Introduced Species—Resource or Threat in Brackish-water Seas? Examples from the Baltic and the Black Sea

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Examples are given from two enclosed brackish-water seas of man-introduced species in man-modified habitats, their origin and routes of dispersal, and relations with other species, including man, and their economic importance to mariculture and tourism and as fouling organisms.

There are thousands of examples from all continents of introductions, both intentional and accidental, of exotic terrestrial species. In similar way, perhaps thousands of mainly shallow-water marine species have been moved around the world over the past five centuries (see Carlton, 1985, 1989 for reviews). Man acts as a biogeographical vector, comparable with many others (wind, ocean currents, animals), spreading water-living invaders but with greater speed. This speed is increasing; the probability of other than the most hardy species surviving such transports has increased (Mooney & Drake, 1987).

Species introductions into marine and brackish-water systems have not been studied systematically prior to the 1950's. Some comprehensive reviews on a regional or sea-wide basis appeared in the mid-80's (Carlton, 1985; for the Baltic Sea, see Leppäkoski, 1984, for the Black Sea Cvetkov & Marinov, 1986). Today this branch of aquatic science is far more than a spectacular piece of work for an "ecology detective" who records new finds of exotic and exciting species. There are several questions of world-wide interest to be answered: why are some habitats more open to introductions than others? why do some introduced species spread dramatically and become pests? why do some of them adapt themselves into an indigenous community without any observable effects on it and why do some species fail to colonize a new target area? what environmental problems will alien species create? should they be considered a potential resource or a threat?

The Baltic Sea and the Black Sea in comparison

Enclosed seas, such as the Black Sea and the Baltic, can be regarded as disjunct "brackish-water islands", with an impoverished fauna and flora, locked in by an "ocean of land" (and thus presenting many semi-continental features) and isolated from other major brackish-water bodies by physical (ocean and land) barriers. In historic time many of these barriers have been weakened through man's activities: the opening up of interoceanic and intracontinental canals (see Por, 1978), the intentional or unintentional transportation of parts of the habitat itself or the biotic community living in it from one area to another (ballast water, dry ballast, fouling communities), the transplantation of commercial species of fish and shellfish with associated organisms, etc. It is to be noted that the common use of sea water as ballast began as late as in the 1870s and 1880s (Carlton, 1985).

The two land-locked seas compared are chracterized by steep physical and chemical gradients, both horizontally and vertically (see, e.g., Leppäkoski & Bonsdorff, 1989, for the Baltic Sea, and Sorokin, 1983, for the Black Sea). After the latest glacial period both of them were fresh-water lakes; presently they have meromictic conditions. The connection between the Black Sea and the Mediterranean through the Bosphorus Strait was opened 10.000 a BP and between the Baltic and NE Atlantic through the Danish Sounds 7.000 a BP, respectively (Por, 1978). Both sea basins are still isolated, in part, from the World Ocean by ecological barriers; one of the most important is the salinity factor. The salinity of the surface waters of the Black Sea (18 o/oo) is less than half of that of the Mediterranean, in which again the salinity is somewhat higher than in the adjacent Atlantic Ocean. This results in an effective barrier to biological invasions between the brackish Black Sea and, e.g., E Atlantic river mouths. The surface salinity of the Baltic Proper is 6-8 o/oo , i.e., approx. a fifth of that of the adjacent North Sea. Both seas are threatened by increasing marine eutrophication and pollution by environmental chemicals. Their coastal ecosystems and living resources are subject to physical, chemical and biological deterioration due to human impact. Contamination of their biota by alien species is an environmental concern which should not be neglected.

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Invasions and introductions

During the last decades a slight increase in the salinity in both seas has been observed, resulting in a spontaneous invasion of several euryhaline marine species, a process known as "mediterranization" (Gomoiu, 1981b, Cvetkov & Marinov, 1986) or "oceanization" (Leppäkoski, 1975) of the fauna in both basins. Both the Baltic and the Black Sea are very young brackish-water seas (see above). Practically all the marine fauna and flora have invaded these areas during the last 10.000 years, and it is obvious that this immigration still continues.

In a review of the ecology of biological invasions Mooney & Drake (1987) pointed out the fact that there is in ecosystems an inherent resistance to invasions. This capacity for resistance may be reduced by the habitat modification which is characteristic of many terrestrial systems highly influenced by man's activities (agriculture, animal husbandry, urbanization). In fact, a major part of introduced terrestrial species are bound to such habitats; thus most of our present knowledge about their impacts on ecosystems originates from studies of such modified systems. Initial symptoms of ecosystem distress are often followed by major changes in species composition, including the invasion by exotic species (Rapport et al., 1985). In brackish-water ecosystems the situation seems to be greatly the same. Here alien species are numerous and locally predominant in strongly modified habitats (harbours, underwater constructions, receiving waters of pollutants and cooling water discharges, aquaculture). Such perturbations tend to alter not only the physical structure of the habitat (offering secondary hard substrates for sessile species or extremely soft bottom material unsuitable for others than some specialized mud dwellers) but also energy flow patterns and interspecific relationships. When an entirely new growth form is introduced in a community, major ecological alterations can be expected. For example, such sessile forms as barnacles (*Balanus* spp. in both seas) and the bivalve *Dreissena polymorpha* (in estuaries and lagoons on the southern Baltic coasts) become space-dominant and influence a great variety of accompanying species.

In the enclosed seas compared, eutrophicated inlets and coastal lagoons and fouling communities on secondary hard bottoms are examples of sub-systems that have been highly modified by introduced species, whereas the open coast and pelagial systems are generally free from them (cf. Leppäkoski, 1984, Carter, 1989). Brackish water regions in estuaries seem to be more open to immigration of exotic species than are the (in geological and evolutional sense older) marine and fresh-water parts of an estuary. In Northwest-European estuaries, some 3-5 % of all species are immigrants in the marine or fresh-water parts of the estuary but in the brackish water areas this percentage can be as high as 20-28 % (Wolff, 1973, Vaas, 1975). One reason for this, mentioned by several authors, is the fact that the number of indigenous species is low and there are many "empty", "vacant" or "free" niches in brackish-water systems. There is evidence from terrestrial systems that the more species already present, the lower the probability of successful invasions (Mooney & Drake, 1987). However, as pointed out by Li & Moyle (1981) and Herbold & Moyle (1986), the presence of an empty niche is difficult to predict because an introduced species may inhabit a different realized niche in its new environment, in response to new ecological conditions.

Due to their ecological and evolutionary history, both the Baltic and the Black Sea seem to be predominately receiver areas of introduced species (cf. Carlton, 1985, 1987); the donor areas of these species are to be found in the adjacent coastal oceanic waters as well as in distant seas. More than 30 species of anthropochorous immigrants (Fig. 1), mainly unintentionally introduced animals, have been reported from the central and northern Baltic or its terrestrial coastal systems (introductions of associated organisms, e.g., disease agents not included). Among this variety of species the following mechanisms of dispersal can be identified: biofouling on ocean-going ships, seawater ballast, dry ballast, active or passive dispersal from adjacent fresh-water systems along rivers or canals, intentional fisheries introductions, aquaculture, and escapees from fur farms. Most of the introduced species belong to the littoral or shallow sublittoral subsystems, or shores (Leppäkoski, 1984). The Eastern Mediterranean Basin has been largely influenced by the Lessepsian immigration through the Suez Canal since its opening in 1869 but obviously low winter temperatures prevent these tropical or sub-tropical species to spread farther to the northern Mediterranean and the Black Sea (Por, 1978)

Carlton (1987) identified at least 14 routes of transoceanic dispersal of introduced species in the Pacific Ocean. Ballast water is known to be one of the most effective vectors for long-distance dispersal by ship's traffic. In addition to frequently occuring larvae of bivalves, gastropods and barnacles, Williams et al. (1988) found more than 35 benthic taxa in sediment samples from ballast tanks of bulk cargo vessels sailing between Japan and Australia. Over 200 species of living phytoplakton and zooplankton were collected from the ballast water of 70 cargo ships arriving in Oregon from Japan (Carlton 1989). Identifiable living organisms were found in 51 of 55 vessels entering the Great Lakes (Carlton, 1985). No such studies are known from the Baltic Sea.

Man-introduced species and man

Several introductions into the Baltic and the Black Sea have resulted in both structural and functional changes and thus influence significant control mechanisms at ecosystem level; in fact, food chains and whole benthic communities can be based upon introduced species in both seas (cf. Leppäkoski, 1984). Most exotics do not have any influence on man's economic interests and their ecological impact has, in most cases, been more or less unobservable. There are only a few harmful introduced species in the Baltic Sea. In biofouling the hydrozoan *Cordylophora caspia*, the barnacle *Balanus improvisus*, and the zebra mussel *Dreissena polymorpha* are of importance. The muskrat (*Ondatra zibethica*) and the Chinese crab (*Eriocheir sinensis*) can cause some damage by their burroving activities; the mink (*Mustela vison*) is a predator on water fowl. In the the Black Sea some recent immigrants have displayed considerable success in spreading and population increase. Some of them have become nuisance organisms causing damage from economical and esthetic points of view. The soft-shell clam (*Mya arenaria*) was introduced in the Black Sea as a ballast species in 1961-62 (possibly from the Baltic Sea; Stoykov, 1983) and it became a mass form in the 1970s. Tons of *Mya* have been deposited every year per 1 km beach at Romanian tourist resorts (Gomoiu, 1981a). These decaying stinking masses along the shoreline must be removed regularly during the warm bathing season. The beach itself no longer consists of mineral sand but is rapidly turning into shell gravel. *Mya* has appeared to be succesful as a recent invader not only in the Black Sea but also on the North-American Pacific coast (Carlton 1989). This gives further evidence for the status of *Mya* as a ballast species and thus verifies the early theory by Hessland (1946) according to which the soft-shell clam is a 16th or 17th century introduction from N America into European coastal seas.

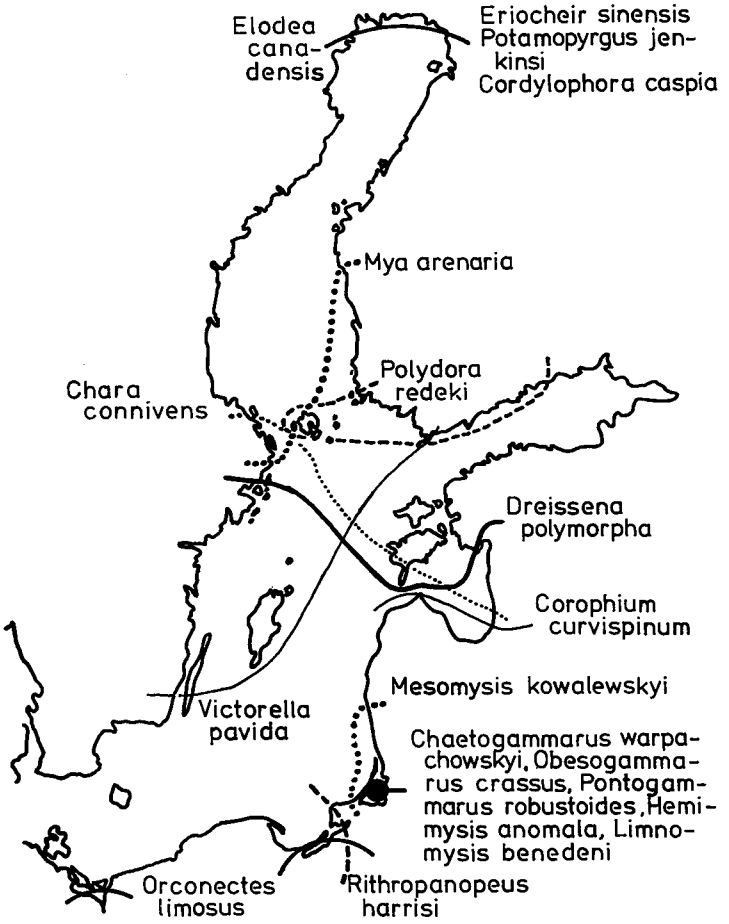

Fig. 1. Distribution of benthic species introduced into the Baltic Sea (E of 13°E). In addition, the barnacle*Balanus improvisus* is found in all parts of the Baltic. (From Leppäkoski, 1984).

The predacious gastropod *Rapana thomasiana* , a ship-borne immigrant from E Asia in the 1940s, has completely destroyed the oyster beds on the Caucasian coast (Gomoiu, 1981b) and severely affected blue shell (*Mytilus galloprovincialis*) banks (Cvetkov & Marinov, 1986). *Mercierella enigmatica* (S Asian polychaete, introduced in the 1920s) together with the barnacles *Balanus improvisus* and *B. eburneus* (both of them N American species, introduced in last century; Cvetkov & Marinov 1986) are common alien species causing biofouling. Seen from an economic perspective some introduced species can be regarded as having mainly positive effects. In the Baltic their contribution to fisheries is still low. Canada goose (*Branta canadensis*) is hunted in Finland and Sweden. In the Black Sea three invertebrate invaders are of economic significance as potential sources of human food: the bivalves *Mya arenaria* and *Cunearca cornea* and the gastropod *Rapana thomasiana*.. Experiments have been made in order to establish the Pacific oyster (*Crassostrea gigas, C. virginica*) in the Black Sea (Monina, 1983). Sometimes even an otherwise unwelcome species can be utilized as a resource: *Rapana* is the basis for a flourishing souvenir industry in Romania. Shells of different sizes are used to make earrings and other trinkets, key rings and candle-holders.

Conclusion

There are four successive stages of invasions: (1) arrival, (2) establishment, (3) spread and (4) persistence (see Mollison, 1986 for a comprehensive discussion). Perhaps hundreds of introduced species have arrived (most of them obviously by mere chance) into the brackish Black and Baltic Seas, or their coastal subsystems, as planktonic larvae in ballast water tanks, as sessile organisms attached to hulls (*Rapana, Dreissena, Balanus*), or as benthic stages living in (or on) the sediment settled on the bottom of the tanks (*Mya , Potamopyrgus*), or have been introduced intentionally (salmonid fishes, Canada goose). Most of them have been unable to maintain a self-sustaining population and thus only some tens of these species have become established in these seas, and still fewer have been able to spread on a sea-wide scale. Their ultimate success may be evaluated in terms of persistence time. *Mya arenaria* has persisted in NW European waters for 300-400 years, in the Black Sea for not more than 30 years to the present. *Balanus improvisus* has been very successful in the Baltic Sea since the late 1800s. There may be several unknown introductions from older times (the importance of prehistoric and even more recent voyages still remains not well understood). As pointed out by Carlton (1989), the problem is not always how we know a species is introduced, but how we know a species is native!

Introductions continue unabated. Examples of the latest newcomers from NE European seas are the American jackknife clam *Ensis directus* (*E. americanus*), first found in the German Bight in 1978, now recorded along the NW European coast and on the Swedish west coast in NE (Essink 1988, Lundälv, 1989), *Merenzelleria viridis* , a spionid polychaete from N America, first recorded in 1983 in the Netherlands, now found in the S Baltic (Essink 1988), and the brown alga *Sargassum muticum*, introduced into Europe in the late 1960s, now found on the Swedish west coast (Rueness, 1989). An example from the Black Sea of recent introductions is the bivalve *Cunearca cornea* (first records in 1983-1984; Gomoiu, 1984, Cvetkov & Marinov, 1986).

All vessels destinated for any Baltic or Black Sea harbour have to pass fully marine waters with oceanic salinities. Thus a relatively simple and cheap method of reducing the risk of unintentional introductions of estuarine (brackish-water) species into these enclosed brackish-water seas would be a mid-ocean exchange of ballast water *en route*, as suggested by Williams et al. (1988).

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