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The Distribution Gap is Closed – First Record of Naturally Settled Pacific Oysters *Crassostrea gigas* in the East Frisian Wadden Sea, North Sea

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With 2 Text-Figures and 2 Tables

Key words: neozoa, Pacific oyster, invasive species, mussel beds, larval drift, tidal flats

Abstract

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Since the 1960s Pacific oysters *(Crassostrea gigas)* were imported to the North Sea coasts for aquaculture. The species was introduced to replenish the stock of the indigenous European oyster *Ostrea edulis* which was strongly diminished in the past by overexploitation, diseases and severe winters. The introduction of this non-native species was regarded as uncritical due to the low water temperatures of the North Sea which would not have promoted natural reproduction and settlement. Nevertheless, strong spatfall of cultured *C. gigas* was recorded in several years in the Oosterschelde estuary (The Netherlands). From these spatfalls wild populations developed in the vicinity of the culture plots. Since the early 1980s Pacific oysters were also observed in the Wadden Sea area near Texel. The pelagic oyster larvae can bridge the distance between the Oosterschelde estuary and Texel by drifting with the residual currents which, at westerly winds, may transport them about 4 to 5 NM per day. Extreme spatfalls from culture plots were also recorded in the backbarrier tidal flats of the North Frisian Islands Sylt and Rømø in 1991, 1994 and 1998. Settlement occurred predominantly on intertidal *Mytilus* beds. The extended wild populations resisted two severe winters which were characterized by a drift-ice coverage lasting several weeks.

In the backbarrier tidal flats of the East Frisian Islands the first specimens of *C. gigas* were found in August 1998 on *Mytilus* beds. In contrast to the wild oyster populations from the Oosterschelde and Sylt, the settlement of *C. gigas* in the study area occurred far away from culture plots. In the following years, further records indicate a continued introduction of oyster larvae. This implies that the distribution gap of *C. gigas* along the Wadden Sea coast is now closed.

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Kurzfassung

[WEHRMANN, A. & HERLYN, M. & BUNGENSTOCK, F. & HERTWECK, G. & MILLAT, G. (2000): Die Verbreitungslücke hat sich geschlossen – Die ersten Funde natürlich angesiedelter Pazifischer Austern *Crassostrea gigas* im Ostfriesischen Wattenmeer. – Senckenbergiana marit., **30** (3/6): 153 –160, 2 Abb., 2 Tab.; Frankfurt a. M.]

Seit Mitte der 60er Jahre wurden im Bereich der Nordseeküste Pazifische Austern *(Crassostrea gigas)* zu Zuchtzwecken eingeführt. Diese Art sollte die durch Überfischung, Krankheiten und Eiswinter in ihren Beständen stark dezimierte europäische Auster *Ostrea edulis* in den zahlreichen Aquakulturen ersetzen. Die Einführung der fremden Art in die Wattengebiete, meist in Form von Saatmuscheln aus Aufzuchtbetrieben, schien unbedenklich, da aufgrund der durchschnittlich niedrigen Wassertemperaturen eine Reproduktion und erfolgreiche Ansiedlung im Freiland nicht zu erwarten gewesen wäre. Trotzdem kam es insbesondere an der südniederländischen Küste im Oosterschelde-Ästuar zu zahlreichen Larvenfällen (7 im Zeitraum 1975–1992) von *C. gigas* aus Aquakulturen. Aus diesen Larvenfällen entwickelten sich in unmittelbarer Umgebung der Aquakulturen grössere Wild-Populationen. Seit Beginn der 80er Jahre wurden Pazifische Austern auch im niederländischen Wattenmeer nahe der Insel Texel gefunden. Eine Überbrückung der Distanz Oosterschelde-Texel während der pelagischen Phase der Austernlarven ist möglich: die Verdriftung mit der küstenparallelen Restströmung beträgt bei westlichen Winden ca. 4–5 NM pro Tag. Intensive Larvenfälle von *C. gigas* aus Austernkulturen wurden auch im Rückseitenwatt der nordfriesischen Inseln Sylt und Rømø in den Jahren 1991, 1994 und 1998 beobachtet. Die Ansiedlung erfolgte in der Regel auf intertidalen Miesmuschelbänken. Die grossen Wild-Populationen blieben auch in strengen Eiswintern bestehen.

In den Rückseitenwatten der Ostfriesischen Inseln wurden lebende *C. gigas* erstmalig im August 1998, ebenfalls auf einer intertidalen Miesmuschelbank, gefunden. Im Gegensatz zu den niederländischen und Sylter Wildvorkommen erfolgte hier eine Ansiedlung trotz fehlender Austernkulturen in der näheren Umgebung. Weitere Funde in den darauffolgenden Jahren weisen darauf hin, dass die Einwanderung durch Larvendrift von den niederländischen Populationen zu erfolgen scheint. Damit hat sich die bislang bestehende Verbreitungslücke von *C. gigas* entlang der Wattenmeerküste der Nordsee geschlossen. Es ist anzunehmen, dass die pazifische Auster zu dauerhaften Veränderungen in den Strukturen der Muschelbänke führen wird.

Introduction

Over the last decades the biodiversity of marine ecosystems changed conspicuously due to the invasion of exotic species. Only a minor part of these invade in a natural way trough, e.g. migration induced by short-term or long-term climatic changes. The introduction and dispersion of most non-indigenous organisms can be related to human activities. Along the North Sea coast the first invasion of a marine organism which can be traced back to anthropogenic causes is that of the soft clam *Mya arenaria*. New data (PETERSEN et al. 1992; NEHRING 1998; BEHRENDS pers. com.) suggest an introduction age which can be correlated to the transatlantic expeditions of the Vikings in the late 10th century. Thereafter, the number of non-indigenous bivalve species in the estuaries and tidal flat areas of the Wadden Sea increases with numerous records of inadvertently or actively introduced exotic species. This process was intensified by global shipping since the 17th century. Up to now a total of 80 non-native species, predominantly invertebrates, macroalgae and phytoplankton, have been recorded as established in the North Sea region (NEHRING & LEUCHS 1999; REISE et al. 1999). Most of the invaders occur within the coastal environments with a preference for brackish estuaries.

When considering species arrival times or their first records it is obvious that the number of exotic species peaked in the 1970s. Discussing the invasion of the American razor clam *Ensis americanus* (erroneously misidentified as the fossil *E. directus* (CONRAD 1843)) in the German Bight in 1978, VON COSEL et al. (1982) concluded that only the new generation of fast ships could have brought living larvae of the endobenthic *E. americanus* with ballast water across the North-Atlantic as the larval stage lasts for a minimum period of two weeks only. However, the transport of freshly spawned larvae from the eastern coast of North America to the German Bight is feasible within 8–10 days by those ships. Another reason for the record peak in the 1970s is that highly effective antifouling paints are in use only since the end of the 1970s.

REISE et al. (1999) noted that up to 32 of the exotic species were introduced together with both American and Pacific oysters imported for mariculture purposes. Spat of *Crassostrea gigas* was first imported to the Netherlands in 1964. At the British North Sea coast hatchery-produced *C. gigas* were also cultured since the 1970s (DRINKWAARD 1999). Spat and larvae of *C. gigas* were repeatedly introduced into the German Wadden Sea since 1971, mostly for aquacultural experiments and studies (NEUDECKER 1985). From several culture plots of the Dutch and German North Sea coast intensive spatfalls were recorded in warm summers. However, in both cases it had been predicted before (as referred to by DRINKWAARD 1999; see also SCHÜMER 1992) that a successful reproduction and spatfall of the introduced non-indigenous species would not be possible because of unfavorable low ambient water temperatures. This erroneous assumption was made although *C. gigas* had already successfully reproduced as non-indigenous species in the waters around Vancouver Island at water temperatures between 19°C (67F) and 24°C (75F) (QUAYLE 1969).

The spatial distribution of the newly established natural stock was predominantly related to culture plots (DRINKWAARD 1999). Also, around the island of Sylt, where the only

German commercial oyster-aquaculture exists, larvae of *C. gigas* dispersed over the adjacent tidal flat areas (REISE 1998). Settlement of *C. gigas* larvae away from the farming sites were reported from Texel in the Dutch Wadden Sea (BRUINS 1983) and from the Ems-Dollart estuary (TYDEMAN 1999). Similarly, the record of naturally settled Pacific oysters in the East Frisian Wadden Sea (this study) cannot directly be related to culture plots in this region.

Regional History of Oyster Fishery and Aquaculture

Until the beginning of the 20th century the indigenous European oyster *Ostrea edulis* formed extensive oyster beds along the coasts of Northern Europe. These were situated in lower intertidal to shallow subtidal positions down to several meters water depth. The last beds of the native species *O. edulis* along the coast of the German Bight disappeared in 1940 (HAGMEIER 1941) as a result of permanent overexploitation since the 18th century.

In the East Frisian Wadden Sea the first activities in oyster fishery began in 1642 (LINKE 1937) around the island of Wangerooge (Fig. 1). Until 1715 further oyster beds were exploited near Borkum, Baltrum, Juist and Langeoog (NEUDECKER 1985). The severe winter of 1740 caused strong damages in the oyster beds and a marked stock reduction. To allow for recovery, oyster harvest was prohibited until 1764 in the area around the island of Borkum. Nevertheless, an armada of Dutch oyster fishers frequently descended over these beds in the following years. Since 1773 several attempts were made to improve the situation by transferring oysters from other regions to the local beds, followed by a close season for the next years. Nevertheless, in 1806 the oyster fishery around the island of Wangerooge had to be abandoned due to the strong decrease of the total catch (LINKE 1937).

For replenishment of the exploited oyster beds unsuccessful attempts in aquacultural reproduction of *O. edulis* were started in 1869. In 1913 the regional oyster fishery was reactivated when non-indigenous oyster species were introduced into the East Frisian Wadden Sea (NEUDECKER 1985). A chronological list of non-indigenous oyster imports for culture plots in the study area is given in Tab. 1 (NEUDECKER 1985 and pers. com.; this study). All these attempts, however, proved unsuccessful or uneconomic.

Table 1. Temporary introduction of several oyster species in the backbarrier area of the East Frisian Islands, southern North Sea.

Site	year	introduced species
Norddeich	1913/1914	introduction of *Ostrea edulis*, *Crassostrea virginica* 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*

Regional Setting and Environmental Parameters

The study sites are located in the East Frisian Wadden Sea which is part of the larger Wadden Sea ecosystem of the southern North Sea (Fig. 1). Its western (Dutch) and central (East Frisian) sections are separated from the open North Sea by a system of 13 larger, mostly elongated barrier islands. In the backbarrier areas of these islands extended tidal flats emerge during low-tide, separated by numerous tidal channels. The semi-diurnal tide in the study area has a mean range of 2.3 m in its western part (Borkum) and 3.9 m in its eastern part (Jade Bay). Regional wind effects often influence the tidal level as well as the duration of emergence. The salinity varies throughout the year between 26 and 34 . The water temperature in the backbarrier area measured in 1994 and 1995 ranged from 1°C in winter to 25°C in summer (KRÖGEL 1997). In severe winters temperatures below the freezing point may result in drift ice and ice coverage in the backbarrier areas. The tidal current velocity normally does not exceed 0.7 m/s in summer, but wind driven currents reach values of up to 1.3 m/s during severe weather periods. Above the tidal flats the current velocity is up to 0.3 m/s (KRÖGEL 1997).

In the winter 1995/1996 the study area was affected by strong drift ice over 64 days (internal ice report WSD 1996). Subsequently, in summer 1996, an intense and approximately simultaneous spatfall of the edible cockle *Cerastoderma edule* and the blue mussel *Mytilus edulis* was observed. Most of the recent *Mytilus* beds and bivalve clusters, which are preferentially populated by the Pacific oysters, originate from this spatfall (WEHRMANN 1999).

After the 1996 spatfall the backbarrier area was again covered by drift ice over a 35 days period in the winter 1996/1997 (internal ice report WSD 1997).

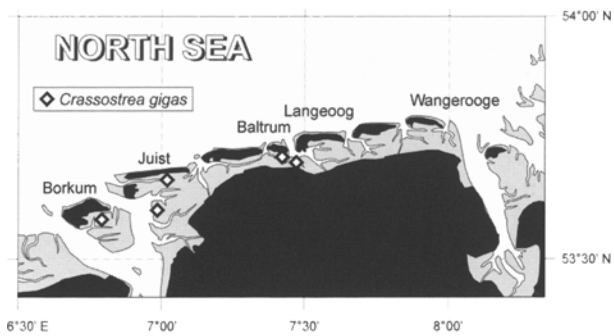

Fig. 1. Geographic map of the southern German Bight. – The map shows the study area and the sites of intertidal *Mytilus* beds with *Crassostrea gigas* in the backbarrier area of the East Frisian Islands, southern North Sea.

Field Survey and Mussel Bed Monitoring

Intensive field surveys in the backbarrier tidal flats of the East Frisian Wadden Sea were carried out between 1988 and 1999 in different scientific programs and by different research groups. Most of the field work concentrated on the eastern section of the barrier island chain. Nevertheless, the backbarrier area was continuously investigated over the last decade.

The investigations concentrated on the spatial, temporal and structural development of mussel beds (HERTWECK 1993a, 1993b; HERTWECK & LIEBEZEIT 1996; WEHRMANN 1999). The biofacies zonation and distribution of characteristic sediment bodies of several catchment areas of the tidal inlets were mapped in detail between 1988 and 1999 (STALLMANN 1993; BOETTCHER 1995; HERTWECK 1995, 1998; CONRAD 1997; MEYER-BOOCKHOFF 1997; BUNGENSTOCK 2000).

The monitoring of the intertidal mussel beds was intensified in the 1980s when the stock of blue mussels declined markedly in the Wadden Sea area. Extensive surveys, based on the analysis of aerial photographs, ground truthing and mapping, were regularly carried out (MICHAELIS et al. 1995; ZENS et al. 1995; MILLAT & HERLYN 1999). A total of up to 187 sites, where *Mytilus* beds, bivalve clusters (sensu WEHRMANN 1999) and bases of beds occur continuously or periodically, were recorded (MILLAT & HERLYN 1999). Ground truthing was done on selected sites only. Systematical search for *Crassostrea gigas* in the East Frisian Wadden Sea started in 1996 with the survey of 34 mussel beds.

Shell dimensions, i.e. length and width (see QUAYLE 1969: Fig. 29), of living specimens of *C. gigas* were measured with a caliper rule to the nearest mm.

Detailed information on appearance, biology, reproduction and ecology of *C. gigas* are given in QUAYLE (1969), KORRINGA (1976) and NEUDECKER (1985).

Results and Discussion

Regional and Temporal Distribution

In the North Frisian Wadden Sea living specimens of *Crassostrea gigas* were found at 17 sites on 21 *Mytilus* beds investigated around the Islands of Sylt and Rømø in 1995 (REISE 1998). In contrast, Pacific oysters in the study area occurred more disperse and less numerous. Until spring 2000 all specimens (living and dead) of *C. gigas* were found on four larger *Mytilus* beds located on tidal flats in the western and central section of the barrier island chain (Tab. 2; Fig. 1). As mentioned above, the total number of mussel beds in the East Frisian Wadden Sea is up to 187.

The first occurrence of the invasive Pacific oyster *C. gigas* in the East Frisian Wadden Sea was observed in August 1998 (WEHRMANN 1999) southeast of the barrier island of Baltrum. The one adult specimen of *C. gigas* was not attached to a hard substrate but was fixed by the byssus threads of numerous living *Mytilus edulis*. Additionally, the left valve of a second adult but dead specimen was found one day later on an adjacent *Mytilus* bed. The preservation status of the shell led to the assumption that no obvious alteration and erosion, respectively, happened since the disarticulation of the valves. The shell was attached to a *Cerastoderma edule* valve.

Until November 1998 no further specimens were found on the tidal flats of the Accumer Ee (tidal inlet) catchment area. In the following spring, 1999, *C. gigas* was found on two sites in the western section of the study area (Tab. 2; Fig. 1). South of the island of Juist 13 medium sized living specimens of the Pacific oyster were recorded during ground truthing in the mussel bed monitoring project. The specimens were mainly attached to shells of *Littorina littorea* and disarticulated valves of *M. edulis* and *C. edule.*

Additionally, two *C. gigas* were found close to the island of Borkum (pers. comm. B. OBERT). Extensive observations on 20 *Mytilus* beds during the spring 1999, distributed over the total study area, yielded no further finds of *C. gigas*.

In spring 2000 a juvenile living specimen was found close to the site where the first record in 1998 was made. Also, a conspicuous population (2–10 ind./m^2) of *C. gigas* represented by at least 3 different year classes has established itself within a *Mytilus* bed in the western section (mussel-bed #21, see Tab. 2).

Occupied Habitats

Up to now, all occurrences of the Pacific oyster *Crassostrea gigas* in the backbarrier area of the East Frisian Islands are related to natural *Mytilus* beds and bivalve clusters, respectively. These are situated in a lower intertidal position. In contrast to *C. gigas* the indigenous but exterminated species *Ostrea edulis* predominantly occurred in the upper subtidal environment. The sandy to muddy tidal flats colonized by the *Mytilus* beds are characterized by an emergence time which normally does not exceed 5 hours. During low tide the mussel beds are visited by a host of seabirds for resting and feeding. Predation effects on *C. gigas* in the study area have not been investigated yet.

The habitats selected and occupied by the Pacific oyster correspond to those in the Sylt-Rømø tidal basin (REISE 1998). Here, all *C. gigas* settled on intertidal mussel beds with a clear preference for more exposed beds. In the subtidal channels where 216 dredge hauls over a 500 m distance were carried out with a classical oyster dredge no Pacific oysters were found (REISE 1998).

Drift Ways: Distribution of Cultured and Wild *Crassostrea gigas*

The invasion of the Pacific oyster *Crassostrea gigas* into the East Frisian Wadden Sea differs significantly from that of the wild populations known from the Sylt/Rømø tidal flats and from the Oosterschelde, as well. There, the populations originate from extensive recruitment and regional dispersion of oysters from local culture plots (REISE 1998; DRINKWAARD 1999). In our study area, the last experimental culture plot (near Norderney, see Tab. 1) was given up in 1987, after only one farming season. Therefore, the larvae of the *C. gigas* spec-

Table 2. Records of *Crassostrea gigas* specimens found in the backbarrier area of the East Frisian Islands, southern North Sea, between August 1998 and May 2000 during field survey. – Habitat number from MILLAT & HERLYN (1999). * pers. comm. mussel farmer W. CHRISTOFFERS.

Date	island	site	habitat / no.	shell length [mm]	shell width [mm]	remarks
18 Aug 1998	Baltrum	Steinplate	*Mytilus* bed #60	89	67	1 living specimen
19 Aug 1998	Baltrum	Dornumer Nacken	Bivalve clusters #68	81	50	1 left valve
25 May 1999	Juist	Nordland	*Mytilus* bed #21	57±18	no data	13 living specimens
23 Aug 1999	Borkum	Randzel	*Mytilus* bed #3	20; 50	no data	2 living specimens
Jan 2000	Juist	Kopersand	sublit. *Mytilus* culture	> 100	no data	1 living specimen*
04 May 2000	Baltrum	Steinplate	*Mytilus* bed #61	43	38	1 living specimen
May 2000	Juist	Nordland	*Mytilus* bed #21	5 to 90	no data	2-10 ind./m²

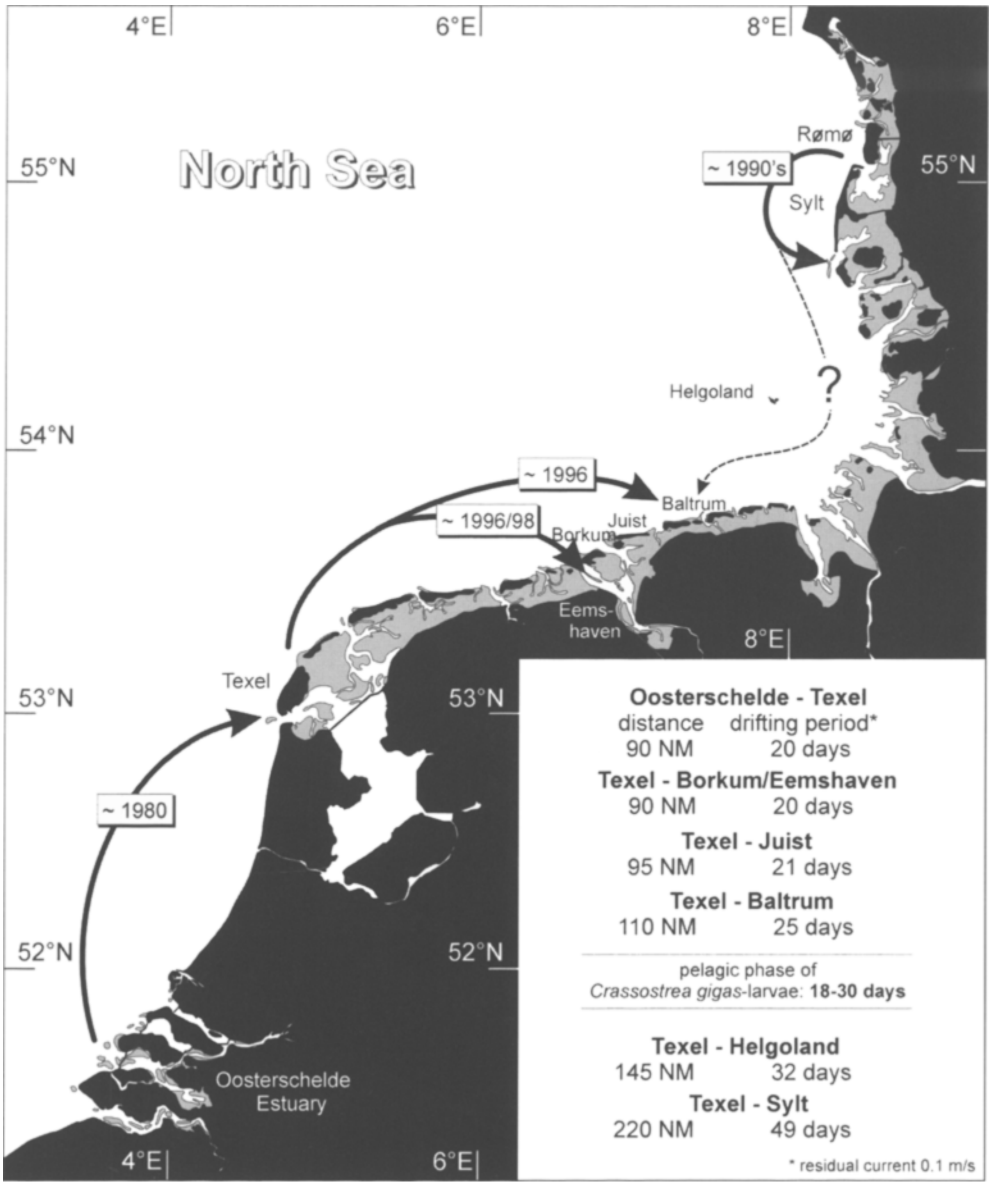

Fig. 2. Potential drift ways and year of invasion of *Crassostrea gigas* larvae from the known culture plots and wild populations of the Oosterschelde estuary and Texel into the backbarrier area of the East Frisian Islands, southern North Sea. – Because of the prevailing meteorological and hydrographic conditions an origin from the Sylt population is unlikely. So far, the southernmost record of *C. gigas* is 45 NM away from Sylt (REISE 1998).

imens recorded in the East Frisian Wadden Sea must originate from distant populations and therefore be brought into the area by current drift. Considering the dominating meteorological and hydrographic conditions of the southern North Sea, an invasion from a more western part of the Wadden Sea coast is most likely. During occasional longer periods of easterly winds larval drift in the opposite direction may occur (ESSINK 1985, 1986). Nevertheless, ESSINK (1986) mentioned that the dispersion of larvae (data concerning *Ensis americanus*, erroneously *E. directus*) in northern direction is much faster than in southwestern direction.

The cultured and wild populations of *C. gigas* in the Netherlands as a source for the invasion of the East Frisian Wadden Sea can be traced back as follows: The first *C. gigas* spat was introduced to the Dutch coast in 1964. This spat was held in the Oosterschelde estuary for aquacultural studies. Until the early 1970s oysters of the genus *Crassostrea* were cultured by Dutch oyster farmers to a small extent only. In the following years several, sometimes strong spatfalls of *C. gigas* were recorded (1975, 1976, 1982, 1986, 1987, 1989, 1992). Although imports were stopped in 1981, *C. gigas* has established in this area, at the latest since the natural larval outburst in 1982 (data from DRINKWAARD 1999). Generally, Pacific oysters of the Dutch North Sea coast are found attached to hard substrates like jetties, stone walls, rocky dike foots and mussel beds in the intertidal level.

Since the 1980's the species was frequently observed in the Dutch Wadden Sea in low abundances near the island of Texel (BRUINS 1983). Most probably, this settlement has its origin both in the cultured and wild populations situated in the Oosterschelde estuary, 165 km or 90 NM to the southwest of Texel. A second extended wild population of *C. gigas* is known from the Eemshaven complex. This population which was estimated to be of approximately 17,500 specimens (density 10 ind./m^2) was first recognized in October 1998 by TYDEMAN (1999). The oysters were predominantly attached to basaltic stones and mussel clumps in the intertidal portion of a dike foot. The average shell length measured was 39.5±8.8 mm but also some larger specimens of up to 110 mm shell length were found.

The limiting factors in the dispersal of the larvae are (i) the residual current velocity, and (ii) the period of the pelagic phase. Prevailing westerly winds in the southern North Sea cause longshore residual currents of approximately 0.1 m/s or 4.5 NM/day, respectively, flowing in NE direction (MITTELSTAEDT et al. 1983). As the pelagic phase of *C. gigas*-larvae lasts for 18 to 30 days (QUAYLE 1969; BRUINS 1983; NEUDECKER 1985) larvae from the Oosterschelde can easily be transported to Texel by drift within 20 days (Fig. 2). This may be taken into account also when considering that the larval period correlates inversely with water temperature (see QUAYLE 1969).

Towards the East Frisian Wadden Sea the larval drift way, directly from the Oosterschelde, is more than twice as long. Thus, an origin of the larvae from the population around Texel (and later also from Eemshaven) seems to be most probable. For all sites (Borkum, Juist, Baltrum) the estimated drifting period from the stepping stone Texel would lie within the period of the pelagic larval phase (see Fig. 2).

A further possible pathway to cover the long distances would be the drift in emitted ballast water. However, shipping with larger vessels within the Wadden Sea is rare. Transport of both adult specimens or mussel seed from the Dutch Wadden Sea by mussel fishers can be ruled out because of the obligatory registration by the appropriate authorities.

For the last years no detailed data about spatfall of *C. gigas* from the Dutch North Sea coast are available whereas from REISE (1998) the length-frequency distribution of distinct recruitments in the Sylt/Rømø area are known. From these data it can be assumed that the settlement of the specimens found near Baltrum occurred in 1996. Additionally, strong spatfall of other bivalves, e.g. *Mytilus edulis* and *Cerastoderma edule*, was observed in 1996 also (WEHRMANN 1999).

The *C. gigas* specimens found near Juist in late spring 1999 (mean shell length 57±18 mm) predominantly originate from a spatfall in 1997 or 1998, whereas two smaller specimens found in 1999 near Borkum presumably originate from the spatfall of the preceding summer. Generally, after the intensive spatfall in 1996 no marked recruitment of bivalve larvae was observed in the following years.

Perspectives

The occurrence of wild oyster populations in the Oosterschelde estuary and on the backbarrier tidal flats of Texel, Eemshaven and Sylt during several years lead to the assumption that *Crassostrea gigas* has established itself permanently in the Wadden Sea area. Initially, several strong spatfalls took place around culture plots. The wild populations which preferentially use intertidal mussel beds as substrates for settlement are apparently capable to survive severe winters with a high standing stock (REISE 1998).

Additionally, an increasing number in *C. gigas* specimens away from aquaculture plots and established wild populations can be observed in the study area (East Frisian Islands). The specimens found at different sites seem to originate from distinct spatfalls, respectively. Therefore a more or less continuous input of drifting oyster larvae into the backbarrier area of the East Frisian Islands has to be assumed.

Conclusions

1. Since the first record of the Pacific oyster *Crassostrea gigas* in the backbarrier area of the East Frisian Islands in 1998 the number of finds is still increasing. Due to their size the specimens can be related to spatfalls of different years. As experimental aquaculture plots were absent since 1987, the oyster larvae must have been brought into the study area by current drift during their pelagic phase.

2. Considering the residual current velocities, a direct drift way of larvae from the Oosterschelde estuary to the East Frisian Islands within the pelagic phase (18–30 days) is not possible. More probably, the larvae originate from the wild populations around Texel which are not more than 90 NM (165 km) or 20 drifting days, respectively, away from the study area. Additionally, since 1998 the oyster population of the adjacent Eemshaven complex can also be considered as a possible source of larvae production. A drift from the North Frisian population (both wild and cultured) is possible in general, but unlikely due to the dominating westerly wind regime.

3. The invasive Pacific oyster preferentially settles on intertidal *Mytilus* beds. Thus, it can be expected that *Crassostrea gigas* will considerably change the community structure of the mussel beds.

4. With the record of *C. gigas* on the backbarrier tidal flats of the East Frisian Islands the distribution gap along the European Wadden Sea Coast is closed.

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