HARBASINS

HARBASINS Report:

Spread of the Pacific Oyster *Crassostrea gigas* in the Wadden Sea

Causes and consequences of a successful invasion

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1 INTRODUCTION AND SCOPE OF WORK

The recent spread of the Pacific oyster *Crassostrea gigas* in the Wadden Sea is one of the most spectacular biological invasions in this ecosystem and has attracted the attention of the public as well as of the scientific community. Pacific oysters have most probably been brought to European waters since ships are sailing between the continents. They have been cultivated in various places for decades and were seemingly not adapted to prosper in the Wadden Sea. Brought out in cultures in France and the Netherlands to substitute the European Oyster which became extinct in many places, it was reported to spread soon in warm summers and form stable populations outside the cultures since the seventies which are increasing until today. Pacific oysters are found in the Wadden Sea since the eighties, where cultivation has been licensed in the Lister Deep between the island of Sylt and the mainland since 1986. As commonly reported from other biological invasions, the development in the Wadden Sea was rather slow over many years and some colonised sites were abandoned again. However, following a period of rather warm summers, Pacific Oysters have drastically increased, overgrown many native blue mussel *Mytilus edulis* beds and are suddenly an abundant and dominating species on the tidal flats. By forming extensive and stable reefs on the tidal flats, Pacific oysters create new habitats which may be suitable for other species living in the mussel bed community. The sudden and fast spread of this invader has raised concern about the ecological impacts. Will blue mussel beds be displaced by Pacific oyster reefs, and if so, what will be the consequences for the benthic communities, how will mussel eating birds be affected? As Pacific oysters mainly settled into native mussel beds they are also considered as a problem for mussel fisheries. On the other hand, it is not quite clear how to deal with an invader in the Wadden Sea ecosystem, a habitat protected in all parts. May fishing or even removal of Pacific oyster reefs be licensed within the Wadden Sea National Parks?

For the first time a comprehensive data compilation of the entire Wadden Sea was carried out in the framework of the TMAP to document the spread of the Pacific Oyster with special emphasis on the recent strong increase. The report aims to provide support for reporting and assessment under the EU Water Framework Directive and Habitats Directive and to support necessary updates of the Trilateral Monitoring and Assessment Program.

The help of our colleagues in compiling for the first time data from the entire Wadden Sea to document the spread of the Pacific oysters is gratefully acknowledged. We would especially like to thank Johan Craeymeersch, Norbert Dankers, Gerald Millat, Achim Wehrmann, Alexandra Markert, Karsten Reise, Per Sand Kristensen and Helle Torp Christensen for making unpublished data accessible. We would further like to thank Harald Marencic and the Common Wadden Sea Secretariat and the Regional Agency for the Wadden Sea National Park of Schleswig-Holstein for support.

2 GENERAL ASPECTS

2.1 Distribution and Ecology of *Crassostrea gigas*

Pacific oysters are cultivated in many countries of the world and they have spread to a variety of new habitats and successfully established stable populations. The introduction of this species has been reported for at least 60 countries (Ruesink et al. 2005). However, although being locally highly important, introduced oyster only make up 6% of the worlds annual oyster harvest of about 3.3 million tons (Ruesink et al. 2005). The spread of the species into new habitats is documented in a variety of sources (e.g. www.issg.org, www.marine.csiro.au, www.nobanis.org) and *C. gigas* is now globally distributed and occurs in the wild on all continents (Fig. 1).

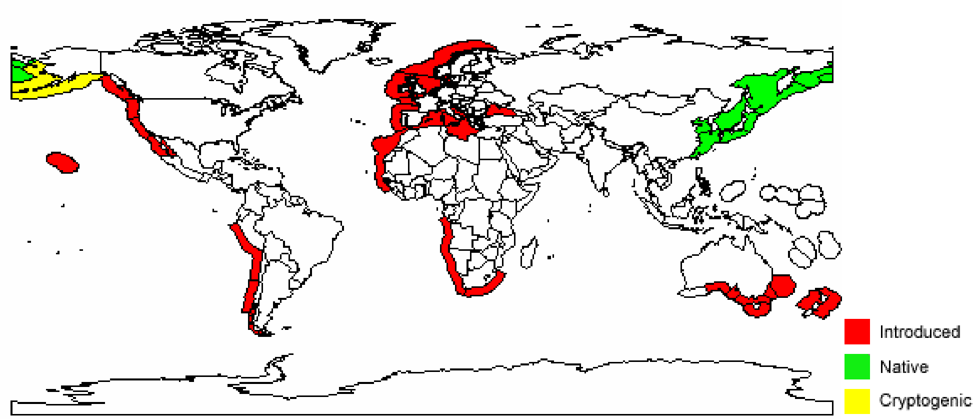

Fig. 1: Worldwide distribution of *Crassostrea gigas* (NIMPIS).

Pacific oysters are currently reported to occur in 24 countries, but only in six of these the species is considered to be invasive (Tab. 1). Interestingly, until recently, the species has been considered not to be invasive in most European countries and the Mediterranean.

Tab. 1: List of countries where *Crassostrea gigas* has established non-native populations (ISSG 2005).

Not invasive	**invasive**	**not specified**
Belgium	Australia	South Africa
China	Canada	
Cyprus	Chile	
Denmark	The Netherlands	
France	New Zealand	
French Polynesia	USA	
Germany		
Greece		
Korea		
Malta		
Morocco		
Norway		
Portugal		
Spain		
Tunisia		
United Kingdom		
Vanuatu		

The biology of *C. gigas* has been recently reviewed by several authors (e.g. Kater 2003, Nehring 2006) and for detailed reading it is referred to these sources. Looking at the species from the Wadden Sea point of view, the following aspects are regarded as important:

- The species reproduces in the summer months at water temperatures exceeding 20° C, but is very tolerant to cold winter temperatures.
- *C. gigas* may live both in intertidal and subtidal habitats. In the Wadden Sea, it mainly lives in the intertidal in the same zone as blue mussels.
- Pacific oysters may live for 30 years; reach a shell length of 30 to 40 cm and an individual weight of more than 1 kg (live wet weight).
- As in other bivalves, Pacific oysters have pelagic larvae spending 3 to 4 weeks in a free-swimming phase.
- Pacific oyster larvae may settle on all kind of natural and artificial hard substrates as mollusc shells, living molluscs, wood, stones, concrete and others.
- Pacific oysters are consumed by a variety of marine animals as Asteroid echinoderms, boring gastropods, boring bivalves, spionid polychaetes. *Carcinus maenas* in the intertidal, *Cancer irroratus*, benthic feeding fish, lobsters in the subtidal zone, black ducks, eider ducks, and wading birds (see NIMPIS). In the Wadden Sea, however, predation seems to be very limited.
- As other bivalves, Pacific oysters are filter feeders consuming phytoplancton and other digestible organic materials from the water column.

2.2 History of introduction and geographical spread

(from Nehring 2006)

More than once during the 19th century, attempts have been made to revive exploited stocks of the European oyster (*Ostrea edulis*) with American oysters (*Crassostrea virginica*) and 'Portuguese oysters *C. angulata*' at several sites in coastal waters of Northern Europe. These attempts largely failed (Wolff and Reise 2002). In 1964 Dutch oyster farmers imported spat of the Pacific oyster (*Crassostrea gigas*) from British Columbia for aquaculture activities in the Oosterschelde estuary. In the following years more imports of spat and adult specimens followed, starting in 1966 also from Japan. In 1975 and 1976 natural spatfalls occurred during very warm summers and resulted in millions of so-called weed oysters in the Oosterschelde estuary. Within several years the Pacific oyster has developed explosively and in the 1980's other Dutch estuaries started to be colonized (Wolff and Reise 2002). In 1983 first specimens were observed near the island of Texel in the Dutch Wadden Sea, probably brought there deliberately from the Oosterschelde in the 1970s (Bruins 1983, Wolff 2005). Since the 1990's this alien species was frequently observed along the entire Dutch coast and in the Dutch Wadden Sea (Dankers et al. 2004). In 1996 a first settlement of the Pacific oyster occurred in the western Wadden Sea area of Germany as well, which may have been dispersed from the Netherlands by natural means (Wehrmann *et al.* 2000).

In Germany 'Portuguese oysters *Crassostrea angulata*' were imported from Portugal and Spain and introduced into the Wadden Sea near Norddeich in 1913-14 and in the Jadebusen and near Sylt in 1954, 1961 and 1964. This did not lead to lasting cultures or establishment of the species (Meyer-Waarden 1964, Neudecker 1992, Wehrmann et al. 2000). Between 1971 and 1987 spat and larvae of the Pacific oyster were repeatedly imported from Scottish hatcheries for scientific aquacultural experiments and studies at different sites in the German Wadden Sea and at the German Baltic Sea coast in the Flensburg Fjord (Meixner and Gerdener 1976, Seaman 1985, Wehrmann et al. 2000). All these attempts, however, proved unsuccessful. Since 1986 commercial farming activities began in the northern area of the German Wadden Sea near the island of Sylt, primarily with spat taken from British and Irish hatcheries (Reise 1998, Nehring 1999). Pacific oysters are cultivated in plastic mesh bags on trestles in the intertidal zone. It takes about 2 years until the Pacific oysters reach marketable size. Shortly after oyster farming had commenced, natural spatfalls occurred and in 1991 the first Pacific oysters were found outside the culture plot (Reise 1998).

In Denmark Pacific oysters from German aquaculture experiments in the Flensburg Fjord were planted in the Little Belt of the Baltic Sea around the island Bogø in 1979. During the last thirty years of the last century large amount of *C. gigas* (> millions) seed oysters were imported from England, The Netherlands, and France to different Danish marine waters for culture in marine aquaculture experiments. The aquaculture took place in the Little Belt, in the waters south of the island Funen, in Horsens fjord, around the island Samsø in Kattegat and in Isefjorden (Kristensen, 1986, Kristensen and Hoffmann in press). In Isefjorden commercial production has taken place and about 100.000 to 300.000 Pacific oysters were harvested annually between 1986 and 1999. Apparently Pacific oysters were abandoned in the area, where they survived for several years but did not expand. Pacific oysters imported by the Limfjord Oyster Company were kept in basins for depuration. They were not cultured - though there are anecdotal information of finding escapees years after the company ceased its activities (Kathe Jensen, pers. comm.). At the end of the last century commercial production has taken place in the Danish Wadden Sea (very limited scale with a few thousands oysters annually) (Per Dolmer and Per Sand Kristensen, pers. comm.). In 1999 first freeliving specimens were observed, which may have been dispersed from the northern German Wadden Sea by natural means (Reise et al. 2005).

The main centre of oyster cultivation in Europe is France, where about 150.000 t of *C. gigas* are harvested annually. Pacific oysters have spread here in the course of warm summers and extended their distribution from the culturing areas Arcachon and Marennes to the North. The spread of *C. gigas* has not been investigated in France but research projects are now started (Hily unpubl.).

Fig. 2: First step into the wild: Young oyster attached to a shell of *Mya arenaria*

3 SPREAD IN THE WADDEN SEA

3.1 Temporal course

Pacific oysters have been brought on several occasions to the Wadden Sea and apart from the only existing culture in the Lister Deep, various attempts have been made to cultivate this species. Tab. 2 lists the documented occasions where Pacific oysters were brought into the German Wadden Sea.

Tab. 2: Oyster cultures and imports into the German Wadden Sea. Information taken from Wehrmann et al. (2000) and Neudecker (1984, 1985).

part of the Wadden Sea	site	year	
Nordfriesland	Husum	1880-1957	culture of Colchester-oysters
	Nordfriesland	1930/ 1963	import of French and Dutch oysters to
	Emmelsbüll	1982/1983	Nordfriesland
			field trials for overwintering of spat and halfgrown
	Amrum	1982/1983	*C gigas* in tanks
			field trials for overwintering of spat and halfgrown
	Sylt	since 1986	*C gigas* in the harbour
			successful culture of *Crassostrea gigas*
East Frisian	different places	1911	introduction of *Crassostrea virginea*
	Norddeich	1913/1914	introduction of *Ostrea edulis, Crassostrea gigas*
			and *Crassostrea angulata*
	Jadebusen	1964	introduction of *Crassostrea angulata*
	Neuharlingersiel	1974	experimental culture plots of *Crassostrea gigas*
	Jade	1976/1982	experimental culture plots of *Crassostrea gigas*
	Wangerooge	1982	experimental culture plots of *Crassostrea gigas*
	Norderney	1987	experimental culture plots of *Crassostrea gigas*
	Wilhelmshaven	1982/1983	field trials for overwintering of spat and halfgrown
			C gigas upwelling ashore, in tanks and
			reattachment frame

Cultivation at a larger scale started already in 1964 to the Oosterschelde in the Netherlands. However, since oysters achieved good spatfall in Dutch waters during some warm summers, imports were stopped after 1977. This was apparently not considered in a later German approval of oyster cultures in the Wadden Sea. In 1983 Pacific Oysters were found near Texel, brought there deliberately or accidentally (Bruins 1983, Dankers et al. 2004). Since 1986 Pacific oysters are in culture on the island of Sylt in the Lister deep (Fig. 3). Though first wild specimens were found in 1991, it took more than a decade that Pacific oysters spread all over the Wadden Sea and to establish dense aggregations. First records in 1998 in the East Frisian Wadden Sea were reported by Wehrmann et al. (2000). Reise et al. (2005) illustrate the development in the entire Wadden Sea (Fig. 4). It demonstrates that the Pacific oyster most likely originates from two different sources which are the Oosterschelde and the cultures in the Lister Deep near Sylt (Germany). Most notably since 2003 Pacific oysters started to increase very strongly in density and biomass (see Fig. 24 and Fig. 25, see also Dankers et al. 2004, Diederich 2005, Kristensen & Pihl 2006, Nehls & Büttger 2006) and developed solid reefs (Reise et al. 2005). Overall, the spread of the Pacific oysters follows the classic development of an alien species which may exist in an ecosystem over a long period with low abundances before the invasive character becomes obvious. Changing environmental conditions might support the spread of this species; the fact, that C. gigas forms reefs and can overgrow existing blue mussel beds, leads to changes in the ecosystem of the Wadden Sea with unpredictable further consequences.

The development of the *C. gigas* population in the Wadden Sea was apparently facilitated from two sources: (1) The Pacific oyster cultures in the Wadden Sea itself (Lister Deep), where an early and isolated development was documented and (2) a later inflow of Pacific oysters from the southwest which was most probably enhanced by larvae drift with current from the western parts of the Wadden Sea, which had most probably been reached by larvae from the Oosterschelde (Wehrmann et al. 2006). To which extent other sources of introduction (Tab. 2) have contributed to this development is not clear. The size of the population in the Oosterschelde and of the culture in the Lister Deep indicate these as the most important sources of Pacific oyster larvae facilitating the strong spread in the Wadden Sea.

Fig. 3: Bags with Pacific oysters on the culture in the Lister Deep, Sylt (Germany).

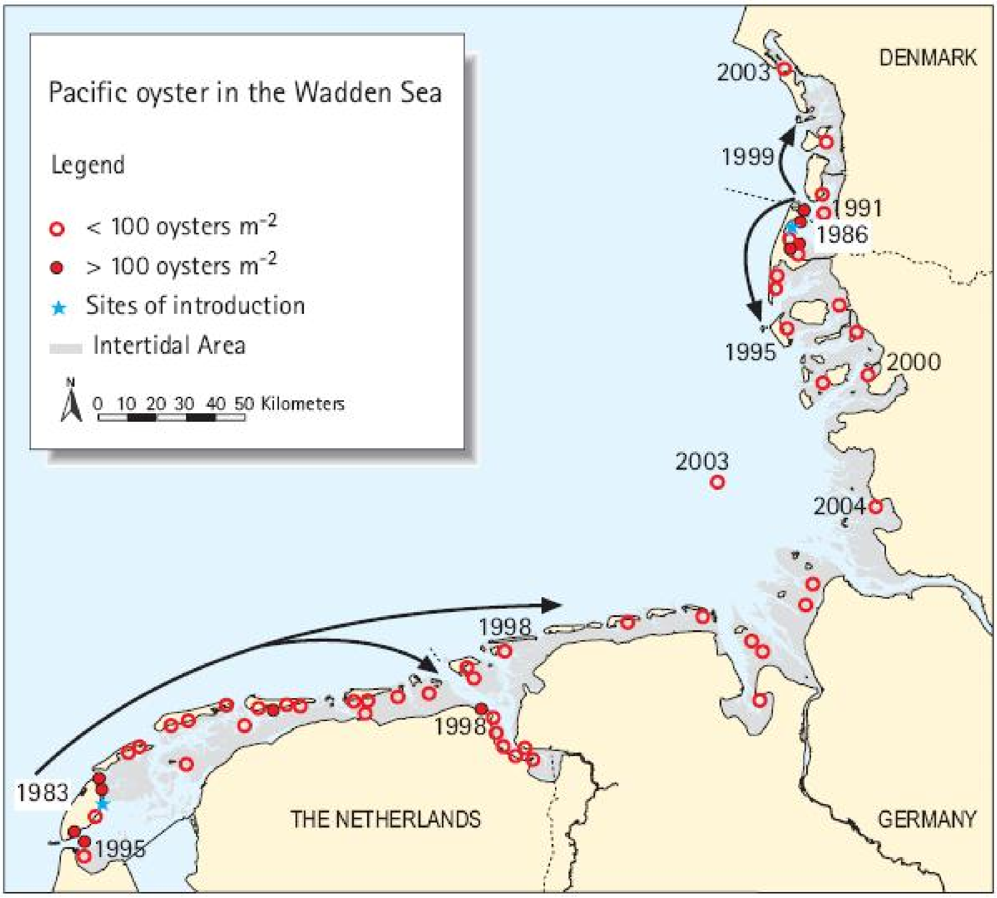

Fig. 4: Pacific oyster in the Wadden Sea. Asterisks indicate sites and years (boxed) of introduction (Texel, Sylt). Other years indicate first records of settlement by larval dispersal for sites. Circles show mean abundances in 2003 (from Reise et al. 2005).

3.2 Development of Pacific oyster density and biomass

By 2006 about 61,000 tons of Pacific oysters (live wet weight) were estimated to live on the tidal flats of the entire Wadden Sea (Fig. 5). This value can be considered as a minimum because not all scattered occurrences outside dense beds or reefs nor those on sluices, seawalls and other artificial substrates could be included and little knowledge exists on Pacific oyster abundance in the subtidal.

As Fig. 6 indicates, Pacific oysters are widely distributed in the Wadden Sea now and they have overgrown many former mussel beds which have now been turned into dense oyster reefs. High values are calculated for the western parts along the Eastfriesian islands and the Dutch Wadden Sea, and again for the northern part north of the island of Sylt. Pacific oyster population in the central parts of the Wadden Sea, e.g. in the area north and south of the mouth of the river Elbe (between Jade and Eider) and also in some parts of the Wadden Sea of Nordfriesland are still comparatively low, but it is not clear, whether this situation will remain stable.

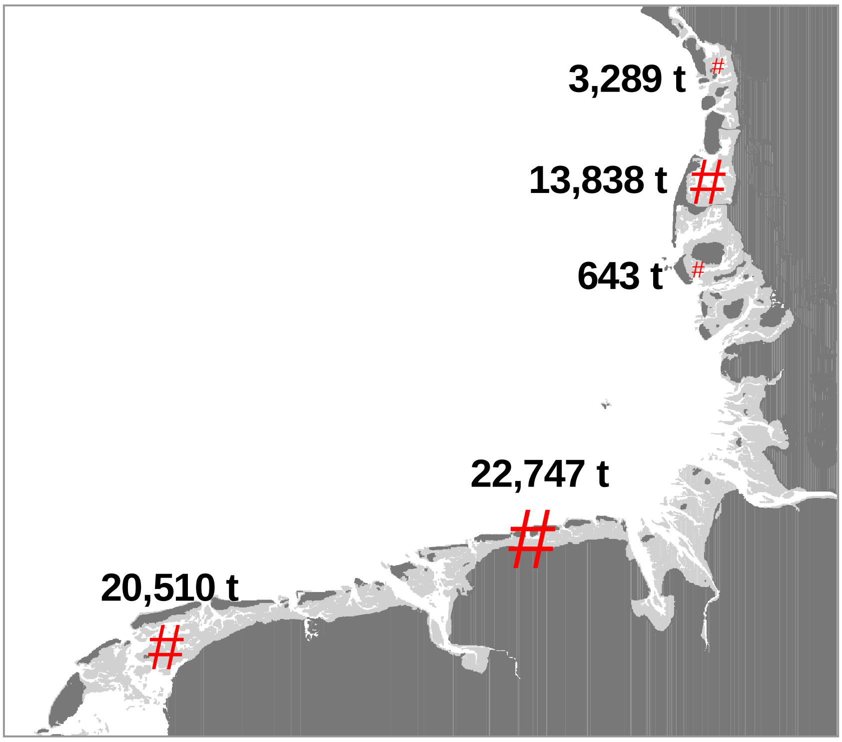

Fig. 5: Total biomass of Pacific oysters in different parts of Wadden Sea 2006. Biomass is given as life wet weight (Craeymeersch, Wehrmann & Markert, Kristensen pers. com.).

Fig. 6: Large Pacific oyster reef in the Lister Deep, Schleswig-Holstein.

The Netherlands:

Pacific oysters were first recorded in the Dutch Wadden Sea in the early eighties as a result from direct releases and/or drifted larvae from the Oosterschelde. *C. gigas* is spreading in the Oosterschelde since the 1970ies which is the oldest population in the North Sea. It is most likely that the growing population in the Oosterschelde is the most important source of larvae facilitating the fast spread of this species in the Wadden Sea. Regarding the fast development in the Wadden Sea, it is worth to consider that the population increase of *C. gigas* in the Oosterschelde might not have reached a ceiling yet. 30 years after this species has been reported to form wild populations, there is a steady increase in the area of Pacific oyster reefs (Fig. 7).

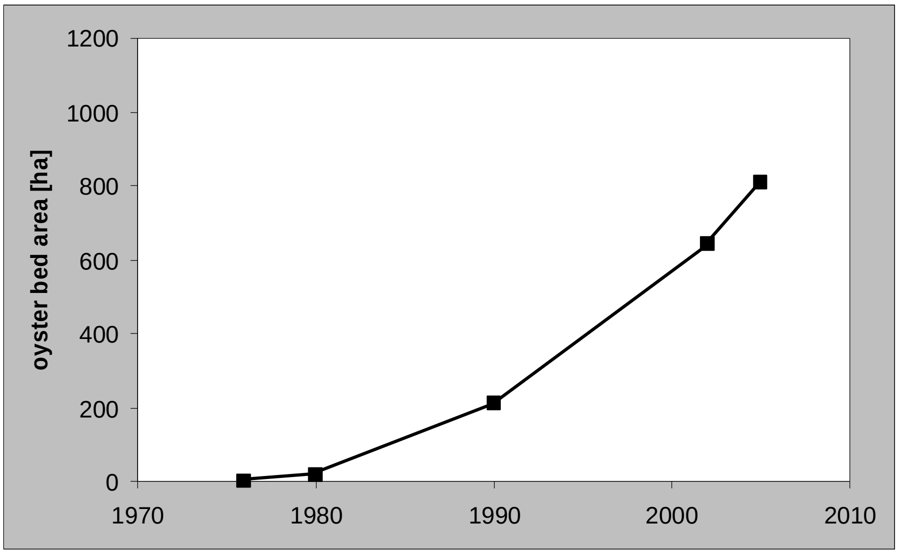

Fig. 7: Development of intertidal Pacific oyster reef area in the Oosterschelde (Kater & Baars, 2003, including RIVO-data, Dankers et al. 2006).

The intertidal area in the Oosterschelde covered by Pacific oysters was repeatedly mapped using aerial pictures and reached 15 ha in 1980 and 210 ha in 1990. In 2002 640 ha were registered and a biomass of 89,000 t living oysters was estimated, in 2003 809 ha. For 2005 the biomass was estimated at about 210,000 t living and dead oysters (Dankers et al. 2006, Geurts van Kessel et al. 2003). In the Oosterschelde, Pacific oysters not only form dense reefs in the intertidal but also colonize subtidal areas. The percentage of subtidal hard substrates covered by Pacific oysters strongly increased during the past two decades (Fig. 8). Oyster biomass within the intertidal reefs usually ranges from 30 to 50 kg m^{-2}.

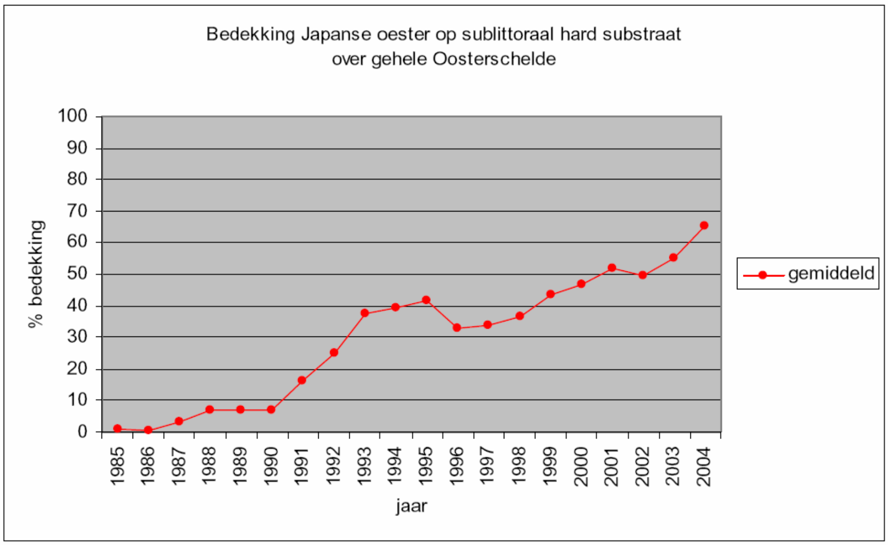

Fig. 8: Pacific oyster coverage of subtidal hard substrates in the Oosterschelde (from Dankers et al. 2006).

In 1983, first Pacific oysters were found near the island of Texel, which is the first record for the Dutch Wadden Sea, and oysters have been spreading since then. Since 2000, *C. gigas* occurs in all parts of the Dutch Wadden Sea (Fey et al. 2007). In 2004 the spread of Pacific oyster increased significantly and therefore oysters occur in many places in massive reefs where the individuals adopt a vertical position (Fey et al. 2007). After the spread in 2004 the mean densities on several places (transect of Oudeschild, oyster reef Zeeburg, mussel bed near Ameland) seem to stabilize, though they still increased on a mussel bed near Ameland in 2006 (Fey et al. 2007). In 2006 the biomass did not increase further but it is too early to conclude on a possible stabilization of the development (Fig. 9).
The maximum density reported by Fey et al. (2007) in the Dutch Wadden Sea was found on the oyster reef near Zeeburg (Texel) with more than 500 indiv./m² in 2003.

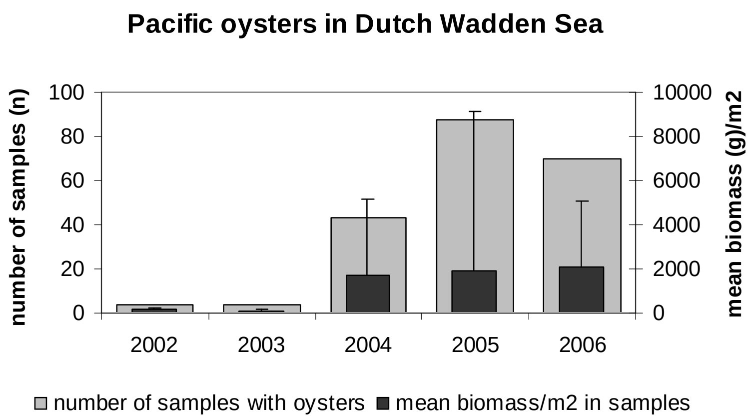

Fig. 9. Samples with oysters (n = 1293 samples with 0.4 m²each) and mean biomass in these samples with standard deviation (from Fey et al. 2007).

The area with a clear dominance of Pacific oysters in the Dutch Wadden Sea covered about 430 ha in 2005 and slightly decreased again in 2006 (Fig. 10). Areas with a mixed community of Pacific oysters and blue mussels increased since 2004, which might be a result from mussel spatfall. Scattered oysters were found in another 250 ha in 2005 and this area increased in 2006 up to nearly 400 ha indicating that Pacific oysters start to populate new areas.

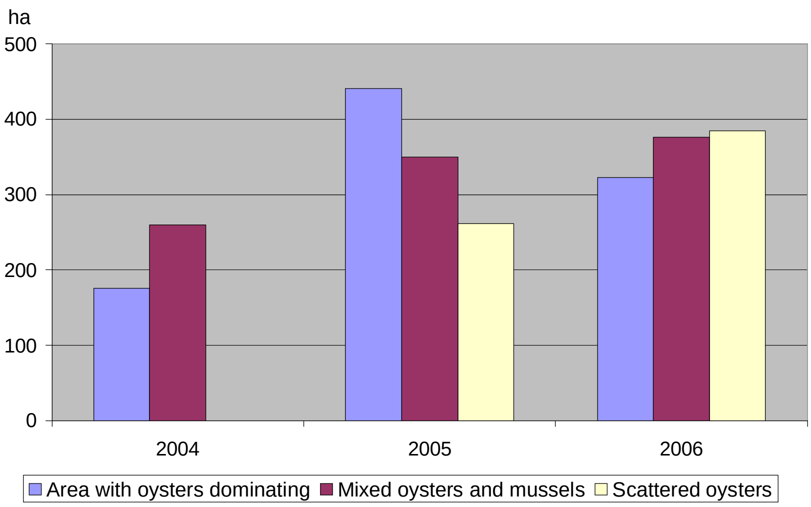

Fig. 10: Development of the area colonised by Pacific oysters in the Dutch Wadden Sea (Goudswaard et al. in prep.).

Lower Saxony

The immense spread of Pacific oysters is a recent process, mainly of the past five years. Oysters can be found today on almost all mussel beds in Lower Saxony. In 2004 and 2005 Pacific oyster distribution followed a gradient in west-east direction with high abundances in the west (Wehrmann et al. 2006), but numbers are increasing in the eastern parts as well especially after a strong spatfall in 2006 (Markert pers. com.). Pacific oysters increasingly dominate mussel beds in the Wadden Sea of Lower Saxony. Millat (2006) described some mussel beds with still very few individuals in 2005 but mentioned that 2006 Pacific oysters occur on all mussel beds (Fig. 11).

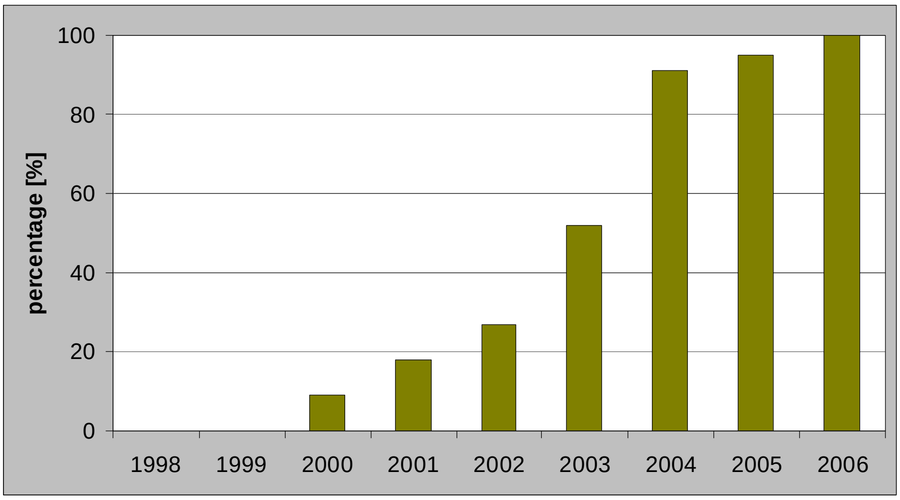

Fig. 11: Proportion of mussel beds with occurrence of Pacific oysters in Lower Saxony (Millat pers. com.).

Densities of Pacific oysters within the reefs in Lower Saxony cannot be directly compared with the other surveys in Denmark, Schleswig-Holstein and Netherlands, as Wehrmann et al. (2006) sampled densities on fixed points which might be situated in an unpopulated area or where mussel beds vanished. In Lower Saxony maximum densities (highest densities of single frames) reached 1460 indiv./m² in 2005 (Fig. 13).

Fig. 12: Pacific oysters in the harbour of the island of Langeoog, Lower Saxony (Markert 2006).

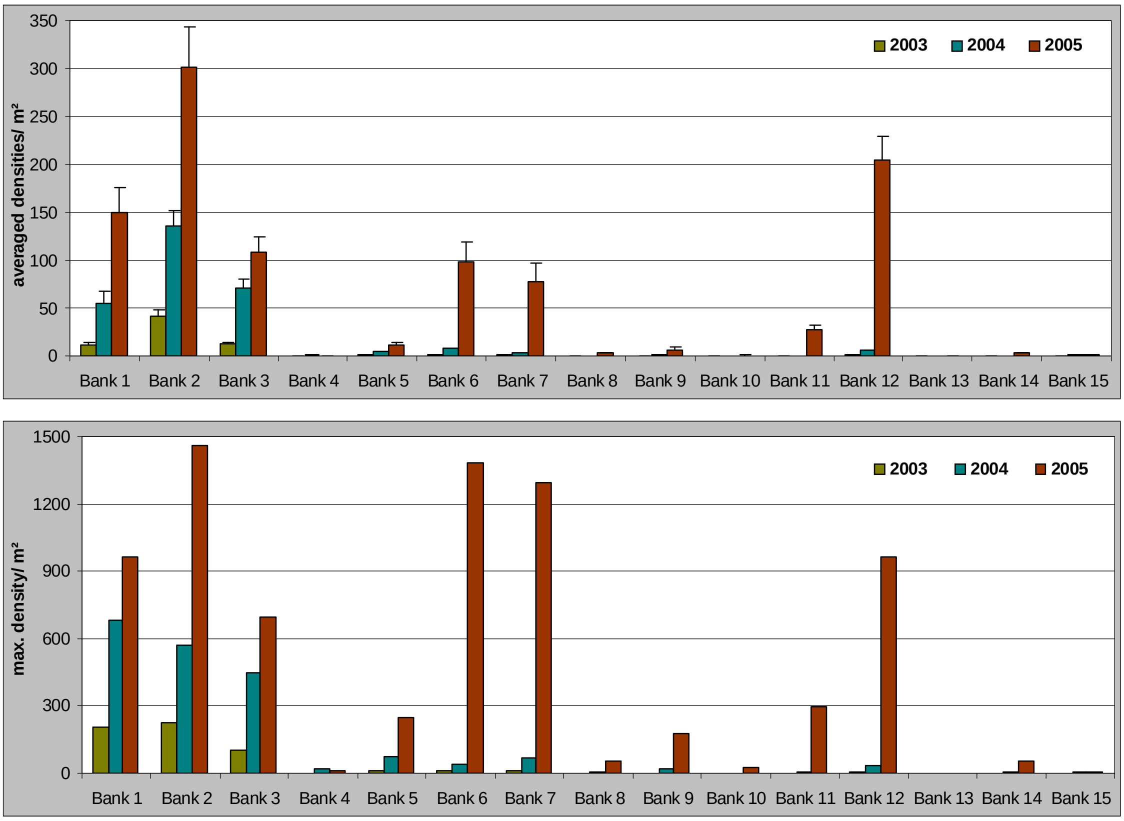

Fig. 13: Development of Pacific oyster densities in the Wadden Sea of Lower Saxony between 2003 and 2005. Data from Wehrmann et al. (2006). The graphs show mean (above) and maximum densities.

Wehrmann et al. (2006) also measured the biomass of Pacific oysters as wet weight (WW), dry weight (DW) and ash free-dry-weight (AFDW) of the flesh. They sampled three beds in 2004 and 2005. The data document the increasing biomass stored in oyster reefs as a result of individual growth and increasing abundances (Fig. 14).

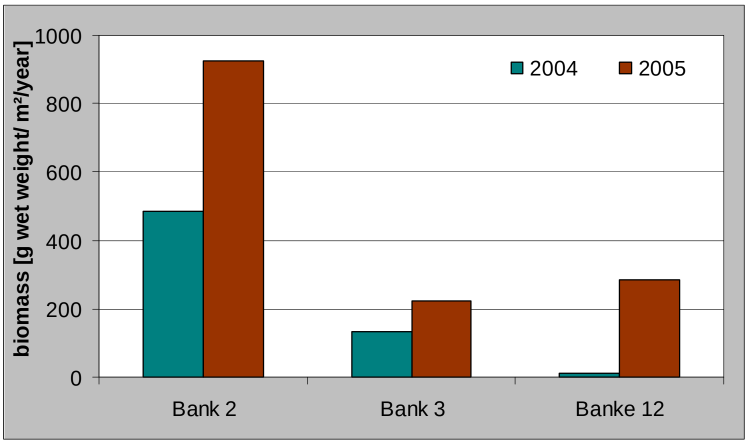

Fig. 14: Average biomass (wet weight of flesh) of three Pacific oyster beds in Lower Saxony (Data from Wehrmann et al. 2006).

Schleswig-Holstein

In the Wadden Sea of Schleswig-Holstein the spread of the Pacific oyster took place mainly in the Lister deep and on the tidal flats between the islands of Amrum and Föhr. In the Lister deep recently nearly all mussel beds have been turned into Pacific oyster reefs (Fig. 16). This process seems to be in the beginning now between Amrum and Föhr (Fig. 15). The spread in the Lister deep is well documented since 1991 (see Reise 1998). First surveys (in 1999) resulted in average densities of about 4 indiv./m². In 2003 Pacific oysters reached densities of > 100 indiv./m^2. Because of a good spatfall in 2002, Pacific oyster densities increased in 2003 and this process still continues. One mussel bed in the Lister Deep revealed mean densities of 1000 indiv./m^2 in 2006. Overall mean densities in the Lister Deep were 722 (± 267) indiv./m² in 2006. Biomass in Pacific oyster reefs reaches 50 kg/m^2 (live wet weight). This is similar to the highest values in the Oosterschelde and may eventually represent an upper level. Since 2005 Pacific oysters form massive reefs in the Lister deep. Pacific oysters settle mainly on former mussel beds but since 2004 some larger areas with empty shells from former mussel beds were colonized. In the area between Amrum and Föhr Pacific oysters appeared since 1998 in low densities. In 2004 higher abundances were recorded. In 2006 a strong spatfall was recorded in many areas of the Wadden Sea of Schleswig-Holstein.

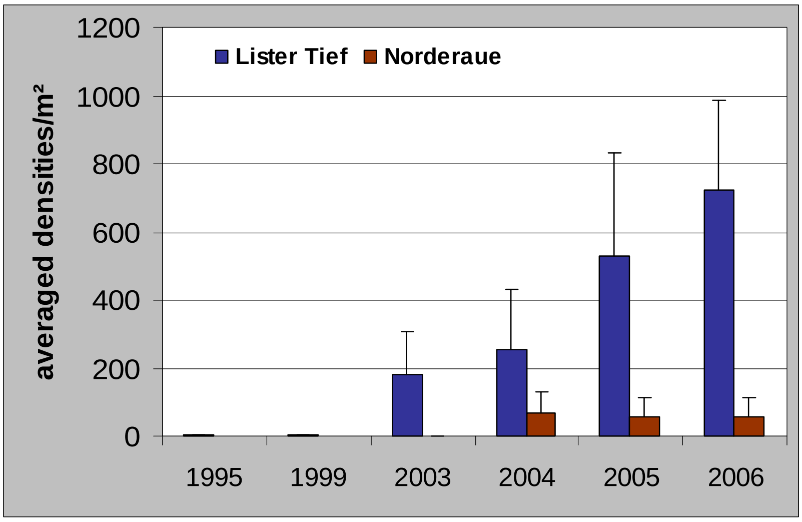

Fig. 15: Development of the average densities of Pacific oysters in two tidal basins in Schleswig-Holstein. Lister Deep and Norderaue (between the island of Amrum and Föhr). Data from Diederich et al. (2005) and Reise (1998).

Different tidal basins in Schleswig-Holstein show different spatial and temporal developments (Fig. 15, Fig. 24). In the Lister Deep the spread occurred earlier and much stronger than in other places. This might be caused by the Pacific oyster cultures present in this area and potentially producing a large number of larvae; here, Pacific oysters are now dominating most former mussel beds since 2004. In the other tidal basin, the Norderaue, Pacific oyster distribution occurred at a later time and oysters so far do not cover large areas. This is remarkable, as Pacific oysters are present in this region at least since 1995 and in 1998 they were found already on nearly all mussel beds, though in low densities (< 1 indiv./m^2). The strong spatfall in summer 2003 lead to high abundances in the following years and the spatfall from 2006 is likely to further increase Pacific oyster numbers in this area.

Going south from these two tidal basins, Pacific oysters are still found in low densities in the tidal basin south of Amrum and on most mussel beds around the islands of Pellworm, Hooge, Gröde and Nordstrand, however, with densities lower than 1 indiv./m². Also, the spatfall in late 2006 appeared to be much less than in the northern area (Fig. 17). The tidal flats and also the mussel beds are muddier in this part of the Wadden Sea, which is a former marsh and peat area, as compared to the sandy flats near the islands Sylt, Amrum and Föhr, which are situated on glacial moraines. Further south, Pacific oysters are still rather rare on the tidal flats between the Elbe and the Eider mouth, although they are abundant on sluices and harbours in this area. On the only mussel bed in the Meldorf Bay Pacific oyster density was still below 1 indiv./m² in 2006. Thus, about 95% of total Pacific oyster biomass in the Wadden Sea of Schleswig-Holstein is still found in the Lister Deep (13,838 t), whereas oyster biomass in the tidal basin Norderaue on the tidal flats near Amrum is rather low (643 t) and in the rest of the area negligible. These differences in the development within the Wadden Sea of Schleswig-Holstein give first hints about potential differences in habitat suitability, however, it is too early to draw conclusions, and it cannot be stated yet, whether this reflects a stable situation or just a delay in the development.

Fig. 16: Dense Pacific oyster reef in the Lister Deep, Schleswig-Holstein.

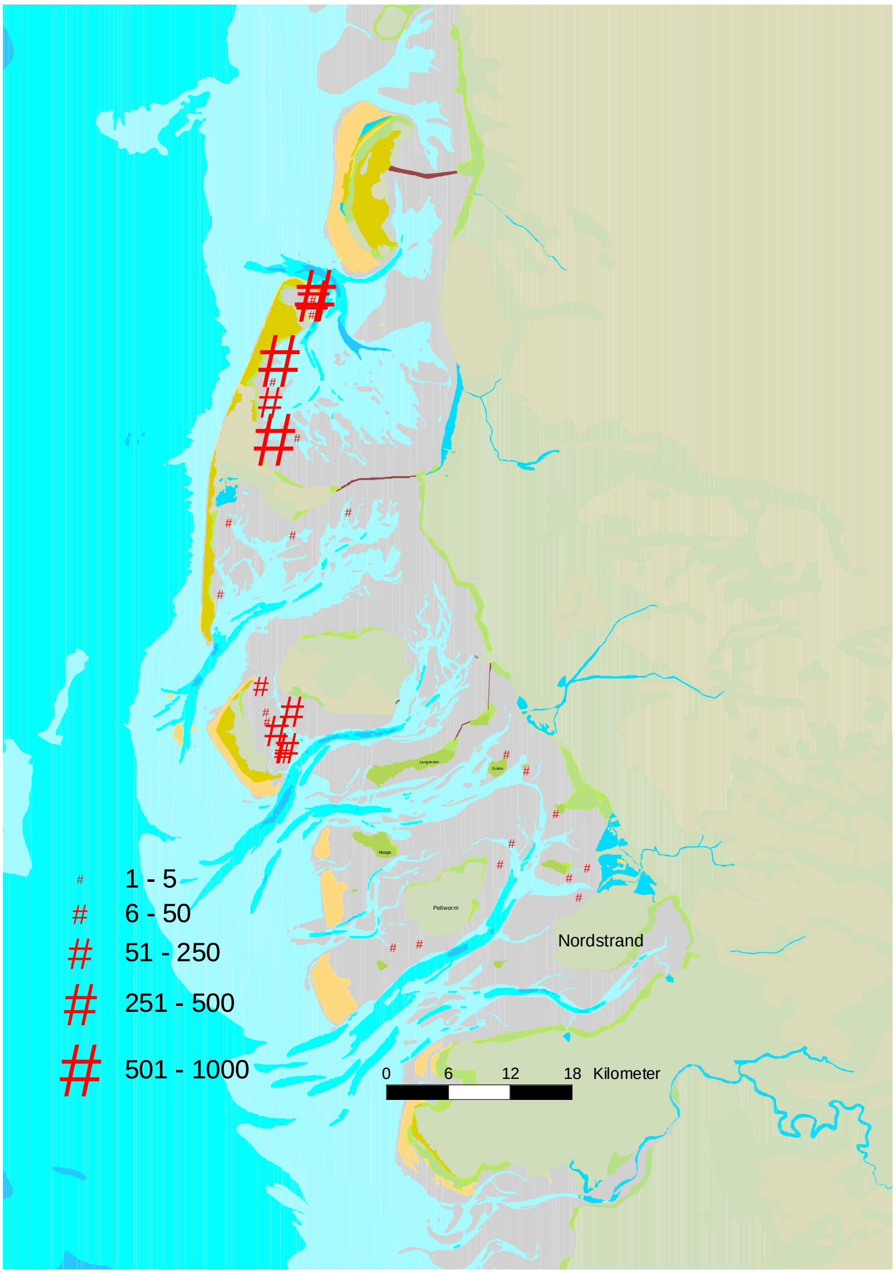

Fig. 17: Pacific oyster density (n/m^2) on intertidal mussel beds in the Wadden Sea of Schleswig-Holstein in 2006.

Denmark

Pacific oysters are recorded in the Danish Wadden Sea since 1999, but until 2004 oysters still occurred in low densities with only few individuals per km² (Kristensen pers. com.). In 2004 a strong spatfall of Pacific oysters on former mussel beds in the Danish part of the Lister deep strongly enhanced the population growth. The biomass was estimated at 1000 tons. Kristensen & Pihl (2006) report biomass values (LWW) of Pacific oysters between 0 and 30.36 kg/m² in 2006. As a result of the growth of the Pacific oysters, biomass increased to 3,289 tons in the Danish Wadden Sea in 2006 (Fig. 18, Fig. 19).
These biomass values are low in comparison to the other parts of the Wadden Sea but a further increase is likely to occur.

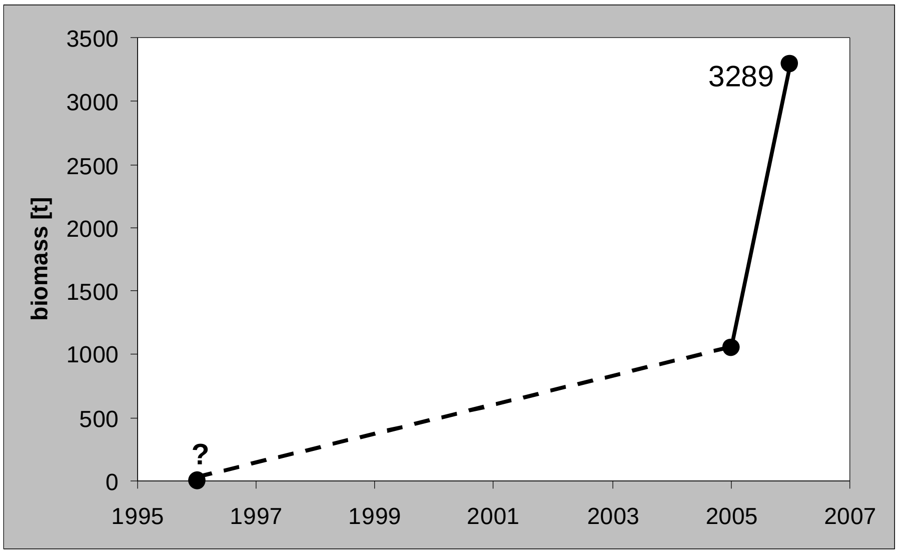

Fig. 18: Development of Pacific oyster biomass in the Danish Wadden Sea. From Kristensen & Pihl (2006).

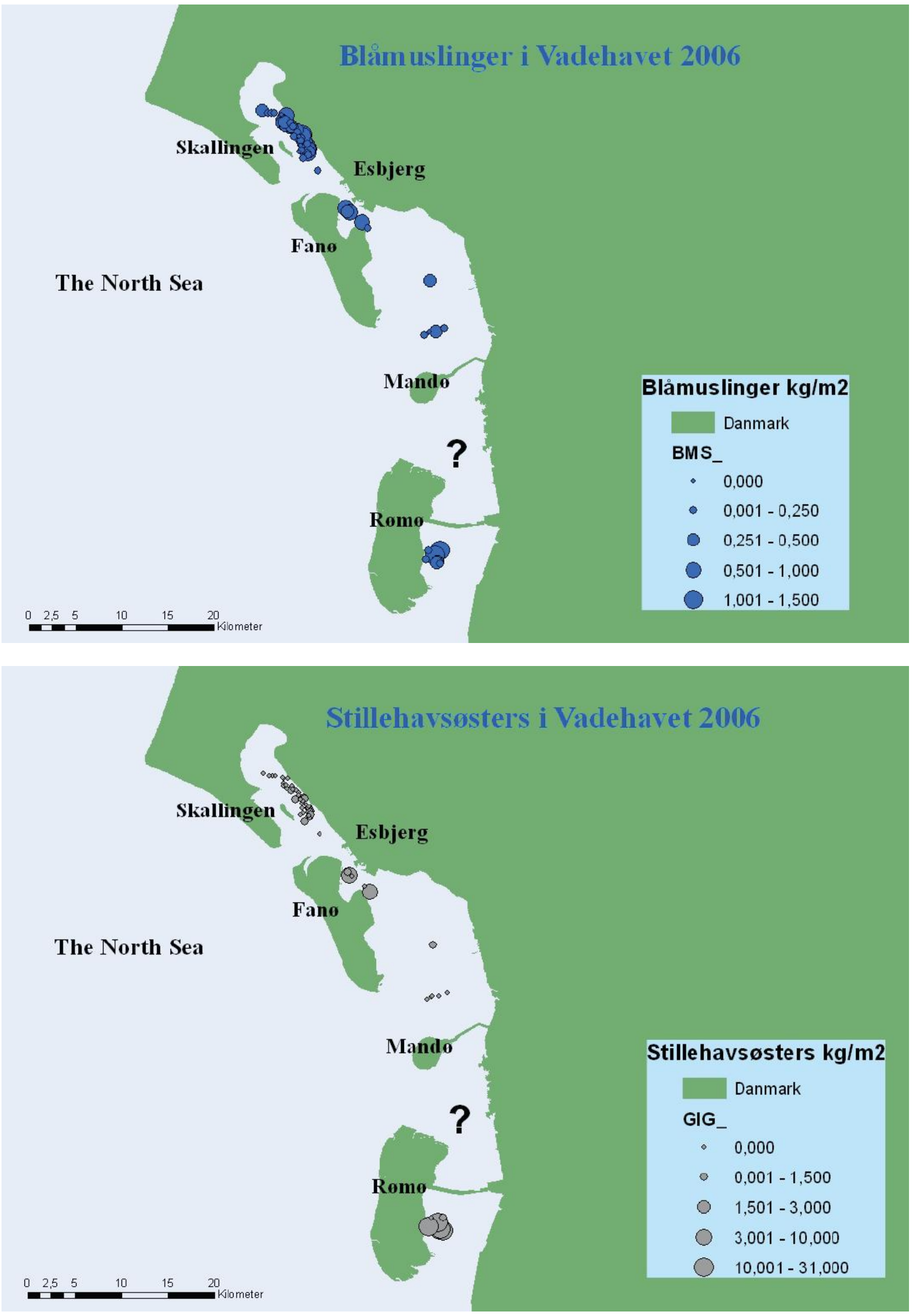

Fig. 19: Biomass (kg/m²) of blue mussels (Blåmuslinger; above) and Pacific oysters (Stillehavøsters) in the Danish Wadden Sea in 2006. The question mark indicates an area with no inspections yet. From Kristensen & Pihl 2006.

3.3 What facilitates the increase of Pacific oysters in the Wadden Sea ?

The spread of the Pacific oyster in the Wadden Sea follows the classic pattern of biological invasions with a long phase of stagnancy followed by a fast increase. A small founder generation has to reach a certain size before a fast growth is possible. However, in the case of the Pacific oyster, it is likely that the recent spread is facilitated by changing environmental conditions, especially an increase in summer temperatures (Nehls et al. 2006).

Before Pacific oyster cultivation was officially approved in the Wadden Sea it was argued that they were not able to proliferate in the Wadden Sea because water temperatures are too low. The lowest temperature allowing reproduction of *C. gigas* is about 20° C, a value, which is, however, frequently reached in the shallow parts of the Wadden Sea in warm summers. Consequently, already in the warm summers of 1976 and 1982 Pacific oysters revealed good spatfall in the Dutch Wadden Sea (Drinkwaard 1999).

The increase of Pacific oyster populations in all parts of Wadden Sea since 2003 coincides with water temperatures above average in summer. In the Lister Deep strong Pacific oyster spatfall occurred in years with a positive deviation of water temperatures to the long-term average (Diederich et al. 2005, see Fig. 20). Years of good spatfall are listed in Tab. 3.

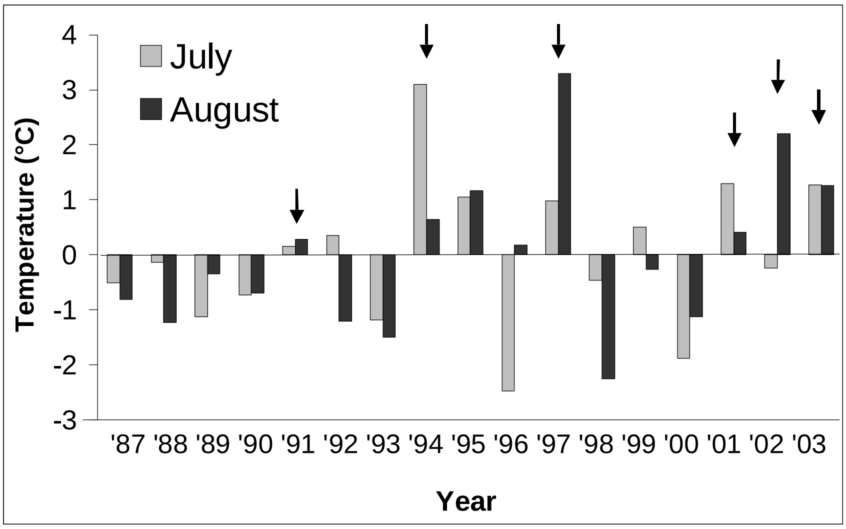

Fig. 20: Deviation of mean monthly water temperature in July and August from the long-term mean (1987 - 2003). Arrows mark years with high *C. gigas* recruitment (1991, 1994, 1997, 2001, 2002, 2003) (Diederich et al. 2005).

Tab. 3: Years of good spatfall in different regions of the Wadden Sea.

region	years with good spatfall	literature and comment
The Netherlands (including Oosterschelde)	1975, 1976, 1982, 1986, 1987, 1989, 1992 2003	Drinkwaard 1999 Dankers et al. 2006
Lower Saxony	1997 or 1998, 1999, 2004, 2006	Wehrmann et al. 2000 & 2006 Markert pers. com.
Schleswig-Holstein	1991, 1994, 1997, 2001, 2002, 2003, 2004, 2006	Tydeman 1999 Diederich et al. 2005 Nehls & Büttger 2006 & unpubl. obs.
Denmark		Oysters recorded north of Rømø since 1999 and years with spatfall are assumed to be parallel to Schleswig-Holstein

- In 2006 we observed a very strong spatfall in most many parts of the Wadden Sea of Schleswig-Holstein which was confirmed for Lower Saxony too (Markert pers. com.).

More factors enhanced the spread of *C. gigas*. First, Pacific oysters are highly tolerant against cold temperatures (Reise 1998, Diederich et al. 2005). Survival of oyster spat in the first winter depends on temperatures while adult oysters seem not be much affected and even survive cold winters when ice covers the tidal flats (Diederich 2006). In addition, so far, no viral diseases are know to impact oyster populations (Reise et al. 2005) and predation rate is apparently very low (Diederich et al. 2005, Diederich 2006), which facilitates a high survival even in times, when many potential predators in the Wadden Sea are present. Finally, they produce very large numbers of larvae and as Pacific oyster larvae prefer to settle on adult oysters, aggregations grow rapidly and finally form dense reefs (see in Diederich 2006).

3.4 Distribution over different habitats

Pacific Oysters settle on different hard substrates along the entire coast. They have been found on blue mussel beds or on conspecifics, rock fills along the coast, sheet pile wall in harbours, stones, shell beds or single shells and on sand (Dankers et al. 2004). Juvenile oysters prefer to settle on adult conspecifics (see in Diederich 2006). In the early stage of the development, Reise (1998) found 85% attached to *Mytilus edulis* (alive and empty shell) and 8% on other bivalves. In Niedersachsen, Pacific oysters settled primarily on blue mussels, cockles and attached barnacles in the first years, but with increasing population densities, Pacific oysters themselves became the most important substrate (Fig. 21).

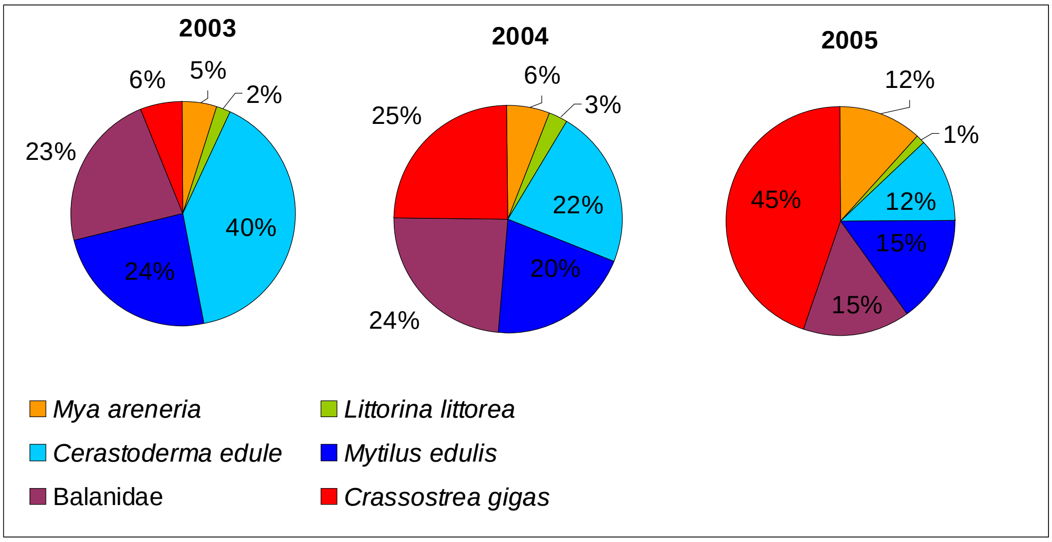

Fig. 21: Settling substrates of Pacific oysters in the Wadden Sea of Niedersachsen (Wehrmann et al. 2006).

In general blue mussel beds are the most important location for the establishment of Pacific oyster reefs so far. This regards not only live blue mussel beds. In Schleswig-Holstein Pacific oysters also colonised former blue mussel beds which had vanished before the settlement of Pacific oyster and the oyster larvae used shells of blue mussels and other bivalves as a substrate (Fig. 22). All areas with a high Pacific oyster density in the Wadden Sea of Schleswig-Holstein are found in existing or former blue mussel beds. Pacific oysters are also found on other bivalve shells than mussels or oysters, however, in most places still in low densities. Even on eroding mudflats with dense layers of dead shells Pacific oysters are remarkably scarce, so the availability of shell material is apparently not the only factor required for successful settlement.

Apart from settlement on tidal flats Pacific oysters today form dense layers on sluices, harbour walls and all kind of solid installations in the Wadden Sea (Fig. 12).

Only limited knowledge exists on the subtidal distribution of Pacific oysters in the Wadden Sea and they seemed to be restricted to the intertidal during the first years. Outside the Wadden Sea in a part of the Oosterschelde subtidal occurrences have been surveyed in 2002 by 'side scan sonar' and about 700 ha are considered by interpolation to be populated by Pacific oysters (Geurts van Kessel et al. 2003). In the Dutch Wadden Sea subtidal occurrences are reported by fishermen who fished clusters of Pacific oysters (Dankers et al. 2006). Near Texel subtidal Pacific oysters influence the water flow and in 2004 higher abundances of fish between oyster beds were mentioned (Dankers et al. 2006).

In Lower Saxony occurrences in the subtidal have been reported by fishermen in southern Randzel and in the Jade (Wehrmann pers. com.). Damm & Neudecker (2006) refer on subtidal Pacific oysters near the island of Langeoog.

In Schleswig-Holstein subtidal occurrences are known from the Lister basin. Here, between 1992 and 1996 no subtidal Pacific oysters were found in dredge hauls (Reise 1998), in 1999 single individuals have been found and in 2004 428 individuals were fished in 10 hauls in the middle of the basin (Diederich et al. 2005). Apart from the Lister basin, subtidal surveys (dredge hauls) in 2005 and 2006 in different channels (but not in the List basin) in the Wadden Sea of Schleswig-Holstein did not detect any subtidal Pacific oysters (Nehls & Büttger 2007). Reise (pers. com.) searched the subtidal parts of the Lister Deep for Pacific oysters in 2006 and reported a mean density of about 2 oysters per 100 m².

In Denmark subtidal Pacific oysters are reported in the Limfjorden (Kristensen pers. com).

Fig. 22: Scattered Pacific oysters on a former blue mussel bed in the Lister Deep, Schleswig-Holstein.

4 ECOLOGICAL CONSEQUENCES

4.1 Do Pacific oysters displace blue mussels?

As blue mussel bed area and blue mussel biomass strongly decreased in most places of the Wadden Sea while Pacific oysters spread out, a burning question about the spread of the Pacific oyster is whether or not they displace native blue mussels. This will be addressed by comparing the development of blue mussels and oysters on different scales.

Nehls et al. (2006) and Wehrmann et al. (2006) both compared the densities of blue mussels and Pacific oysters within existing blue mussel beds and found contrasting results. On a blue mussel bed near Sylt a positive correlation of blue mussel and Pacific oyster density was apparent, whereas on a blue mussel bed in Lower Saxony both species were negatively correlated. The background of these differing results is not quite clear, however, it is possible that the results from Sylt just reflect the fact that Pacific oysters preferably settled in the denser parts of the blue mussel bed. Several studies pointed out, that the abundance of blue mussels apparently remains on a stable level even in dense Pacific oyster reefs. In dense Pacific oyster reefs near the island of Sylt, blue mussel density until now remained at a level exceeding 1000 indiv./m^2 (Fig. 23), however, densities have decreased and the biomass of blue mussels in these beds is now much lower than it was before Pacific oysters were present. This indicates, that Pacific oysters might be able to locally depress abundance and biomass of blue mussels in dense reefs, however, it is not clear, whether this has an impact on a larger scale.

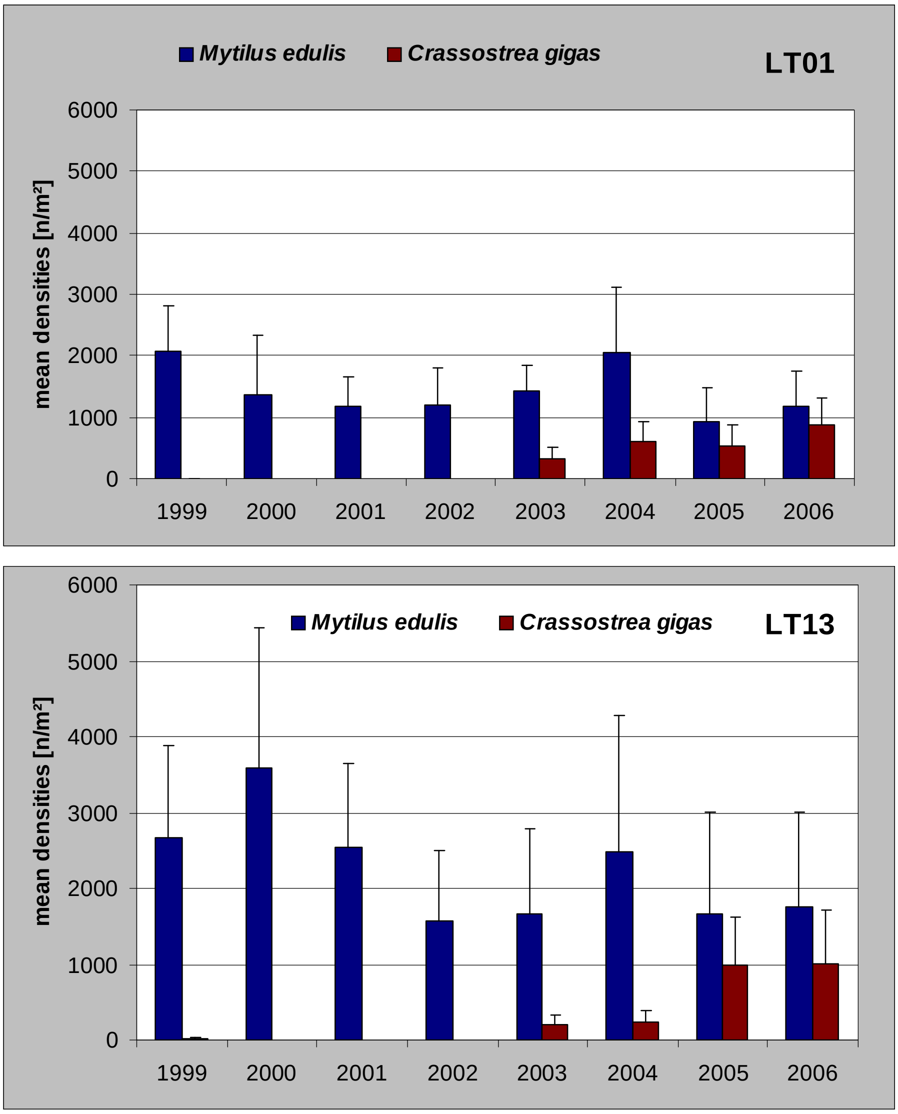

Fig. 23: Mean densities (± standard deviation) of blue mussels (standard sampling method) and Pacific oysters (counting frame) on two blue mussel beds in the Lister Deep in Schleswig-Holstein.

Comparing the development of blue mussel and Pacific oysters on the scale of whole blue mussel beds indicates, that the decrease of the blue mussel and the increase of the Pacific oyster did not occur at the same time and thus are likely to be independent processes. As shown for two blue mussel beds in Schleswig-Holstein, blue mussels biomass and area decreased long before the Pacific oysters reached significant densities which could have affected the blue mussels; the decrease is even apparent on those beds, where oysters still reach low densities (Fig. 24).

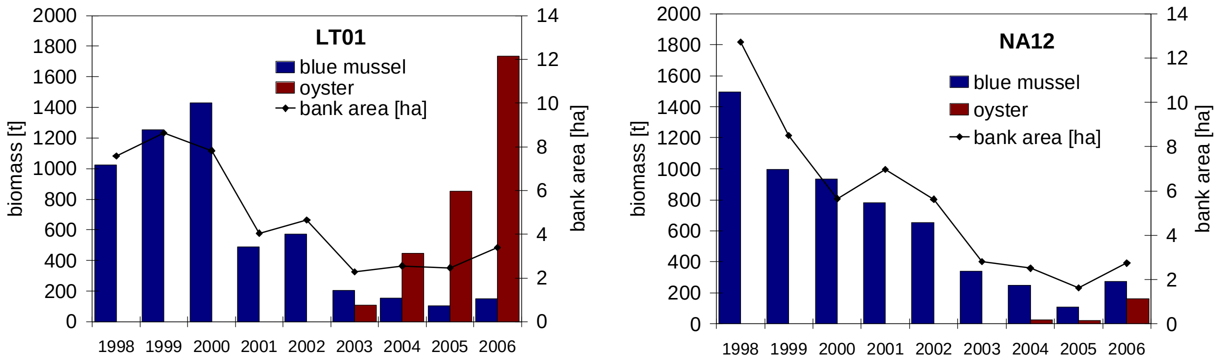

Fig. 24: Development of total biomass of Pacific oysters and blue mussels in Schleswig-Holstein on two mussel beds in the tidal basins Lister Deep and Norderaue. Biomass given as life wet weight.

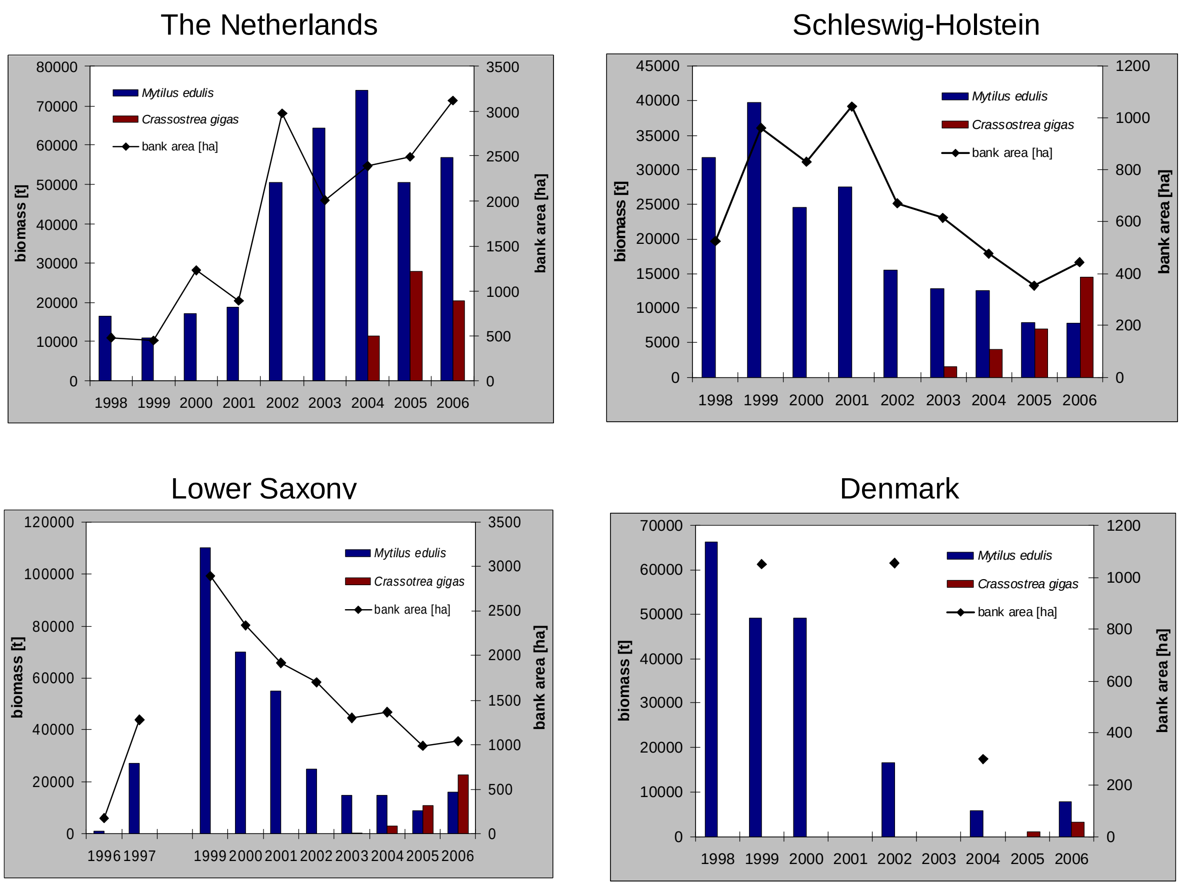

Fig. 25: Development of Pacific oyster and blue mussel biomass in the Wadden Sea regions between 1998 and 2006. Biomass given as life wet weight (Craeymeersch, Millat, Wehrmann, Markert and Kristensen pers. com.).

Considering the four regions of the entire Wadden Sea reveals, that blue mussels decreased in three regions – Lower Saxony, Schleswig-Holstein and Denmark – since at least 1998; however, a notable increase of the Pacific oyster is only apparent since 2003 (Fig. 25). In all Wadden Sea countries the total biomass of Pacific oysters is still much lower than the former blue mussel biomass. There is no indication, that spreading Pacific oysters have caused the decline of the blue mussels. Interestingly, in the Dutch Wadden Sea blue mussel bed area and blue mussel biomass recovered from a low level and increased to a total area of 2600 ha and a biomass of more than 70,000 t in 2004 and remained on a high level as Pacific oysters spread out.

The contrasting developments of blue mussels and Pacific oysters as well as the different development of blue mussels in the different regions of the Wadden Sea raises questions about the causes of this development. Several recent studies highlight the significance of predation on the recruitment success of bivalves in the Wadden as the most important factor (e.g. Strasser & Günther 2001, Strasser 2002, Beukema and Dekker 2005). It is likely, that annual variation in predation rate and recruitment success relates to winter temperatures: cold winters result in low predation rates because the main predators of bivalve spat such as shrimps and crabs occur later on the tidal flats; consequently, the bivalve s can successfully establish new year classes. In turn, warm winters lead to high predation rates and low recruitment success. These findings explained why recruitment of blue mussels to existing beds was low and the establishment of new beds was rare during a long period of mild winters since 1995/96.

Considering the Pacific oyster, it appears that predation plays a minor role in the recruitment in the Wadden Sea. Thus, the combination of mild winters causing low recruitment rates of blue mussels and warm summers causing high survival of Pacific Oysters seems to explain well why blue mussel beds turned into oyster reefs (e.g. Nehls et al. 2006). These findings also offer a potential perspective of the consequences of climate change in the Wadden Sea: a warming Wadden Sea will be beneficial for Pacific oysters and lead to further decreases of blue mussel beds. The development in the Netherlands, however, puts some caution to these expectations and demonstrates that there is still a lack of knowledge about the ultimate factors governing these population dynamics; with blue mussel beds increasing in the Netherlands, questions arise especially about the recruitment process of blue mussels in the Wadden Sea.

Concerning competition and coexistence of Pacific oysters and blue mussels it will be most important whether or not blue mussels are able to recruit in greater numbers into oyster reefs and either coexist or overgrow them in years of good spatfall. The recent development within the Dutch Wadden Sea offers at present the best opportunities to study the interactions of these two species.

4.2 Blue mussel and oyster beds and their associated species communities

The growing Pacific oyster population in the Wadden Sea experienced several strong spatfalls in the past five years. New Pacific oyster reefs developed mainly on former blue mussel beds. Blue mussel beds are known as centers of high diversity. Because of their three-dimensional structure they offer a rich habitat for epibenthic as well as for endobenthic species and they play an important role in marine food webs (e.g. for birds and other predators). Several surveys assessed these different relations on blue mussel beds (Asmus 1987, Dittmann 1990, Hertzler 1995, Günther 1996). Now, as Pacific oyster reefs increasingly replace blue mussel beds in the Wadden Sea, the question arises what happens to the associated community (Broekhoeven 2005, Görlitz 2005 and Markert 2006).

Broekhoeven (2005) investigated the macrofauna along two transects covering different Pacific oyster reefs and the adjacent mudflats in the Oosterschelde (NL). The aim was to investigate the influence of the Pacific oysters on the macrofaunal diversity. In total, 38 species have been found and diversity and abundances were higher on Pacific oyster beds than on the adjacent mudflats. Species numbers and abundances did not differ significantly between both sampled beds. However, species composition did, but this might be related to other factors which have not investigated (e.g. drift direction, elevation above low water line, compare Saier 2001).

The two other investigations compared the faunal communities of blue mussel beds and Pacific oyster reefs. Görlitz (2005) compared the associated community of blue-mussel beds and Pacific oyster reefs in the Lister deep in the Wadden Sea of Schleswig-Holstein in 2004 and also considered beds covered by *Fucus vesiculosus* forma *mytili.* It is known that this algae influences the abundances of different epibenthic species (Albrecht 1990, Albrecht & Reise 1994). *Fucus vesiculosus* forma *mytili* cannot settle on Pacific oyster because this algae depends on blue mussels which attach them with their byssus threads. Some epibenthic species are supported by *Fucus*-cover, however, others occur in lower densities. Görlitz (2005) found 49 species on Pacific oyster reefs. Species richness did not differ significantly between blue mussel beds and Pacific oyster reefs, the community of oyster reefs was more similar to the community of blue mussel beds than to the community of *Fucus*-covered beds. Several species had different abundances and therefore it was concluded that the dominance structure of the associated community will be different between blue mussel and Pacific oyster beds, which might lead to changing functional relationships in the ecosystem. Losses of species have not been documented yet. *Cirripedia* showed similar densities on blue mussel and Pacific oyster beds, only densities of *Semibalanus balanoides* were lower on oysters. Of *Littorina littorea, Ralfsia verrucosa* and *Polydora ciliata* higher densities were registered upon Pacific oyster reefs, whereas only juvenile crabs (*Carcinus maenas*) were found in lower densities. The fouling with macroalgae and sessile invertebrates was higher on Pacific oyster beds. Analysis of sediments did not yield significant differences of biodeposits between the different beds (percentage of sediment fraction < 63µm taken as value for bio deposition).

Markert (2006) surveyed the macrofauna of a blue mussel bed in Lower Saxony near the island of Juist. This study compared the associated community of Pacific oyster dominated, blue mussel dominated and mixed beds as well as the adjacent unpopulated mudflats. Species richness, abundances and biomass were higher on Pacific oyster dominated beds. 45 taxa were found in the Pacific oyster dominated beds. All species found on Pacific oyster beds have been found on blue mussel beds before (former surveys) and no new species were detected. Similar to Görlitz (2005), Markert (2005) found higher abundances of epibenthic species (mobile species of the epibenthic) on Pacific oyster beds. This might be related to the somewhat larger potential space of the three dimensional structure offered by oysters positioned in a vertical position. Markert (2005) found a shift in species composition, from deposit-feeders on blue mussel beds to opportunistic filter-feeders on Pacific oyster beds However, Markert (2005) assumes impoverishment of endobenthic species below Pacific oyster layers.

As part of the blue mussel monitoring in the Wadden Sea National Park of Schleswig-Holstein the associated macrofauna of blue mussel beds has been monitored since 1999 (Nehls & Büttger 2006). The macrobenthic communities of two beds in the Lister Deep near the island of Sylt have been studied from 1999 to 2005, thus during the period that these beds turned into in Pacific oyster reef.
Referring to the species list which takes different determination levels into account, between 26 and 48 taxa were found during seven years of monitoring. At all 53 taxa have been found on both beds (unconsidered steadiness and abundances, only presence/absence-data). Several taxa occurred just in one year with low abundances, and might represent single events. For example the species *Pagurus bernhardus* was observed in several years on LT01 but never on LT13. The bed LT01 is located close to the low water line adjacent to a deep subtidal area from where individuals could immigrate. On the other hand *Ligia oceanica* was found in some years only on LT13, but always with few individuals only.

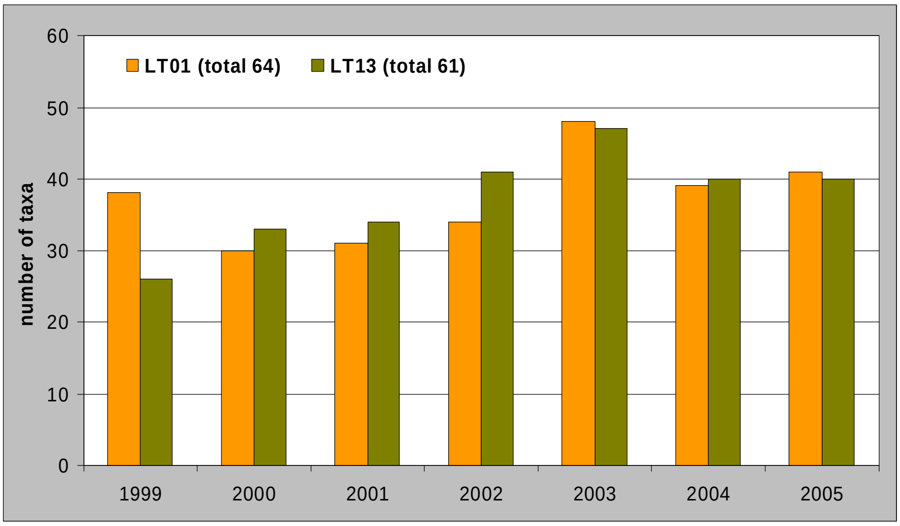

Fig. 26: Number of taxa on two beds between 1999 and 2005 (because of different determination level some taxa were combined on a higher taxonomic level for comparability).

The number of taxa does not give much information about the community structure and similarity of the species composition and their abundances between the different years. To illustrate the relations a non-metric MDS-plot is used (Clark & Warwick 2001). The MDS-Plot bases on the Bray-Curtis similarity matrix which determines the similarity between each year to each other. Years which are more similar to each are plotted closer to each other. Cluster analysis was used to group years which are more similar to each other and clusters formed at three arbitrary levels are superimposed on the MDS-Plots. Community structure of both beds was similar with 65% over all years, considering species composition and mean abundances. The changes in community structure proceeded almost analogue at both beds, but began before Pacific oysters started to dominate (see Fig. 24 and Fig. 25.

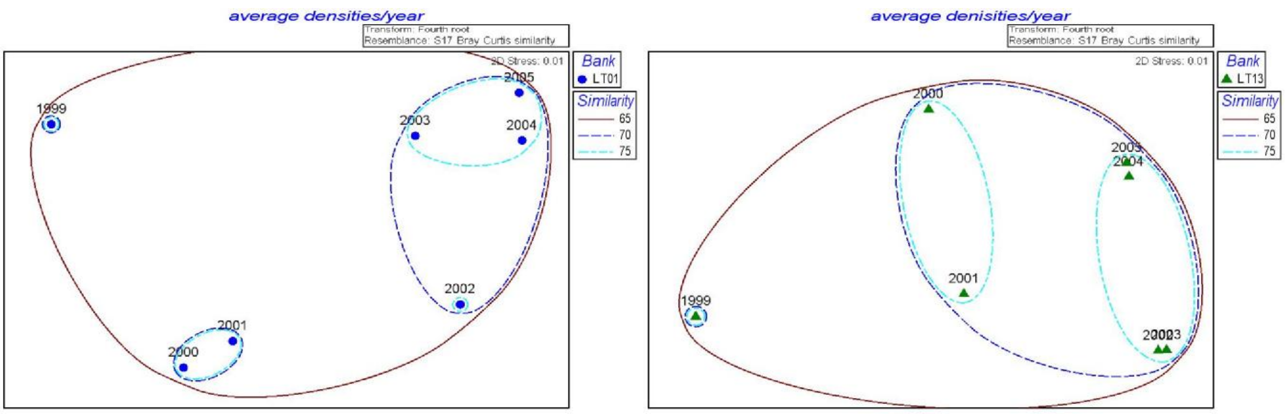

Fig. 27: MDS-Plots (Bray-Curtis-Similarity, fourth root transformation), comparing community structures of two localities during 1999-2005. Left: considering average densities on bed LT01; right: considering average densities on bed LT13; Oligochaeta undet. are ignored (see text).

These changes of community structure can be explained with increasing densities and biomass of the macrozoobenthos. On both beds biomass of macrozoobenthos and the total number of individuals increased during the study period (Fig. 28) and both beds showed the same development. Maximum values of biomass were achieved in 2002 and 2003, but decreased thereafter. Total number of individuals was highest in 2003.

Within the macrozoobentos community, changes were dominated by barnacles. However, abundances of polychaets, Anthrozoa undet. and Bivalvia increased too, especially from 2003-2005 on both beds (Fig. 29). Abundances of Gastropoda increased, representing mainly *Littorina littorea* and *Crepidula fornicata*, which occurred in higher densities.

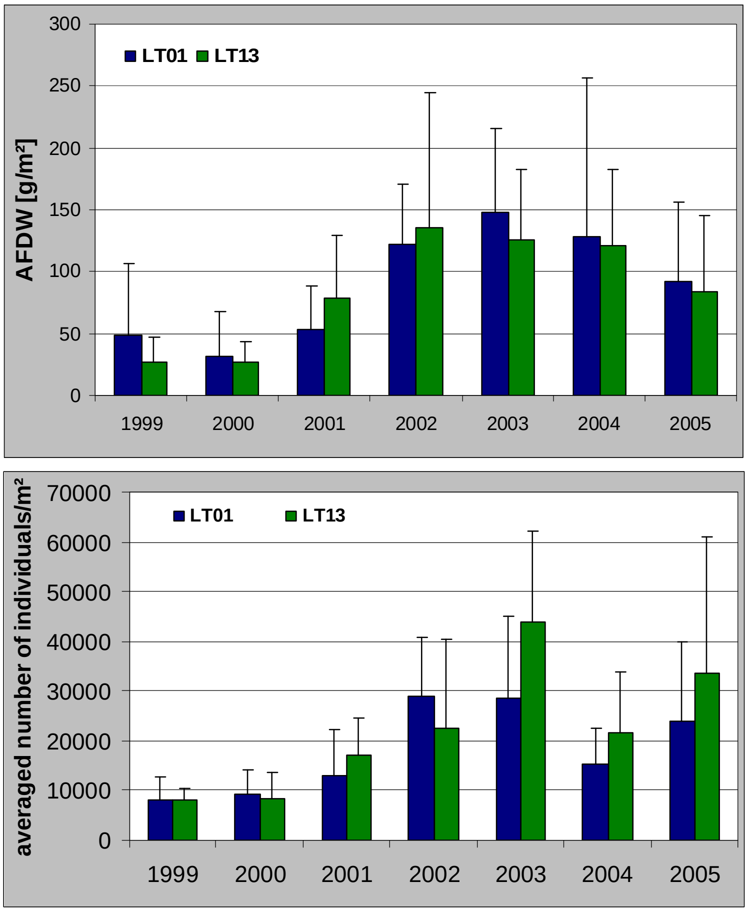

Fig. 28: Biomass and number of macrobenthic species on the beds LT01 and LT13 in the Lister Deep (Oligochaeta undet. not considered; given are average numbers of individuals and standard deviation).

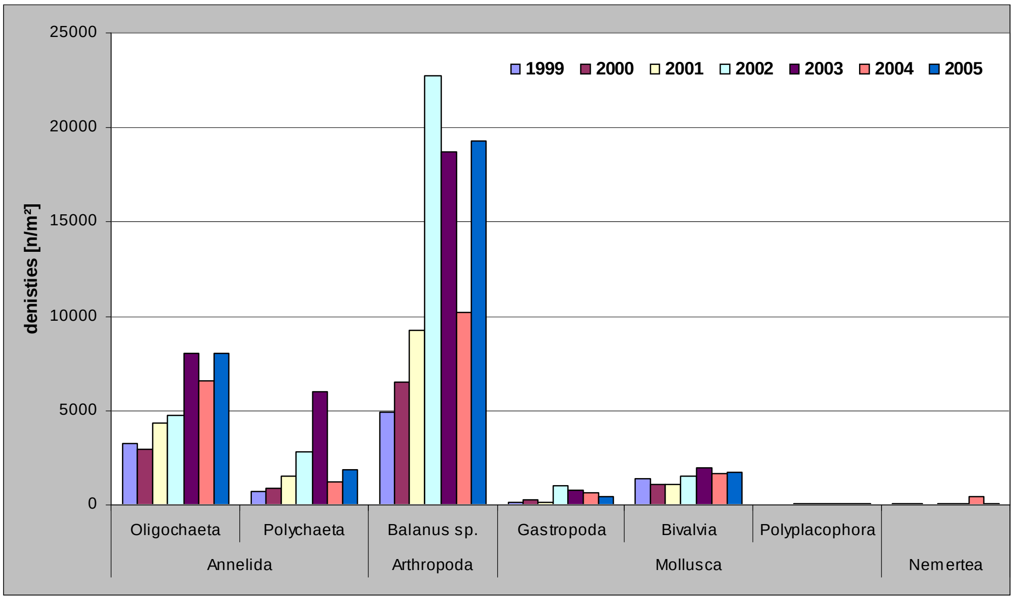

Fig. 29: Mean denisties of selected classes on the bed LT01 between 1999 and 2005.

Abundances of Oligochaets (only > 1mm due to sieve size) increased during the monitoring period (Fig. 29). Markert (2006) found highest densities of Oligochaets in oyster beds while Görlitz (2005) did not find differences between blue mussel and Pacific oyster beds.

These changes form a complex picture probably influenced by three interdependent processes. First the ageing of the blue mussel beds due to missing spatfall offer a more diverse physical structure because of dead shells (Tsuchiya & Nishihira 1986) which facilitates the associated epibenthic community. Secondly on both beds the *Fucus*-coverage decreased and it could be assumed that barnacles and some other epibenthic species have been promoted. Thirdly the increase in three-dimensional structure due to the Pacific oysters (initially with low densities and since 2003 increasing) enhanced in particular epibenthic species.

De Kluijver & Dubbeldam (2003) investigated the influence of Pacific oyster densities on the diversity of subtidal beds in the Oosterschelde (NL). They state that oyster densities up to 50% coverage lead to higher diversity but higher densities caused decreasing diversity. This aspect might become important also in the Wadden Sea, since the short time period of the Pacific oyster spread still allows for further developments and increasing impact of this indigenous species.

In summary, some general statements can be made:

- No species losses were observed yet.
- Blue mussels are able to coexist with Pacific oysters in their reefs.
- Pacific oyster reefs offer species of blue mussel beds an alternative habitat.

- Changes are mainly caused by increasing abundances of the epibenthic species, but also abundances of endobenthic species increased.
- Species dominance changed.
- The increase of Pacific oyster densities, biomass and coverage is still an ongoing process; single surveys and a long-term monitoring is necessary to observe, document and further analyse and assess this process of changing mussel communities and structures as well as the changes in the development of the associated community (species, densities, biomass).

4.3 Introduction of other species associated with oysters

Many new species have been introduced in Europe along with the oyster imports but most did not establish stable populations (Wolff & Reise 2002). Considering the criteria that a) species occur in Japan or on the pacific coast of North America, b) their occurrence coincides with the period of oyster imports, Wolff & Reise (2002) present a list of species which could have potentially been introduced with oysters (Tab. 4)

Tab. 4: Species which might have been introduced with oysters (Wolff & Reise 2002).

scientific name
Gymnodinium miki
Alexandrium leeii
Fibrocapsa japonica
Chattonella sp.
Thalassiosira punctigera
Coscinodiscus wailesii
Sargassum muticum
Undaria pinnatiiida
Grateloupia doryphora
Dasysiphonia sp.
Anotrichium furcell
Polysiphonia senticulosa
Pileolaria berkeleyana
Hydroides ezoensis
Ammothea hilgendorfi

Reise (1998) mentions species which were introduced (*Aplidium nordmanni, Verruca stroemia, Ascophyllum nodosum*) or re-introduced (*Pomatoceros triqueter*) with oyster imports to Wadden Sea around the island of Sylt (Germany). Two species, *Sargassum* *muticum* and *Styela clava*, are established now but might be imported on other paths than oyster imports.

Nehring & Leuchs (1999) give a list of species which have been introduced and background information how they reached the German coast. For the Pacific Oyster they mention five species, which have been introduced with oyster imports:

Anthrozoa:	*Diadumene cincta*: introduced by oyster imports or as fouling on ships, distributed only around Helgoland, common.
	Haliplanella luciae introduced as fouling on ships, mussel imports as vector seem to be possible. No recent population along the German coast.
Mollusca:	*Crepidula fornicata*: introduced with mussel imports to GB, further distribution of larvae by current to the Netherlands and Belgian. Import to Lower Saxony and Schleswig-Holstein with Ostrea edulis.
	Petricola pholadiformes: introduced in GB by oyster import, eastward dispersal by larvae with current and/or imports of Ostrea edulis
Tunicata:	*Aplidium nordmanni*: first records 1992 on oyster cultures near the island of Sylt, probably introduced with oyster imports for the culture. Only around Sylt and rare.

Recently Dekker found the alien species *Hemigrapsus penicillatus* on oysters near Texel (Cadée 2007).

Oysters also brought some of their parasites (*Mytilicola orientalis* and *Myicola ostreae*) with them to France and the Netherlands. These parasites were found in other species of shellfish too but seem to be harmless to them (Wolff & Reise 2002 therein cited His 1977 and Stock 1993). Wolff & Reise (2005) mentioned no strong evidence about introduced shellfish diseases with oyster imports.

4.4 Consequences for energy flow and top predators (birds)

Bivalve suspension feeders are very important members in intertidal food webs (e.g. Asmus et al. 1998). In the Wadden Sea, blue mussel beds represent the most productive benthic communities; even though only about 1% of the tidal flats are covered with blue mussel beds, they reach a significant proportion of the total energy flow due to their intensive production per area. In the Lister Deep, blue mussel bed annual production reaches 762 g C m^{-2} and thus is 28 times higher than the average of the other communities (Asmus et al. 1998). An important aspect of the high production of blue mussel beds is, that a high share of this production is available for higher trophic levels especially birds. On blue mussel beds in the Lister Deep, bird predation by eider duck *Somateria mollissima*, oystercatcher *Haematopus ostralegus* and herring gull *Larus argentatus* almost matches the annual production of the blue mussel bed (Nehls et al. 1997). As Pacific oysters are not eaten by eiders and only rarely by other birds, production and biomass of this species is hardly available for higher trophic levels and the energy flow will be redirected into the storage compartment (cf. Asmus 1987) and microbial decomposition.

To which extent this has an effect on the bird population in the Wadden Sea is not clear and needs further investigation. For mussel eating birds, the change of blue mussel beds to Pacific oyster reefs is certainly not an advantage. While oystercatchers and herring gulls may adapt to the new species and learn how to handle at least small individuals of this new prey, this will certainly not be the case with eider ducks which swallow their prey with shells.

In general, the ecological consequences of the spread of the Pacific oyster and the change of the blue mussel bed community is far from clear and urgently needs further investigations because it poses a variety of changes to the entire ecosystem. At present it is not clear, how the change in the blue mussel bed community will affect biomasses, productivities and filtration rates and what may be the impacts on the surrounding tidal flats.

5 OYSTER FISHERIES

Although cultured Pacific oysters are sold at higher prices as most other shellfish, wild oysters have attracted only very limited action of the fisheries. As wild Pacific oysters are often attached to big clumps, exhibit a variety of forms, are overgrown with barnacles and other epifauna and reach sizes which would overlap a plate, they do not fulfil the standards of high-priced food. Consequently, Pacific oysters are collected by some local fishermen and other people walking on the tidal flats of the Wadden Sea but there is apparently limited interest in harvesting the new species at a larger scale. In the Oosterschelde large amounts of Pacific oysters were removed from some sites, but as there was no demand for further use of the oysters, they were just dumped at some other locations (Baptist 2005, Wijsman et al. 2006). At present, in no part of the Wadden Sea Pacific oysters are commercially fished and at present there seems to be no interest of the fisheries to do so in the near future.

In Schleswig-Holstein, the company running the culture in the Lister Deep has been licensed to collect seed oysters from the Wadden Sea in 2005. However, as only single-grown Pacific oysters of a limited size are useful for the culture, only a small fraction of the wild oyster population is suitable for their purposes and the demand to collect seed oysters appears to be limited.

Though the interest of the fisheries in Pacific oysters is apparently low, the example from Schleswig-Holstein shows, that some fishing activity may still develop and on the other hand, fisherman may be interested to remove oysters from mussel beds in order to improve the mussel fisheries, as has been done in the Netherlands (see below).

6 MANAGEMENT

The spread of the Pacific oyster has to be regarded as the consequence of a careless introduction of an alien species to a sensitive and protected ecosystem. However, no options are available to prevent the species from further spread. It is important to note, that the reproductive capacity of the Pacific oyster is too high and that the oyster population has grown far beyond a point, that it could be removed from the Wadden Sea again. The Pacific oyster obviously has established a stable population not only in the Wadden Sea but also in many other European coastal waters and as other invaders, like the Soft-shelled clam *Mya arenaria* and the American razor clam *Ensis americanus*, they have to be regarded as permanent members of our coastal ecosystems.

In the Oosterschelde some measures have been taken to locally remove oyster reefs (Wijsman et al. 2006). They showed that Pacific oysters could locally be removed efficiently even in dense reefs, however, the effort required to do so was considerable (20 days per ha) and due to a lack of commercial interest in the Pacific oysters, these were just dumped in deep gullies. The effect of these measures on the ecosystem is not clear yet and subject of an ongoing study.

Blue mussel fisheries in the Wadden may be affected by the spread of the Pacific oyster in the future from two reasons. First, Pacific oysters may settle on culture lots and overgrow the blue mussels. At present, it seems to be unlikely that this will be a major problem for the fisheries, as Pacific oysters apparently rarely settle on young blue mussels and in general do not settle in high densities in the subtidal. As blue mussel cultures are stocked with young seed mussels and are located always in the subtidal it seems at present to be unlikely, that they might be overgrown by Pacific oysters. Second, oyster may be present on seed mussel beds and make it impossible to fish purely for blue mussels. This might be the case, if blue mussel spatfall occurs in Pacific oyster reefs, but it is not clear yet to which extent this may happen. As long as blue mussel seed is fished in the subtidal this will be of no problem for the fisheries, because of low Pacific oyster densities in these places. In the intertidal where Pacific oysters build up dense reefs, they may in fact make these areas unattractive for blue mussel fisheries and offer some protection for intertidal habitats, however, at present it is not clear to which extent this may be a problem for the fisheries. From an ecological point of view any intentions to remove Pacific oysters in order to promote blue mussel fisheries must be regarded with caution, as this may well lead to more damage then benefit. Any measure should clearly comply with the guiding principle of the Wadden Sea, which is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way. It is recommended that any steps should be based on a thorough impact assessment according to the habitat directive before approval.

7 MONITORING/ASSESSMENT

The spread of the Pacific oyster poses major changes to the Wadden Sea and there is an urgent need to monitor the further development also to fulfil the monitoring requirements from the habitat directive and the water framework directive. Once Pacific oysters had been able to establish dense populations in the Wadden Sea, they have started to form dense reefs which harbour a diverse benthic community similar to mussel beds. It must be noted, however, that these reefs, initiated by an alien species, are situated within a protected area, the Wadden Sea. Although they form a diverse habitat by itself which might be of some added value for the resident species ecological as well as formal aspects have to be taken into account and it has to be assessed in the near future, whether oyster reefs fulfil the definition of the habitat type 1170 reef of the habitat directive or not.

It is recommended to extend and update the TMAP manual on monitoring (TMAG/CWSS 1997) with respect to the spread of this important new species. Regarding the fast development during the last years, it is strongly recommended that the development of the Pacific oyster becomes subject of a detailed monitoring program covering the following aspects in a yearly rhythm:

- Extension of the area covered by Pacific oysters
- In selected areas: density, size structure and biomass of both, blue mussels and Pacific oysters, respectively
- Annual recruitment of blue mussels and Pacific oysters

These data will allow to follow the most important aspects of the general development but more detailed investigations on filtration rate, production and energy flow as well as investigations into the changes of the associated benthic community are highly recommended.

Biomass of Pacific oysters should be measured as cooked flesh weight. Live wet weight, which is often used in the monitoring of blue mussels is useful, however, data from both species cannot be compared directly as the flesh content of oysters is much lower than that of blue mussels.

The monitoring of Pacific oyster beds can in many aspects follow the standards of the blue mussel monitoring implemented in the Wadden Sea (TMAG/CWSS 1997), but it has to be stressed, that the current monitoring activities on blue mussels will not allow to monitor this fast development adequately. Like the blue mussel beds, oyster reefs can easily be identified from aerial photos, however, both communities cannot be distinguished in most cases, thus there is an added need for ground-based investigations. Similar to blue mussel beds, oyster reefs can be mapped at the tidal flats with a GPS. Sampling of oyster reefs needs somewhat larger frames as used for blue mussels because the density is lower. In the monitoring of blue mussel beds in the Wadden Sea National Park of Schleswig-Holstein a 25 x 25 cm frame is now used to sample both species and it is recommended to use it as a standard for further monitoring. Samples may both be taken either randomly over the whole bed or in the covered heaps only if coverage of the bed is assessed in the same time.

Fig. 30: Oyster reefs near Sylt – a familiar view in many parts of the Wadden Sea.

8 SUMMARY

For the first time a comprehensive data compilation of the entire Wadden Sea was carried out in the framework of the TMAP to document the spread of the Pacific Oyster *Crassostrea gigas* with special emphasis on the recent strong increase in all parts of the Wadden Sea. This study describes the successful spread of an alien species following a careless release which is now leading to remarkable changes in the ecological structure of the Wadden Sea.

Oysters have been brought into the Wadden Sea to stock cultures for more than 30 years and a permanent culture was licensed near the island of Sylt, Schleswig-Holstein in 1986. Pacific oysters are today found in all parts of the Wadden Sea. They form dense layers which have all characteristics of reefs on former beds of the blue mussel *Mytilus edulis* and settle on all other kind of hard substrates. Total biomass in the Wadden Sea is calculated at 61,000 live wet weight (LWW) in 2006. Regional figures are as follows: The Netherlands: 20,510 t, Lower Saxony: 22,747 t, Schleswig-Holstein: 14,481 t, Denmark: 3,289 t. In Schleswig-Holstein, about 95% of the oysters biomass (LWW) are found in the Lister Deep near the island of Sylt. Distribution and temporal course of the spread of the Pacific oysters indicate two main pathways: The oyster culture in the Lister Deep and an inflow of larvae from areas south of the Wadden Sea, most probably from the Oosterschelde where Pacific oysters are cultured and spreading since the 1970ies. Within dense reefs oysters reach abundances of about 1000 indiv./m^2 and reach a biomass of up to 50 kg/m^2 live wet weight. The spread of the Pacific oyster is apparently highly facilitated by warm summer temperatures and years with good spatfall are characterised by water temperatures above average. Climate change – as it will lead to higher temperatures - will thus further promote the development of this introduced species.

A comparison of the development of Pacific oyster and of blue mussel provided no indication, that oysters are the cause of declining mussel stocks. In three regions – Lower Saxony, Schleswig-Holstein and Denmark – mussel bed area and biomass showed a long-term decrease which started before oysters were spreading and in The Netherlands, mussel beds markedly recovered to high values in the same period as oysters spread out. Although competition of the two species on a local scale cannot be ruled out, the decline of mussel beds on a larger scale cannot be explained by the spread of the oyster.

Studies of the macrofauna community structure of oyster beds revealed a diverse community which is in many aspects similar to that associated with of blue mussel beds. So far no species losses have been detected and oyster reefs seem to serve as a new habitat for all indigenous species of mussel beds. However, comparison of results indicated differences in dominance structure and in endobenthic functional groups composition between blue mussel beds and Pacific oyster beds. Therefore, further spread of oysters might lead to functional

changes in the Wadden Sea and to changes in the whole associated community. However, this is an ongoing process and further development cannot be predicted.

The consequences of the spread of the oysters for the Wadden Sea ecosystem cannot be overseen yet and a further rapid extension of the population is expected. Unlike blue mussels oyster are only consumed by a few species and suffer little predation. Energy flow of an oyster reef is thus anticipated to be highly different from mussel beds and not directed to higher trophic levels. Oyster reefs are apparently of little value for mussel eating birds and especially eider ducks *Somateria mollissima* cannot make use of the oysters.

Consequences for mussel fisheries are expected to be rather low at present, as the distribution of Pacific oysters is still mainly restricted to the intertidal parts and there is no indication yet, that oysters have an impact on mussel spatfall.

No options exist for management to reduce or even stop the spread of the Pacific oyster. The Pacific oyster obviously has established a stable population not only in the Wadden Sea but also in a number of other European coastal waters and as other invaders, like the Soft-shelled clam *Mya arenaria* and the American razor clam *Ensis americanus*, the species has to be regarded a permanent members of our coastal ecosystems. Any intentions to remove Pacific oysters for whatever reason should be assessed carefully, as this would be a considerable impact with yet unforeseen consequences and could potentially lead to more damage then benefit. Any measure should clearly comply with the guiding principle of the Wadden Sea, which is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way. It is recommended that any steps should be based on a thorough impact assessment according to the habitat directive before approval.

The further spread of the Pacific oyster and possible consequences to the Wadden Sea ecosystem should be subject of detailed research and monitoring. Monitoring standards should be harmonized within the entire Wadden Sea and comply with the objectives of the habitat directive as well as of the water framework directive.

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Annex 1: Conclusions and Recommendations

Conclusions and Recommendations
from the Trilateral Workshop on
Pacific Oyster Invasion in the Wadden Sea
Consequences for Ecology, Monitoring and Management
22 March 2007, Wilhelmshaven

Background

The Pacific Oyster has spread over the entire Wadden Sea. Results from ongoing research projects have indicated that spreading of the Pacific oyster has increased considerably during the last 5 years.

In order to obtain an up-date of the status of the Pacific oyster invasion and to assess the possible consequences for the ecosystem, as well as for monitoring and management, also with regard to the EC Habitats and Water Framework Directive, a trilateral report with a comprehensive data analysis was compiled by Georg Nehls and Heike Büttger (BioConsult SH) on behalf of the Common Wadden Sea Secretariat.

The work was co-funded by the Interreg IIIB project HARBASINS and supported by the Research Institute Senckenberg (Wilhelmshaven), the Schleswig-Holstein National Park Agency (Tönning) and the Lower Saxon National Park Administration (Wilhelmshaven). Additionally, the Institute of Marine Research-IMARES (Texel), the Danish Fisheries Research Institute and the Alfred Wegener Institute-AWI (List/Sylt) provided recent data on oyster distribution.

The report was the starting point for a discussion at a trilateral workshop on 22 March 2007 in Wilhelmshaven with scientists and managers from the Wadden Sea and England to discuss the recent status and possible consequences of the Pacific oyster spreading in the Wadden Sea and to prepare recommendations regarding follow up-activities in the fields of research, monitoring and management. The workshop program is in Annex 1 and the list of participants is in Annex 2.

Conclusions

Sporadic occurrence of the Pacific oyster in some parts of the Wadden Sea is known for over 20 years, but a rapid increase in the entire area has been documented only for the last 5 years. Areas populated by the Pacific oyster (blue mussel beds, hard substrates) increased significantly in the past years, also including formerly soft sediments. The Pacific oysters form massive reefs in all parts of the Wadden Sea. The total oyster biomass in the intertidal area of the entire Wadden Sea has increased to about 61.000 tons fresh weight in 2006 (The Netherlands: 20.510, Lower Saxony: 22.747, Schleswig-Holstein: 14.481; Denmark: 3289). In many places Pacific oysters have overgrown former blue mussel beds to form dense and solid reefs. Abundance in dense reefs is about 1000 oysters m^{-2} with a mean biomass 30 to 50 kg m^{-2} live wet weight.

1. Factors influencing oyster distribution

Abiotic factors:

As a main abiotic factor the substrate availability must be pointed out. Pacific oysters settle on hard substrates which are of limited occurrence in the Wadden See. They often settle initially upon barnacles, blue mussels and dead bivalve shells. Further on Pacific oysters create their own substrate and as oyster larvae prefer conspecifics to settle, they initiate massive clumps which grow further as more oyster larvae settle on top.

Salinity does not seem to significantly influence the distribution of the Pacific oyster in the Wadden Sea.

The reproduction of the Pacific Oyster in the Wadden Sea is highly correlated to summer temperatures. The high summer temperatures in the last 10-12 years have been identified as a main factor causing the recent increase of the Pacific oyster. A few days in July and August with water temperatures above 18-20 °C may already trigger the reproduction of the oyster. On the other hand, the Pacific oyster is able to survive cold winters better than previously expected.

Mass mortality among Pacific oysters was observed occasionally in shallow bays and harbours. In late summer after spatfall (when condition of oysters is low).This is probably caused by local factors such as limited water exchange.

Biotic Factors

The Pacific oyster has almost no natural predators in the Wadden Sea. But predation by birds like oystercatchers and herring gulls has been observed. So far neither starfish, shore crabs, birds nor parasites induce high mortality that could stop or reduce the oyster's population growth.

The observed population development is considered to have been promoted by an extension of phytoplankton blooms in late summer which enhance especially successful settling of oyster larvae.
On the other hand, phytoplankton spring blooms have developed later in the year (due to increased grazing pressure during mild winters) providing less food for blue mussels, cockles and Baltic tellins during their reproductive period.

2. Future development

From experiences in the Dutch Delta region (Oosterschelde), where the Pacific oyster showed a continuous increase over the last 30 years, it can be assumed that the spread in the Wadden Sea will continue further. Total biomass (life wet weight) of Pacific oysters in Wadden Sea is still less than half of that known from the Oosterschelde.

Climate change will further enhance the spread of the Pacific oyster. Warmer winters are assumed to have a negative influence on reproduction of blue mussels and other bivalves, because predators like shore crabs and shrimps return earlier in spring to the tidal flats reducing bivalve spat significantly. On the other hand, proliferation of oysters is facilitated by warm summers. The warm summer of 2006 lead to a strong oyster spatfall in the entire Wadden Sea and further spread and increasing abundances and biomass are to be expected.

The questions whether or not native blue mussel beds will disappear from the Wadden Sea due to the invasive nature of the Pacific oyster or whether a coexistence of Pacific oysters and blue mussels is possible cannot be answered so far. In future, all three types of beds might occur: blue mussel beds, oyster reefs and mixed beds.

There are several examples of co-existence of blue mussels and oysters in mixed beds.
In the Dutch Wadden Sea, blue mussels have successfully re-established a strong population in the last years. If sufficient blue mussel recruits manage to settle, new beds may develop and blue mussels may co-exist with oyster reefs.

To evaluate the further development of the Pacific Oyster in the Wadden Sea annual monitoring should be carried out, accompanied with investigations on ecology and development in other coastal waters of our globe.

3. Consequences for the ecosystem

Until now the species composition of the associated fauna of oyster reefs compared to that of blue mussel beds does not differ significantly. Negative effects on the biodiversity have not been detected, but the dominance structure of the associated fauna has changed.

Most bird species seem to be able to adapt to the appearance of oyster reefs because they feed mainly on the associated fauna, such as worms and shore crabs. Birds with food preference for blue mussels, like Eider and Oystercatcher, are not able to use oysters as food resource.

In the Oosterschelde (SW Netherlands) a management experiment was carried out consisting of the removal of 50 ha of oyster reefs in March 2006. Effects on sedimentation and benthic infauna community at the oysters plots and reference areas were also investigated. The interim report (Wijsman et al. 2006) stated that the removal is effective. Oyster beds exhibit muddy sediments with higher organic carbon content which becomes apparent in the associated community (higher diversity, characterized by polychaetes, decapods and amphipods). Oyster removal might lead to sandy sediments with a less diverse community (more molluscs). A negative side effect may occur through suffocation of the benthic fauna living in areas where the removed oyster bed is dumped.

4. Human use

Negative effects on recreational activities can be expected because oyster shells are sharp and swimmers and surfers may be hurt; however, this will be restricted to few areas only.

The spread of the Pacific oyster may have some effects on the blue mussel fishery because mixed beds with blue mussels and oysters can no longer be exploited. At present no specific data on this issue are available.

At present there is only limited interest in fisheries for Pacific oysters as the wild oysters are of little commercial value.

Positive effects of developing oyster reefs on coastal protection issues are not considered to be of significance.

5. Monitoring

The spread of the Pacific oyster is a major change in the Wadden Sea ecosystem and should therefore be properly documented to assess future changes. A higher effort is therefore necessary to gather the required data.

The ongoing national monitoring programs in the TMAP document the location of blue mussel beds and in this context also the occurrence of Pacific oyster. However, no information on oysters is available for areas which are not surveyed in the mussel monitoring.
There is a gap in the monitoring in the Netherlands in 2007 (only few beds are monitored regularly in connection with blue mussel fishery).

Apart from the monitoring program, more research is urgently needed to investigate and assess the changes of the Wadden Sea ecosystem which may be induced by the change of a key ecological community. Such data are also needed against the background of the Habitat Directive.

Methods of the Trilateral Monitoring must be standardized with respect to the adequate monitoring of oyster reefs.

6. Management

There are no successful management options available for removal of the Pacific oyster from the Wadden Sea. Therefore, these oysters have to be considered as permanent members of the Wadden Sea ecosystem. The ecosystem has been always changing and interference by severe management measure should be avoided. This would be in line with the guiding principle that natural processes in the Wadden Sea should proceed as undisturbed as possible.

In order to control, or reduce the occurrence of the Pacific oyster in the Wadden Sea, no viruses or diseases should be introduced because of their unforeseeable and uncontrollable effects.

Local management / removal may be possible as already discussed for the Oosterschelde. In any case a better scientific basis has to be established to assess the impact of such a management measure on the ecosystem and its processes.

Recommendations

1. Research

The workshop underlined the urgency of further ecological research in order to better assess the consequences of the Pacific oyster invasion for the Wadden Sea ecosystem. A good scientific foundation has to be prepared now and in this phase of oyster spreading, to be able to better assess future changes.

In general there is a need for more basic knowledge on ecosystem effects in order to support management decisions. Experiences from other coastal waters of the world should be used.

Cooperation of research institutes in the Wadden Sea and other countries (F, UK, Asia) and exchange of knowledge is recommended. The CWSS is asked to coordinate research activities and future initiatives, and to investigate possible funding from the EU (such as COST, FP7).

2. Monitoring

At present, the monitoring of Pacific oysters in the Wadden Sea is not done in a harmonized way. For example, no monitoring takes places in the Dutch Wadden Sea in 2007, whereas further assessments in Niedersachsen and Schleswig-Holstein are guaranteed until 2008. Pacific oyster monitoring cannot be simply included in the existing monitoring of blue mussel beds, and therefore requires extra funding.

The further developments of the Pacific oyster and its effects on the ecosystem should be part of the harmonized assessment of the data for the entire Wadden Sea. The Trilateral Monitoring and Assessment Program (TMAP) is the instrument to provide Wadden Sea wide data in a harmonized and effective way.

The present gaps in monitoring of the Pacific oyster should be filled as soon as possible by establishing a regular monitoring within the framework of the TMAP, starting already in spring 2007
The CWSS in cooperation with N. Dankers, P. S. Kristensen, G. Millat, G. Nehls and A. Wehrmann will prepare a proposal for a TMAP manual for Pacific oyster monitoring.

3. Management

The spread of the Pacific oyster in the Wadden Sea has to be regarded as the consequence of a careless introduction of an alien species to a sensitive and protected ecosystem. This underlines that the introduction of alien species in an ecosystems has to be avoided as much as possible.

The judgement on possible removal of Pacific oyster beds as a management option needs more supporting scientific knowledge and must be based on thorough impact assessment. The first trial has been done in the Oosterschelde in March 2006 (Wijsman et al. 2006) and more results have to be awaited.

Annex 2: Final Workshop Program

Co-funded by ERDF

HARBASINS

Trilateral Workshop on

Pacific Oyster Invasion in the Wadden Sea

Consequences for Ecology, Monitoring and Management

22 March 2007

Senckenberg Research Institute,

Südstrand 40, Wilhelmshaven

Organized by the Common Wadden Sea Secretariat in the framework of the HARBASINS project

Program

11.00 Welcome and introduction (Chair: Karel Essink)

11:10 Distribution of the Pacific Oyster in the Netherlands, Germany and Denmark: Temporal and spatial trends (Georg Nehls, BioConsult SH)

11.40 Distribution of the Pacific Oyster in South-west England (Gemma Couzens, Natural England, UK)

11:50 Distribution of Pacific Oyster in the Danish Limfjord (Helle Torp Christensen, Danish Technical University)

12:00: Topical presentations

- 12:00 Associated fauna (Heike Büttger, BioConsult SH, Husum)
- 12:10: Filtration experiments (Achim Wehrmann, Research Institute Senckenberg, Wilhelmshaven)

12:20– 13:15 Lunch

- 13:15 .Field experiments on artificial oyster reefs (Karsten Reise, Alfred-Wegener-Institute, Sylt)
- 13:30 Larviphagy by oysters, mussels and cockles (Wim Wolff / Karin Troost, Uni Groningen)
- 13:45 Consequences for birds (Bruno Ens, SOVON, NL / Gregor Scheiffarth, Inst. Avian Research, Wilhelmshaven)
- 14:00 Oyster monitoring in the TMAP (Georg Nehls, BioConsult SH, Husum)

14:15 – 14:30 Break

14:30 Plenary Discussion

Topics

- Oyster distribution in the Wadden Sea: main factors, future developments;
- Consequences for the ecosystem,
- Consequences for human use (recreation, fisheries, coastal protection);
- Adaptation of monitoring and management,

15:45 Conclusions

- Main findings and recommendations
- Follow up (research projects, monitoring proposals)

16:00 Closing

Annex 3: Workshop Participants

Name		**Institute**
The Netherlands		
Essink	Karel	Chairman
Dankers	Norbert	Institute for Marine Resources & Ecosystem Studies
Fey-Hofstede	Frouke	Institute for Marine Resources & Ecosystem Studies
Wijsman	Jeroen	Institute for Marine Resources & Ecosystem Studies
Braaksma	Sytze	Min. Landbouw, Natuur & Voedselkwaliteit
Kouwenhoven	Angelo	Min. Landbouw, Natuur & Voedselkwaliteit
Schermer Voest	Wilbert	Min. Landbouw, Natuur & Voedselkwaliteit
Ens	Bruno	SOVON
de Vlas	Jaap	RIKZ
Wolff	Wim	Uni Groningen
Germany		
Reise	Karsten	Alfred-Wegener-Institute
Ruth	Maarten	ALR-Kiel, Abt. Fischerei
Büttger	Heike	BioConsult SH
Nehls	Georg	BioConsult SH
Rolke	Manfred	Bundesamt für Seeschifffahrt und Hydrographie
Marencic	Harald	Common Wadden Sea Secretariat
de Jong	Folkert	Common Wadden Sea Secretariat
Markert	Alexandra	Forschungsinstitut Senckenberg
Schmidt	Andreas	Forschungsinstitut Senckenberg
Wehrmann	Achim	Forschungsinstitut Senckenberg
Zwaka	Hanna	Forschungsinstitut Senckenberg
Lenz	Mark	IFM-GEOMAR
Dittmann	Tobias	Institut für Vogelforschung
Esser	Wiebke	Institut für Vogelforschung
Exo	Michael	Institut für Vogelforschung
Scheiffarth	Gregor	Institut für Vogelforschung
de Leeuw	Andries	Landesverband Schleswig-Holsteinischer Angler und Fischer e.V.
Oberdoerffer	Philipp	Landwirtschaftskammer Niedersachsen
Knoke	Vera	Ministerium für Landwirtschaft, Umwelt und ländliche Räume Schl.-Holst.
Eskildsen	Kai	Nationalparkamt Schleswig-Holst.
Borchardt	Thomas	Nationalparkamt Schleswig-Holst.
Millat	Gerald	Nationalparkverwaltung Niedersächsiches Wattenmeer
Claußen	Alina	Nationalparkverwaltung Niedersächsiches Wattenmeer
Stede	Michael	Nds. Landesamt f. Verbraucherschutz u. Lebensmittelsicherheit
Gubernator	Manuela	Niedersächsische Muschelfischer GbR

Name		Institute
Herlyn	Marc	Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz
Pogoda	Bernadette	Universität Bremen, Marine Zoologie
Denmark		
Jensen	Jan Steinbring	Danish Forest and Nature Agency
Christensen	Helle Torp	Danish Institute for Fisheries Research Technical University of Denmark
Knudsen	Tom	Ministry of the Environment Environmental Center Ribe
UK		
Couzens	Gemma	Natural England
Donnelly	Conor	Natural England