'Natural' processes in the Wadden Sea – challenging the concept of 'an intact ecosystem'

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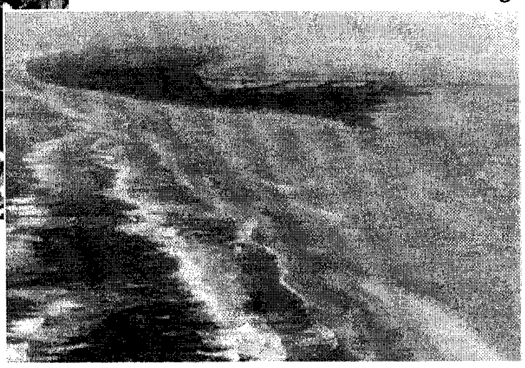


In 1991, the 6th Intergovernmental Conference of the three Wadden Sea countries – Germany, Holland and ~~Belgium~~ Denmark – met at Esbjerg, and adopted the guiding principle for a policy for trilateral management of the Wadden Sea: as far as possible, the objective should be a natural and self-sustaining ecosystem, in which natural processes can operate without interference. After the 7th Intergovernmental Conference at Leeuwarden in 1994, estuaries were included in the trilateral cooperation area, so river mouths are also covered by the Wadden Sea protected status. This future-oriented approach gives priority to the natural development in the Wadden Sea and its estuaries. Local activities (fishery, hunting, building dikes, mining for sand), and importation of remotely generated noxious or fertilizing substances, should be restricted, as has already been done in some smaller areas. However, a review of the latest results of German coastal research makes it clear that 'natural' processes in the Wadden Sea ecosystem include surprising aspects, inconsistent with the theoretical image of an ecologically sound Wadden Sea.

Decline of blue mussel beds

Since the mid-1980s there has been a continual decline in wild beds of the blue mussel *Mytilus edulis* over wide areas of the Dutch and East Friesian Wadden Sea, and it is feared that they may become extinct in the eulittoral (intertidal) zone of the area. The factors responsible for this decline are still the subject of discussion, but the cause seems to be a combination of natural factors (*inter alia* storms, freezing winters, feeding pressure of birds) and developments of anthropogenic origin (eutrophication, mussel-harvesting, input of contaminants and so on). What is striking, however, is the fact that blue mussels in the North Friesian and Danish Wadden Sea are not yet similarly threatened.

Other organisms threatened in at least parts of the Wadden Sea include the amphipod *Corophium volutator* and the shore crab *Carcinus maenas*, both of which repeatedly suffer mass kills. The mortalities have probably been due to an excessive infestation of these animals by parasitic trematodes. The increase in the populations of many sea-birds may also play a role here: infested birds are final hosts to these worms and massive excretion of infective stages may lead to high infestation rates of other animals (the so-called primary hosts). Depending on the degree of infestation, the animals may die off in a very short time. Whether these developments have only natural causes (parasite cycles are in evolutionary terms nearly as old as the hosts themselves), or whether there are also anthropogenic influences, remains a topic for further studies.

However, the disappearance of species is not the only puzzle. It is also unclear why some macrozoobenthic species (> 1 mm in size) – for example, the polychaetes *Spio filicornis* and *Nepthys cirrosa* – have extended their area of dispersal considerably. Recently, three genuine brackish-water species were rediscovered in the Weser Estuary, having previously disappeared for many decades. These are the snail *Hydrobia ventrosa* and the bryozoan *Electra crustulenta*, along with the amphipod *Leptocheirus pilosus*, thought to be extinct along the entire German North Sea coast.

Invasion of alien species

Over the last 100 years, the Wadden Sea and its estuaries have been invaded by numerous alien macrozoobenthic species, of which some, such as the bivalve *Ensis americanus* and the polychaete *Marenzelleria viridis*, have even became dominant (Table 1). Invading species arrive in ballast water or as encrustations on ship hulls, with oyster spat imported for cultivation, or indeed simply by being intentionally released off the North Sea coast. Other species which can live in freshwater and brackish water have spread through rivers and canals (from the Caspian Sea, for instance) into the estuaries of German rivers. Over the past 100 years the banks of European oyster (Figure 1, opposite) have disappeared completely, and *Sabellaria* reefs, sertularian moss and eelgrass, with their associated faunas, have almost become extinct. Surprisingly, however, an inventory of the present state of the macrozoobenthos shows an increase in species diversity, an increase in population densities, and in some areas also an increase in biomass.

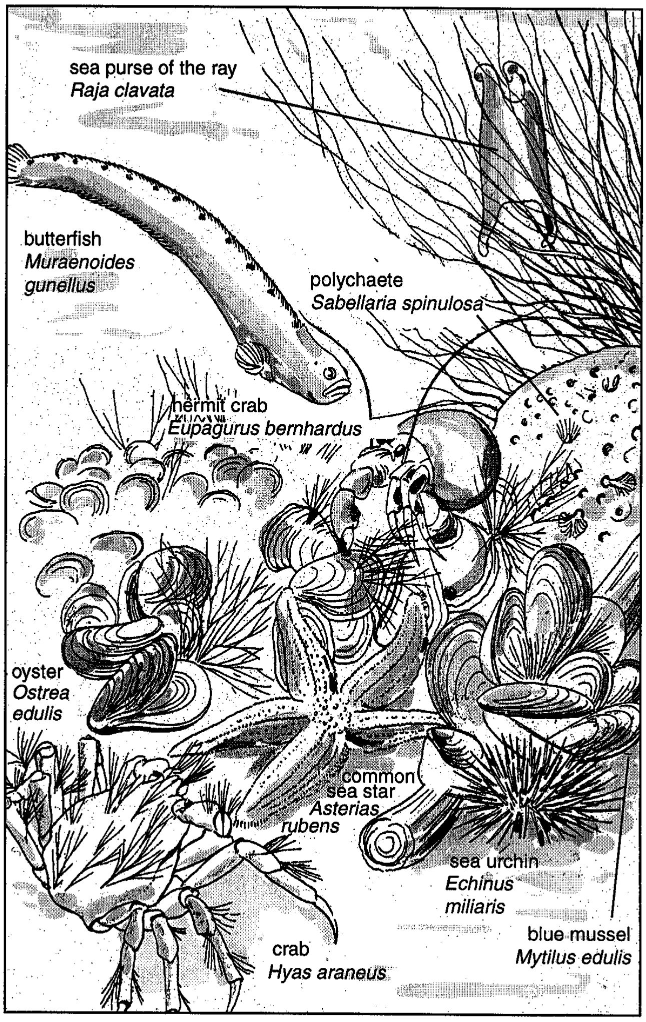
An interesting example of population 'enrichment' is the Pacific oyster, *Crassostrea gigas*, introduced in 1971 for cultivation. In the past few years some specimens that had gone wild have been found living in eulittoral mussel banks as 'squatters'. This alien species appears to be more 'ecologically potent', i.e. more adaptive, than its local predecessor, the European oyster (*Ostrea edulis*), although it requires warmer water of at least 20°C for spawning. However, it is difficult to assess the likelihood of natural oyster banks becoming established in the Wadden Sea, along with their associated community of organisms (Figure 1).

In addition to the Pacific oyster, there is one other introduced alien species that can be classified as an accessory species of oyster banks – the tunicate *Aplidium nordmanni*. The barnacle *Verruca stroemia* and the polychaete *Pomatoceros triqueter*, which used to live mainly on oyster banks, are again being found more frequently. It will probably take several years without disturbance before the typical Wadden Sea

Table 1 *A selection of macrobenthic species which have established populations in the German Wadden Sea and its estuaries in the past 100 years.*

Species	Year of first appearance	Possible origin	Likely transport mechanism
Crustacea			
Corophium curvispinum	~1920	Caspian Sea	Migration/drift/encrustations
Elminius modestus	1952	Australia	Ballast water/encrustations
Eriocheir sinensis	~1910	China	Ballast water
Gammarus tigrinus	1965	North America	Released
Gastropoda			
Crepidula fornicata	1935	North America	In aquaculture products
Potamopyrgus antipodarum	~1900	New Zealand	Ballast water/encrustations
Bivalvia			
Corbicula fluminalis	1968	North America	Ballast water/encrustations
Crassostrea gigas	1971	Japan	Imported as aquaculture product
Ensis americanus	1978	North America	Ballast water/encrustations
Petricola pholadiformis	1904	North America	Ballast water/encrustations
Polychaeta			
Nereis virens	~1920	?	?
Marenzelleria viridis	1983	North America	Ballast water
Marenzelleria wiremi	1932	North America?	Ballast water
Tharyx killariensis	~1970	?	?
Tunicata			
Aplidium nordmanni	1985	Netherlands	In aquaculture products

Figure 1 *The community associated with the European oyster bank (*Ostrea edulis*) in the northern Friesian Wadden Sea at the beginning of the 20th century.*



This illustration is a modification of a drawing in Das Tier als Glied des Naturganzen *by F. Doflein, published in 1914 by Teubner, Leipzig.*

'oyster bank' biotope can become established in the same way that the predecessor species were. Oyster larvae need a solid substrate for colonization, preferentially accumulations of shells. The sites of the former oyster banks in the sublittoral (i.e. below the low water line) are nowadays occupied by blue mussel cultures. However, the decline of eulittoral mussel beds, mentioned above, will perhaps allow a successful dispersal of the Pacific oyster.

Another important group, namely phytoplankton, shows a distinct increase in species diversity. In contrast to invasions by macrozoobenthos, the great majority of phytoplankton invasions have come via natural current pathways. Here, it is notable that during the past ten years or so it has been mostly thermophilic plankton species (including the potentially poisonous dinoflagellate *Gymnodinium catenatum*) that have been able to establish persistent populations in the surface waters of the Wadden Sea. It is thought that climate change, with repeated milder winters, has contributed to this phenomenon, although the measurable slight trend of increasing surface-water temperature (approximately 1 °C) over the past 100 years is still within the range of natural variability.

Climate change – the factor of the future

The Wadden Sea is subject to diverse influences. For some years now, intensive efforts have been made to find solutions for the adverse effects of many anthropogenic impacts on the ecosystem (such as eutrophication, fishing and agricultural practices). There is also the uncertainty of future climate scenarios, which many experts have discussed in the general context of 'global change' but have so far examined only theoretically, concluding that coastal ecosystems will experience massive changes. These changes include (to mention only two): decrease of intertidal areas, as sea-level rises faster than tidal flats build up, and establishment of communities that are richer in species but have fewer individuals (similar to those found today on the French coast of the Atlantic, or in historical terms, during the last interglacial episode (the Eemian) that ended about 70 000 years ago). For the Wadden Sea, therefore, impacts of climatic change are becoming an influence to be borne in mind for the immediate future, not just for 50–100 years from now.

Already, one can observe along German coastlines changes in flora and fauna that are probably temperature-induced (either because of natural cycles or because of the enhanced greenhouse effect). As far as the Wadden Sea is concerned, it is possible that climate-impact research (a discipline established in Germany in 1991) will suggest that potential impacts of future climate change can be inferred from experimental combinations of expected processes and, especially, by comparative analyses of previous and present changes. It might then be possible for meaningful political and administrative strategies for coastal management to be developed.

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