dynamiek van bestanden aan kokkels (*Cerastoderma edule*) en nonnen (*Macoma balthica*) in de Waddenzee, Ooster- en Westerschelde. In: RIVO Rapport C058/03, pp. 1–180. https://open.rws.nl/open-overheid/onderzoeksrapporten/@20558/deelproject-h4-invloed-natuurlijke/.
Kraan, C., Piersma, T., Dekinga, A., Koolhaas, A., Van der Meer, J., 2007. Dredging for edible cockles (*Cerastoderma edule*) on intertidal flats: short-term consequences of fisher patch-choice decisions for target and non-target benthic fauna. ICES J. Marine Sci. 64, 1735–1742.
Kraan, C., Dekinga, A., Piersma, T., 2011. Now an empty mudflat: past and present benthic abundances in the western Dutch Wadden Sea. Helgol. Mar. Res. 65, 51–58.
Laursen, K., Asferg, K.S., Frikke, J., Sunde, P., 2009. Mussel fishery affects diet and reduces body condition of eiders *Somateria mollissima* in the Wadden Sea. J. Sea Res. 62, 22–30.
Leopold, M.F., Dijkman, E.M., Cremer, J.S.M., Meijboom, A., Goedhart, P.W., 2004. De effecten van mechanische kokkelvisserij op de benthische macrofauna en hun habitat. Alterra-rapport 955, 1–146. https://edepot.wur.nl/19102.
Magalhaes, L., Freitas, R., de Montaudouin, X., 2016. Cockle population dynamics: recruitment predicts adult biomass, not the inverse. Mar. Biol. 163, 16.
Mendonca, V.M., Raffaelli, D.G., Boyle, P., Haskins, S., 2008. Spatial and temporal characteristics of benthic invertebrate communities at Culbin Sands lagoon, Moray Firth, NE Scotland, and impacts of the disturbance of cockle harvesting. Sci. Mar. 72, 265–278.
Nomden, E., Duiker, M., Van den Berg, J.H., Smaal, A.C., 1999. Effecten van kokkelvisserij op sediment en bodemleven. RIVO rapport C034/99, pp. 1–47. https://edepot.wur.nl/524167.
Norris, K., Bannister, R.C.A., Walker, P.W., 1998. Changes in number of oystercatchers *Haematopus ostralegus* wintering in the burry inlet in relation to the biomass of cockles *Cerastoderma edule* and its commercial exploitation. J. Appl. Ecol. 35, 75–85.
Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J.J., Dekker, R., Essink, K., 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. J. Appl. Ecol. 38, 976–990.
Pitcher, C.R., Hiddink, J.G., Jennings, S., Hilborn, R., 2022. Trawl impacts on the relative status of biotic communities of seabed sedimentary habitats in 24 regions worldwide. Proc. Natl. Acad. Sci. 119, e2109449119.
Rappold, C., Ens, B.J., Dijkman, E., Bult, T., 2003. Scholeksters en hun voedsel in de Waddenzee. Alterra Rapport 882, Alterra, Wageningen. https://edepot.wur.nl/25512.
Sinclair, B., Watson-Creek, A., Nevin, O., Carr, A., Smith, D., Mehrota, R., 2018. Pilot Study Examining the Effects of Hydraulic and Elevator Dredge Harvesting of Marine Bivalves Such as the Common Cockle (*Cerastoderma edule*) on Intertidal Communities. CQUniversity Report. https://hdl.handle.net/10018/1250457.
Smit, C.J., Dankers, N., Ens, B.J., Meijboom, A., 1998. Birds, mussels, cockles and shellfish fishery in the Dutch Wadden Sea: how to deal with low food stocks for eiders and oystercatchers? Senckenberg. Marit. 29, 141–153.
Spaans, A.L., 1971. Feeding ecology of herring Gull *Larus argentatus* Pont in northern part of Netherlands. Ardea 59, 73–188.
Swart, J.A.A., Van Andel, J., 2008. Rethinking the interface between ecology and society. The case of the cockle controversy in the Dutch Wadden Sea. J. Appl. Ecol. 45, 82–90.
Troost, K., van Asch, M., van den Ende, D., van Es, Y., Perdon, K.J., van der Pool, J., Suykerbuyk, W., van Zweeden, C., van Zwol, J., 2022. Schelpdierbestanden in de Nederlandse Kustzone, Waddenzee en zoute deltawateren in 2021. Centrum voor Visserijonderzoek (CVO), IJmuiden. https://edepot.wur.nl/565199.
Van der Meer, J., Folmer, E., 2023. A re-evaluation of the effects of mechanical cockle dredging in the Dutch Wadden Sea. J. Appl. Ecol. (in press).
Van der Meer, J., Piersma, T., Beukema, J.J., 2001. Population dynamics of benthic species on tidal flats: The possible role of shorebird predation. In: Reise, K. (Ed.), Ecological Comparisons of Sedimentary Shores. Springer, pp. 317–335.
Van der Meer, J., Dankers, N., Ens, B.J., van Stralen, M., Troost, K., Waser, A.M., 2019. The birth, growth and death of intertidal soft-sediment bivalve beds: no need for large-scale restoration programs in the Dutch Wadden Sea. Ecosystems 22, 1024–1034.
Van der Zee, E.M., et al., 2012. Spatially extended habitat modification by intertidal reef-building bivalves has implications for consumer-resource interactions. Ecosystems 15, 564–573.
Van Gils, J.A., Piersma, T., Dekinga, A., Spaans, B., Kraan, C., 2006. Shellfish dredging pushes a flexible avian top predator out of a marine protected area. PLoS Biol. 4 (12), 2399–2404.
Van Roomen, M., Van Turnhout, C., Van Winden, E., Koks, B., Goedhart, P., Leopold, M., Smit, C., 2005. Trends in benthivorous waterbirds in the Dutch Wadden Sea 1975–2002: large differences between shellfish-eaters and worm-eaters. Limosa 78, 21–38.
Verhulst, S., Oosterbeek, K., Rutten, A.L., Ens, B.J., 2004. Shellfish fishery severely reduces condition and survival of oystercatchers despite creation of large marine protected areas. Ecol. Soc. 9 (1), 17.
Waser, A.M., Deuzeman, S., Kangeri, A.K., van Winden, E., Postma, J., de Boer, P., van der Meer, J., Ens, B.J., 2016. Impact on bird fauna of a non-native oyster expanding into blue mussel beds in the Dutch Wadden Sea. Biol. Conserv. 202, 39–49.

Widdows, J., Brinsley, M., 2002. Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone. J. Sea Res. 48, 143–156.
Wijnhoven, S., Escaravage, V., Herman, P.M.J., Smaal, A.C., Hummel, H., 2011. Short and mid-long- term effects of cockle-dredging on non-target macrobenthic species: a before-after-control-impact experiment on a tidal mudflat in the Oosterschelde (the Netherlands). Mar. Ecol. 32 (Suppl. 1), 117–129.
Zwarts, L., et al., 2004. Bodemgesteldheid en mechanische kokkelvisserij in de Waddenzee. Rapport RIZA/2004.028, pp. 1–129. http://www.vliz.be/imisdocs/publications/ocrd/68914.pdf.