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Alien species in the North Sea: invasion success and climate warming

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All over the world, marine and estuarine systems are being increasingly subjected to human-mediated invasion of non-indigenous species. This is resulting in greater uniformity of biological communities on a global scale. A number of these alien species have become numerically dominant in invaded communities and have caused damage to environmental and commercial interests. Currently there is no way to predict exactly how an alien species will behave in a new habitat. In addition, we have observed the first signs of a much larger climate-induced change in the communities of the North Sea, which might significantly alter marine biodiversity in the future.

Colonization of new habitats by foreign species has always been part of natural evolutionary processes. Only some of the species now living in northern Europe were able to survive under the conditions of the last glacial period. Therefore, the present communities consist in large part of species that have been introduced, or have migrated in from other regions.

In addition to natural spreading mechanisms (such as migration and larval drift) there are various anthropogenic vectors which enable species to cross distribution barriers. Apart from species imports for economic use or scientific experiments, the primary ways in which alien animal and plant species have been introduced to new areas are shipping and the construction of canals.

Damage by alien species to economic interests is occurring repeatedly. Ecological damage has to be assumed, because being mostly highly competitive opportunists, alien species can threaten specialized native species. Their geographical spread also leads to a greater uniformity of biological communities, because communities which were once separated become merged, causing a loss of biodiversity at another level.

Against the background of global warming it cannot to be ruled out that as far as marine exotics are concerned, conditions in the North Sea are continually improving. Along our coasts there are already alien species living in low abundances, 'waiting' for more favourable conditions under which they can increase dramatically.

Species number and the species spectrum

Since the beginning of taxonomic studies in the 19th century, particularly on plankton in the North Sea, almost every water sample has contained organisms which could not easily be identified at the species level. However, not all of them truly represent species that are new to the area. Some will certainly have been overlooked previously through ignorance, especially those small species that are hard to identify even with a microsope, and representatives of taxonomic groups that are not yet well known. In the German Bight, along with the Wadden Sea and several estuaries, a total of 41 introduced aquatic species have established permanent populations. This means that of an inventory of an estimated 2000 known species, currently 2% are of allochthonous origin, i.e. have come from outside the region. In other European coastal waters, e.g. off Great Britain and Scandinavia, approximately the same number of alien species, forming a similarly high percentage of the total stock, has recently been recorded.

Introduced species are distributed among most taxonomic groups, although so far no new vertebrates have been able to establish a permanent population on the German North Sea coast. The main group consists of macroinvertebrates such as molluscs (e.g. the Pacific oyster, *Crassostrea gigas*; Figure 1(a)), crustaceans (e.g. the Chinese mitten crab, *Eriocheir sinensis;* Figure 1(c)) and polychaetes (e.g. the tubeworm *Ficopomatus enigmaticus*; Figure 1(b)) – a total of 27 alien species altogether – followed by phytoplankton with seven species, and macrophytes (e.g. the common cord-grass, *Spartina anglica*; Figure 2) with six species. Among the zooplankton, only one alien species has so far been recorded.

It is striking that the majority of alien species are fouling organisms (i.e. macroalgae, hydrozoans and barnacles, which as adults live fixed on the surface of hard substrates) or are mobile epifauna (e.g. amphipods and crabs); on the other hand, genuine bottom infauna are strongly under-represented, with only five alien species (of which one is the invasive American jack-knife clam *Ensis americanus*). The reason for this contrast lies in the transportation vectors involved: almost all alien animal species have in their life-cycle a planktonic larval phase which can be transported in ballast water. However, as adult organisms, infaunal species are mostly transported in the sediment at the bottom of a ballast water tank, so the chance of one of these reaching a new area is probably smaller than it would be for fouling or free-moving species, transported on hulls or in mariculture products. Additionally, it has to be taken into account that the recent world-wide ban on the antifoulant biocide tributyl tin, TBT (and other organo-tin compounds) on ships' hulls could result in more bio-invasions through shipping, if alternative antifouling paints lack the effectiveness of organo-tin antifoulants.

At present, there are several species of macrozoobenthic species for which it is not clear if they can actually be classified as established alien species along the German North Sea coast. One example is the blue crab, *Callinectes sapidus*, a species first found in 1964 in the Elbe estuary, for which no new records of living individuals have to date been published.

Estuaries as habitats for alien species

Calculations of the number of individuals entering ports on the German North Sea coast via discharge of ballast water from overseas indicate that 2.7 million organisms are released there every day. In relation to this enormous quantity, the current number of 41 established alien species has to be regarded as extremely low. One can conclude that as a rule the majority of potential new arrivals are eliminated immediately because they are not adaptated to the local biotic and/or abiotic environmental conditions. German coastal waters are characterized by fishing activities, hydraulic engineering, pollution and, of course, by tidal dynamics with all its consequences (e.g. development of tidal flats and of a transition zone between marine and freshwater conditions). As one single factor can determine the distribution of a species, generalists are likely to have the best chance of settling here.

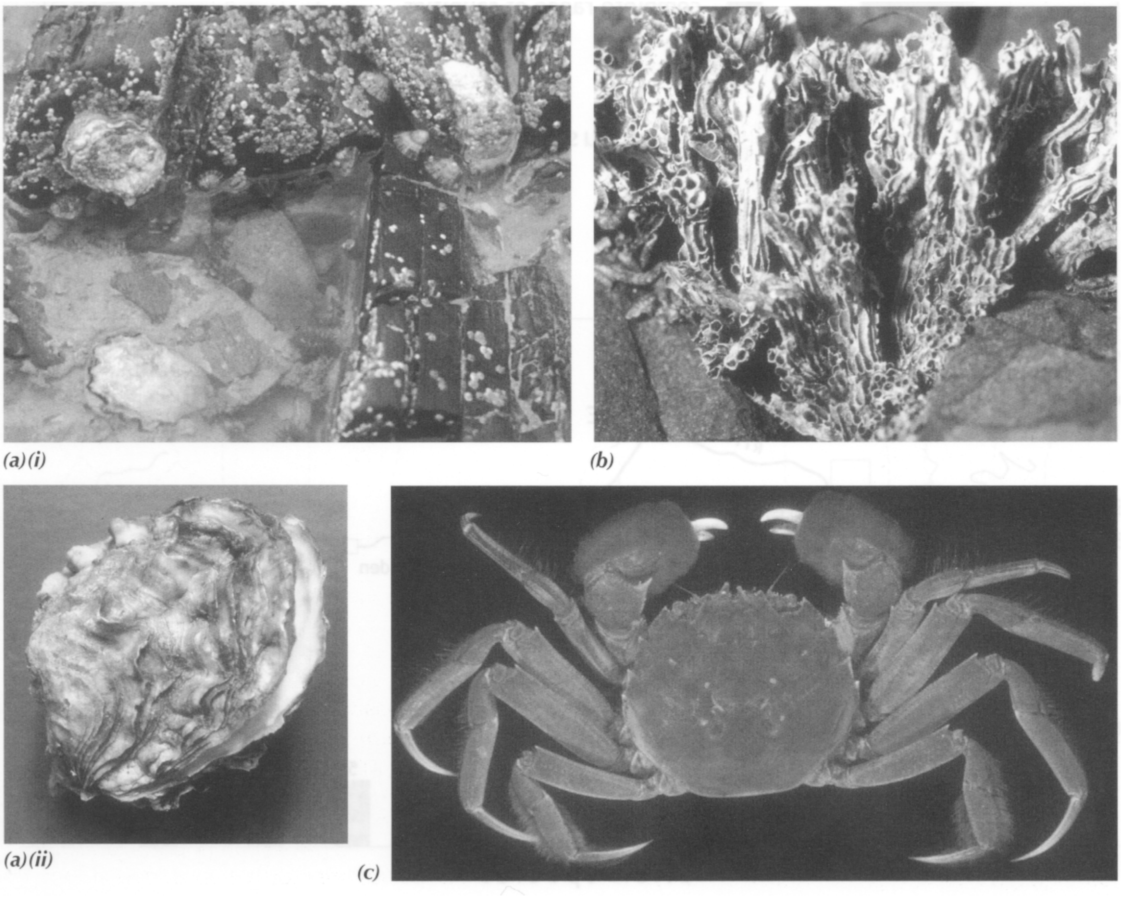
Consequently, among the aliens established in German waters, opportunistic species and strong competitors predominate. It is remarkable that most of those introduced species that have established permanent populations have done so in the estuaries of the German North Sea (19 species in total). This can be explained by the fact that the

Figure 1 *Examples of alien fauna now established in the German Bight.*

(a)(i) *The Pacific oyster,* Crassostrea gigas, *first imported into Europe for commercial production in 1964 (also seen here are limpets and barnacles); as a result of reproducing successfully over the last two decades, under increasingly warm conditions,* C. gigas *is now found throughout the Wadden Sea and on rocky shores. In some areas there are now reefs built up of successive generations.* **(ii)** *Close-up of an individual specimen of* C. gigas, *~12 cm across; some may attain widths of ~30 cm.*

(b) *A colony of the tubeworm* Ficopomatus enigmaticus, *a native of the Indian Ocean brought into the North Sea on ships' hulls in 1975; this warm-water species builds massive calcareous reef-like aggregates, which can affect the form and stability of (say) harbour structures.*

(c) *The Chinese mitten crab,* Eriocheir sinensis *(width of carapace ~5 cm).* E. sinensis *was accidentally introduced into Germany in ballast water in the early 1900s, then proliferated and spread to many northern European rivers and estuaries where it has affected local fisheries and undermined banks. Populations have increased so much that the crabs have been re-imported to Asia for human consumption.*



(a)(i) *(b)* *(a)(ii)* *(c)*

The majority of alien species are macro-invertebrates such as molluscs, polychaetes and crustaceans

Plant alien invaders include saltmarsh species, as well as marine algae

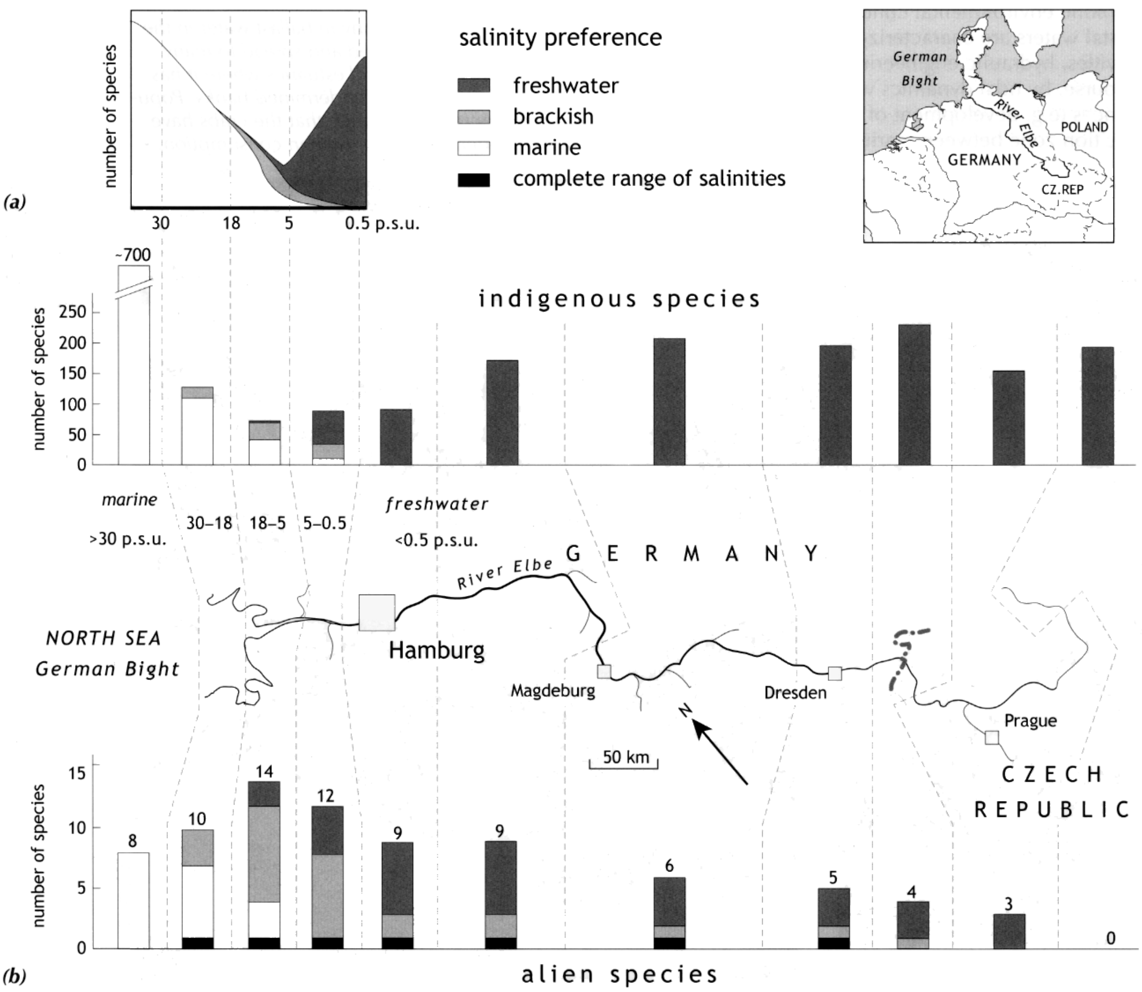
Figure 2 *The common cord-grass,* Spartina anglica, *(the larger plant in the photograph) was introduced into the Wadden Sea to promote sediment accretion, and is a fertile hybrid of the European* S. maritima *and the North American* S. alternifolia. *Recently, this alien species has been spreading naturally, perhaps because of higher spring temperatures, and grows as a pioneer plant in the intertidal zone, where it displaces the native glass-wort,* Salicornia stricta *(in the foreground).*

salt-tolerant freshwater species (seven in total) originally reached the coast via estuaries. Also, the area is characterized by intense inter-continental shipping and is open to a higher potential infection rate, particularly given that ballast water often has an estuarine character and thus transports primarily nearshore organisms. In addition, about half of the introduced macro-invertebrates in these estuaries are genuine brackish-water species, which are characterized by a high tolerance for changing environmental conditions and therefore have a better chance of being transported alive than truly marine species.

However, there is one characteristic of estuaries that does not apply to the open North Sea and the Wadden Sea, and is of considerable importance – the natural minimum in indigenous species in brackish water (Figure 3(a)). This phenomenon, first described in 1934 by the famous German marine biologist Adolf Remane on the basis of

Figure 3 ***(a)*** *Schematic diagram to show the variation of numbers of species of macrozoobenthos with salinity in estuaries, as described by Remane. The fewest species are found where salinities are 5–18 p.s.u.* ***(b)*** *Species number and salinity preference of indigenous and alien species in the River Elbe, from its source to the North Sea (cf. inset map).*

Along estuaries, the number of alien species is greatest where salinities are 5–18 p.s.u. and there are fewest indigenous species



macrozoobenthic investigations in the Baltic Sea, can also be found in the macroinvertebrate fauna of the River Elbe. As described by Remane, the greatest 'species poorness' of indigenous animals occurs here where salinities are 5–18 p.s.u. (upper histograms in Figure 3(b)). By contrast, this area is characterized by the *highest* number of *alien* macrozoobenthos species found in German waters (14 species) (lower histograms in Figure 3(b)). Both downstream in fully marine waters, and upstream, their number is significantly lower. A recent analysis for Dutch estuaries has also shown an increasing occurrence of alien macroinvertebrates in the low to moderate salinity zone (0.5–18 p.s.u.). The simple conclusion to be drawn from all this information is that the 'poorer' a community is, or the more vacant ecological niches there are, the more alien species can potentially establish themselves. In other words, there is space available for immigrants as long as they can tolerate brackish, changeable estuarine conditions, which are unfavourable for most species.

In the Baltic Sea, the world's largest brackish-water sea area, only very few primary introductions of alien species are known. This is due to the fact that in the Baltic there are only minor aquaculture activities and little intercontinental ship traffic. However, the Baltic is subject to secondary introductions from both the North Sea area and adjacent inland waters, and it is assumed that, in all, some 60 alien species have been able to establish and maintain self-sustaining populations within the various sub-regions of the Baltic Sea, whereas on the German Baltic coast only 20 alien species are known.

Warm-water species

Within the last few years another abiotic factor has increasingly moved to the centre of interest: temperature. In contrast to aspects of the terrestrial fauna and flora, which are generally used in Germany as bioindicators for climate change, all links between 'global change' and changes in communities of coastal areas have been purely hypothetical, because the reasons for non-indigenous species becoming established, or for the disappearance of native species, are not straightforward.

The ecological niche for a species is determined by many factors. Besides chemical factors such as variations in nutrient supply or concentrations of trace substances, there are numerous physical factors, which are related to climatic conditions. Global variations in the water cycle, with impacts on water temperature or salinity, or changes in wind velocity or direction, may all influence the dispersal of organisms. However, because of the direct dependence of marine organisms on water temperature, global warming is one of the most critical factors for climate-induced changes in species composition.

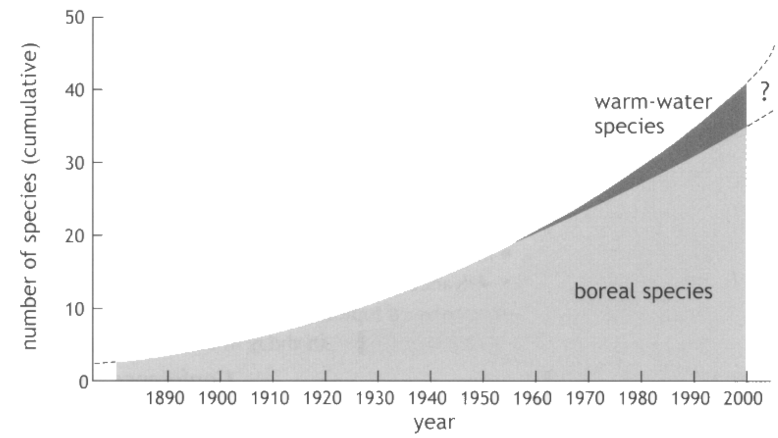
It is possible to detect that over the last 20 years there has been an increase in the rate at which introduced species, once only native to warmer habitats, are becoming established along the German North Sea coast (Figure 4). The most numerous introductions are phytoplankton species from the Pacific, among which are several toxic forms (e.g. the Japanese flagellate *Fibrocapsa japonica*, a fish-killing species, transported in ballast-water tanks and unintentionally released by discharges into the North Sea). Since the 1970s, Dutch and German oyster farmers have begun to cultivate the Pacific oyster (*Crassostrea gigas,* Figure 1(a)) in coastal waters of the North Sea. It was assumed that there would be no problem with the introduction of the Pacific oyster as seed stock because these oysters, native to Japan, would not be able to reproduce at the latitude of the Netherlands and Germany. However, massive spawnings from culture plots have occurred, especially during the last two decades of warm summers. Spat settle on any hard substrate in the Wadden Sea, but preferentially upon wild banks of the Blue mussel (*Mytilus edulis*), which are currently being transformed into oyster reefs.

In addition, indications are growing that more and more warm-water species are migrating naturally as a result of being carried in currents from southern European Atlantic coasts into the German Bight, where they become established. This trend of northward expansion has been observed for phytoplankton, jellyfish, crustaceans and, especially, fish. Additionally, during the last decade, increased recruitment of fish taxa living at the edge of their normal geographic distribution in the North Sea, such as Anchovy (*Engraulis encrasicolus*), Red mullet (*Mullus surmuletus*) and John Dory (*Zeus faber*), has been observed.

Consequently, to some extent it is already possible to observe major ecological changes in the fauna and flora, which experts on global change predicted would occur in the next 50–100 years. It is presumed that global warming will play an important role throughout all trophic levels, with a cascading set of effects, at least in the Northern Hemisphere, with the continued occurrence of mild winters and hot summers. And it seems highly probable that changing climate will cause a new wave of aliens to establish, even in the absence of other human interference.

Figure 4 *The increase in observations of newly introduced species on the German North Sea coast since ~1800, with special reference to warm-water species.*

Records suggest that alien warm-water species have been arriving in increasing numbers over the last few decades



Ecological consequences

The complete coastal ecosystem consists of both the biota and their environment. Each individual in a population interacts with other members of that population, with other species, and with the environment. In principle, alien species are considered as one of the main causes of biodiversity loss worldwide. When a foreign species reaches a new ecosystem, different ecological reaction mechanisms are possible:

- The new species cannot establish itself.
- The new species establishes itself and coexists with the native species without significant interaction.
- The new species establishes itself and alters relationships between species living in a particular area, establishing a new dynamic of competition and predation, and/or displacing native species directly, or indirectly by acting as a vector for parasites or diseases.

In the literature, spectacular cases of alien species invasions in aquatic and terrestrial systems are described from many parts of the world. Up to now, however, no really problematic alien species has been found in German waters. Even if displacement of native species by aliens is sometimes assumed, so far only decreased abundances have been documented, with no actual extinctions of native species.

Because of their self-contained nature, the ecosystems of geographically isolated environments such as islands and lakes are extremely vulnerable to damage caused by introduced species. In German coastal waters, the situation is different. Here, the species compositions of the native aquatic communities are subjected to continuous natural interference from species from adjacent marine ecosystems, and fluctuate with the seasons, the tidal cycle, the drainage regime and other environmental factors. As a result, the nature of such communities is distinctly dynamic, and the establishment of alien species usually has no significant influence on the stability of existing ecological systems in German waters; non-indigenous species are often simply integrated into the community. It seems that most aquatic systems should, to some extent, be capable of either absorbing or resisting invaders. However, knowledge of other coastal regions (e.g. around the Black Sea, San Francisco Bay) shows that it is hard to foresee what the consequences of the introduction of new species might be for an ecosystem.

Outlook

Further climate change will influence the geographical distribution of many species and will lead to significant changes in marine communities. Higher water temperatures will also favour the survival capability of alien species from subtropical regions. Several species already introduced into the English Channel will also expand their distribution range northwards as temperatures rise. Potential candidates might include the Manila clam, *Tapes phippinarium*, and the tubeworm *Hydroides ezoensis*. Whether all newcomers will serve merely as a 'disturbance signal' in our coastal waters, like the species introduced so far, cannot be predicted with any certainty. An environmental monitoring programme specifically to document in detail the effects of alien species on native communities should be designed and put into action as soon as possible.

Further Reading

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