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Research Article

THE FIRST TWENTY YEARS OF INVASION BIOLOGY IN THE BALTIC SEA AREA

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Abstract

The history of research into nonindigenous species and invasion biology in the Baltic Sea is briefly reviewed from faunistic notes made by the early naturalists of the early 1800s to more sophisticated and diversified studies that began in the last decade of the 20th century. In the 1990s, biologists working in the Baltic Sea area increasingly contributed to the understanding of the role of alien species as part of anthropogenically induced change in both a regional and international context.

INTRODUCTION

When seeking for a history of aquatic invasive species arrival in the Baltic Sea we must accept the fact that a lot of the earliest history remains unknown. By contrast, the short history of systematic research into invasion biology can be described in detail, as it covers a period of no more than 20 years. The introduction of new species into areas far from their native ones is by no means a recent phenomenon: transfers and artificial introductions of fish and crayfish have likely taken place since ancient times.

In this review I examine the history of research into human-mediated biological invasions and alien (non-native, nonindigenous; hereafter NIS) species in the Baltic Sea by reviewing a sample of the work done since the early 1800s. The aim is to summarize the development of scientific awareness of the occurrence, distribution, and impacts of aquatic NIS in the Baltic Sea (including the Kattegat).

Since the classical works of Segerstråle (1957) and Zenkevitch (1963), the history of biological research in the northern Baltic Sea has been surveyed for Finland (*e.g*., Haahtela 1996, Leppäkoski and Rönnberg 1988, Leppäkoski 2001), Estonia (Ojaveer *et al*. 2000), and the Gulf of Riga (Ojaveer and Andrushaitis 2004). There are also several recent reviews available on NIS, their origin, spread and impacts in the Baltic Sea (Jansson 1994, 2000, Gollasch and Mecke 1996, Gollasch and Leppäkoski 1999, Olenin and Leppäkoski 1999, Leppäkoski and Olenin 2000a, Leppäkoski *et al*. 2002b, Ojaveer *et al*. 2002, Baltic Sea Alien Species Database 2004).

In the beginning - faunistic notes in the 1800s

The Baltic has a long history of human-mediated invasions (see Baltic Sea Alien Species Database 2004 for references). The bivalve *Mya arenaria* probably appeared already by the 13th century in Danish waters (Petersen *et al*. 1992). The deliberate introduction for stocking purposes of lobster, crabs, oyster, and blue mussel from Denmark to the Finnish and Estonian coasts was planned by Russian authorities as early as in the mid-1700s (Hamel 1852). These plans were partly based on statements made at the Royal Swedish Academy of Sciences as early as 1743. Delivery of settlings failed, however, and further efforts were questioned by scientists referring to the low salinity. The first benthic species recognized as non-native included the zebra mussel *Dreissena polymorpha*, reported from the Curonian Lagoon in the 1820s (Schrenk 1848), and the barnacle *Balanus improvisus* found in 1844 in Königsberg/Kaliningrad) area (Gislén 1950). In addition, two Ponto-Caspian species, the gastropod *Lithoglyphus naticoides*, and the hydrozoan

Cordylophora caspia, first appeared in the southeastern lagoons of the Baltic Sea in the early 1800s, most probably after opening of the first canals connecting the watersheds of the Baltic and Black Seas (*e.g*., Neman - Dniepr and Vistula - Bug) at the end of the 18th century (Jażdżewski 1980).

Faunistics during the interwar period and until the 1970s

The present knowledge of the introduction of NIS into the Baltic Sea has developed through a stepwise process from the first records of single new species during the interwar period (*e.g*. Luther 1927, Smirnov 1935, Schlesch 1937), toward more sophisticated studies in invasion biology.

There was some administrative interest in this topic during the interwar period, expressed by the ICES Combined Baltic and Transition Area Committee. In a document from 1935, this body "recommended that the report concerning the occurrence of non-endemic animals in the Baltic Sea and the causes of their appearance...should be printed." (Anon. 1935) However, the fate of this report remains unknown.

The first generation of papers date back to the 1940s and 1950s in which NIS were discussed as an issue of minor importance. Nikolaev (1951) and Segerstråle (1957; seven NIS mentioned) were the first to draw attention to the changes in the Baltic Sea flora and fauna, related to human-mediated introduction of alien species. In his classic textbook on the ecology of brackish waters, Remane (1958) also mentioned some few immigrants into European semi-enclosed seas, but without any further discussion of their status or vectors.

Samples taken during an expedition between the period 1946-1948 revealed some few NIS that were recorded in virtually all parts of the Baltic Sea. The 15 NIS mentioned in Nikolaev's (1951) review include the diatom *Odontella* (*Biddulphia) sinensis*, the brown alga *Colpomenia peregrina*, the bivalve *Petricola pholadiformis*, the mud snail *Potamopyrgus* (*cristallinus*) *antipodarum*, the gastropod *Mytilopsis leucophaeata* (as *Congeria cochleata*), the copepod *Acartia tonsa*, the Chinese mitten crab *Eriocheir sinensis*, and the soft-shell clam *Mya arenaria*. In his later papers, Nikolaev (1963, 1974) completed the list by adding the zebra mussel *Dreissena polymorpha*, the decapod *Rhithropanopeus harrisii*, the amphipod *Corophium curvispinum*, and the mysids *Hemimysis anomala*, *Paramysis lacustris* (as *Mesomysis kowalewskyi*), and *Limnomysis benedeni*. In addition, Nikolaev (1974) briefly discussed the three major ways of dispersing organisms: water transport, canal connections, and intentional introduction of species.

In a study of the Copenhagen port area, Rasmussen (1958) demonstrated the relationship between cooling water discharges and the occurrence of NIS (*R. harrisii* and *Ficopomatus* (*Mercierella*) *enigmatica*). A number of notes on the

occurrence and spread of *E. sinensis* was published from several countries since its first appearance in the Baltic in the mid-1930s (*e.g*., Luther 1934, Haahtela1963, Grabda 1973). Similarly, the spread of another easy-to-detect species, the barnacle *Balanus improvisus*, was followed up in both Finland (Luther 1950, he also reviewed earlier records) and Sweden (Gislén 1950).

In the oligohaline lagoons of the southeastern Baltic (Curonian, Vistula and Szczecin Lagoons), *Corophium curvispinum*, the most common Ponto-Caspian amphipod in the Baltic drainage, was recorded in the 1920s and 1930s (Jażdżewski 1980 and references therein).

While one of the most important contributions to aquatic invasion biology in the 1940s was recognising the invasive status and North American origin of *Mya arenaria*, one of the commonest shallow-water molluscs of western Europe (Hessland 1946), no reference was made specifically to the Baltic Sea.

The 1960s heralded the arrival of several new NIS, originating from accidental releases as well as intentional introductions into adjacent fresh-water bodies. Due to an extensive program of transplantations of Peracarida by the former USSR that began about 1950, where more than thirty amphipod species from the ”Caspian complex” were used for acclimatisation purposes (Gasiunas 1964), several nektobenthic species, including amphipods and mysids spread along rivers to the coastal lagoons of the southeastern Baltic.

Early findings of NIS living in or on soft-bottoms are scarce. In southwestern waters of the Finnish archipelago, the polychaete *Polydora* (*Boccardia*) *redeki* was found in the early 1960s, some 1000 km from its' nearest known locality in the Kiel Channel (Eliason and Haahtela 1969). In a study of secondary hard bottoms (piles) in the Dead Vistula, Arndt (1965) recorded five NIS among a total of fifteen fouling species.

In the 1970s, increased focus was placed on the distribution and biology of some shallow-water NIS: the biology of the North American crab *Rhithropanopeus harrisii* was studied in Polish waters (Turoboyski 1973), the North American amphipod *Gammarus tigrinus* in the German fjord Schlei (Bulnheim1976), and the New Zealand mud snail *Potamopyrgus antipodarum* in Denmark (Lassen 1978).

Early notes on aquatic macrophytic NIS in the inner Baltic Sea appear to be restricted to two species, *i.e*. *Chara connivens*, probably transported with ballast sand, from the Swedish east coast Luther (1979), and *Elodea canadensis* from coastal inlets in Southern Finland (Luther 1951).

Increased activity in the 1980s

In a review from the early 1980s (Leppäkoski 1984), the distribution of 35 NIS was mapped. Although far from comprehensive, this review can be

regarded as the first basin-wide approach to invasion biology in the Baltic Sea (*cf.* the title of the present overview). In the same year, Elmgren (1984) presented a list of 14 NIS (vertebrates excluded), among them *Balanus improvisus*, which was erroneously omitted from Leppäkoski's (*loc. cit.*) paper.

An inventory of NIS in Danish waters was published by Knudsen (1989). One of the first Masters theses on NIS in the northern Baltic area might be that of Halsinaho (1984) on the distribution of the polychaete *Polydora* (*Boccardia*) *redeki* on the coast of Finland.

In the Curonian Lagoon, Kublickas & Rubinas (1985) studied the impacts of NIS on fish nutrition, while along the Finnish coast, Vuorinen *et al*. (1986) may have been among the first to document economic consequences of NIS in the northern Baltic in their study of fouling organisms in power plants. Among the five most common fouling species, they found two NIS (*Balanus improvisus* and *Cordylophora caspia*), although no reference was made to their non-native origin.

In the late 1980s, the North American spionid polychaete *Marenzelleria viridis* had increased tremendously along the German and Polish coasts and reached Lithuanian waters. Consequently, several studies were addressed to describe its spread and biology in its new area (Bick and Burckhardt 1989, Gruszka1991, see Zettler 1997 for a bibliography).

In the 1980s, the NIS were also included in broader considerations of ecosystem health, and the symptoms of ecosystem pathology as well as the mechanisms by which a brackish sea copes with stress were discussed by Rapport (1989) and Leppäkoski and Mihnea (1996). These include changes in nutrient turnover, energy flow, changes in community structure, life-history adaptations from long and complicated to short and simple life-cycles, shortened food-chains and other alterations in interspecific relationships, reduced species diversity, increasing dominance of introduced species, reduced population stability, and increased dominance of r-selected species.

Diversification, internationalisation and organisation in the 1990s

The late 1990s saw an increased interest in ecological studies, including experimental work on NIS. Inventories of NIS were published for German Baltic waters (Gollasch and Dammer 1996, Gollasch and Mecke 1996). The work performed since 1995 expanded the understanding of the functional role of NIS especially in benthic subsystems (*e.g.*, Olenin & Leppäkoski 1999, consult Baltic Alien Species Database 2004 for further references). The increasing commitment to invasion biology was also fuelled by the harmful impacts on fisheries through the invasion of the fishhook water flea *Cercopagis pengoi* in mid-1990s. The rapid spread of this highly successful Ponto-Caspian

species (first found in 1992), as well as its benthic counterpart, the North American polychaete *Marenzelleria viridis*, was the key event in the development of research into bioinvasions. These recent invaders also catalysed public awareness of the problem of alien species, and served to highlight the fact that an increased understanding of the ecological and economic impacts of NIS, and effective monitoring of their spread are essential elements in the study of human-mediated changes in the Baltic Sea ecosystem.

In the Baltic Sea countries, aquatic NIS were added to the environmental policy agenda only in the late 1990s. Consequently, NIS were not addressed in the HELCOM Periodic Assessments of the State of the Baltic Sea before the 3rd one, issued in 1996 for the period 1989-1993.

Prior to 1996, preliminary overviews of the occurrence and invasion history of NIS in the Baltic Sea were presented at international fora in the early 1990s, among them EMECS'90 - Environmental Management and Appropriate Use of Enclosed Coastal Seas - held in Kobe, Japan, in 1990 (Leppäkoski 1991), an EC Workshop in Monaco in 1993 (Leppäkoski 1994a), and a conference on Nonindigenous Estuarine and Marine Organisms in Seattle, USA, in 1993 (Leppäkoski 1994b).

However, international cooperation in invasion biology of the Baltic Sea began formally in 1994, when the Baltic Marine Biologists (BMB), a non-governmental scientific organisation, established the Working Group on Estuarine and Marine Nonindigenous Organisms (NEMO). The Working Group (WG) is probably the first regional cooperative network on aquatic NIS. It aims to (i) facilitate contacts between marine biologists working on NIS, (ii) maintain the Baltic Alien Species Database since 1997, (iii) present the results of joint investigations at BMB biannual Symposia and elsewhere, and (iv) contribute to intergovernmental/international bodies such as HELCOM, ICES and the IMO.

The first internet-based inventory listing 78 nonindigenous species (both established and occasional) was issued in 1997. In the same year, the first Nordic PhD course on the ecology of marine invasions and introductions was held in Turku, Finland. During the period 1995-2000, several workshops were organised by the WG in Klaipeda, Gdynia, St. Petersburg, Pärnu, and Copenhagen. NIS were included in the topics first at the 16th BMB Symposium in Klaipeda in 1999. A regional risk assessment project, probably the first of its kind to be carried out in Europe, covering five Nordic harbours, was initialised by the BMB Working Group members in 1997 as a part of a Nordic Council of Ministers´ project (Gollasch and Leppäkoski 1999). Other activities initiated by the NEMO Group include involvement in a European Union-funded Concerted Action "Testing Monitoring Systems for Risk Assessment of Harmful Introductions by Ships to European Waters" between 1998-2000, and

publishing a comprehensive book ”Invasive Aquatic Species of Europe: Distribution, Impacts and Management” (Leppäkoski *et al*. 2002a).

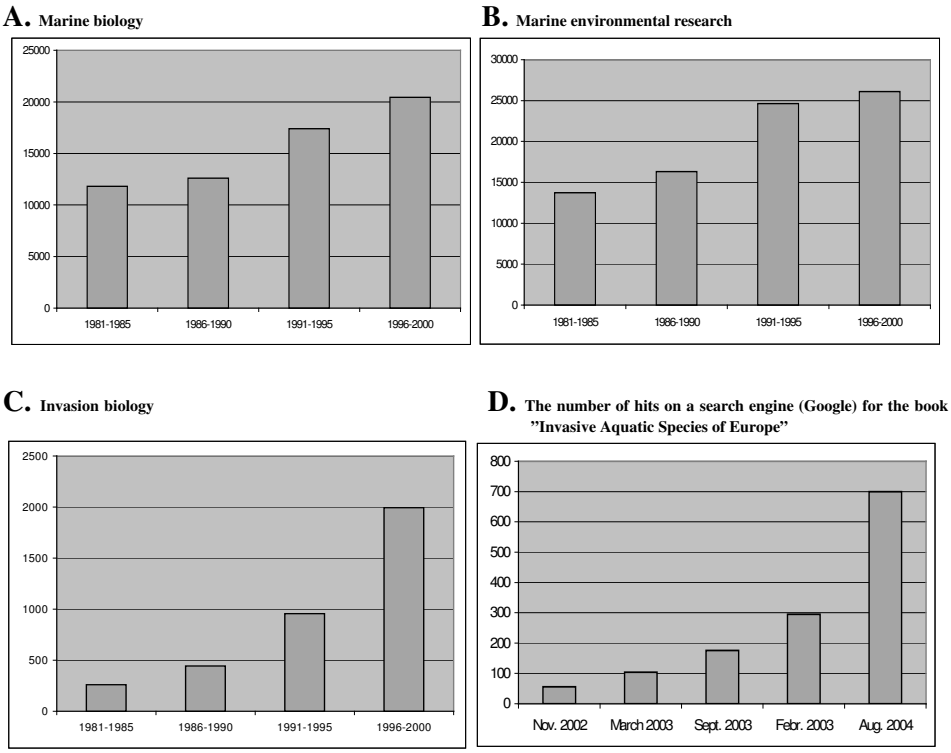

Fig. 1. The volume of published work during the period 1981-2000 increased steadily in marine biology (A; search terms used phytopl*, zoopl*, benth*), marine environmental research (B; search terms eutroph*, pollut*), and invasion biology (C; search terms exotic, alien, invasive, non-native, nonnative, nonindigenous, non-indigenous). The number of hits on a search engine for the book ”Invasive Aquatic Species of Europe”, initiated by the Baltic Marine Biologists’ Working Group on Estuarine and Marine Nonindigenous Organisms (first published in 2002), increased after a certain time lag (D). N.B. The scales are different.
Sources: Aquatic Sciences and Fisheries Abstracts (A-C), and Google (D).

Since the 1990s, the worldwide interest in aquatic alien species and their impacts is reflected in the activities of many bodies. In addition to the BMB WG, Baltic Sea research also contributes to the work of international organisations such as the ICES WG on Introductions and Transfers of Marine

Organisms, and the ICES /IMO Study Group on Ballast Water and Other Ship Vectors (see Panov *et al*. 2002 for a review).

The thematic and biogeographical internationalisation of invasion biology began with comparisons of the Baltic and Black Seas and their invasion status in the early 1990s (Leppäkoski 1994, Leppäkoski and Mihnea 1996). Ten years later, the comparative approach has broadened to also cover the Great Lakes of North America and European inland waters (Ojaveer *et al*. 2002).

The huge increase of research into aquatic invasion biology reflects global trends in marine biology as indicated by the volume of published work between1981-2000 (Fig. 1A-1C). Towards the end of the 1990s, the quantitative expansion of invasion biology continued both internationally and regionally. There is a certain delay in making an international audience aware of a single product of, *e.g*., the BMB WG activities (see above), such as the book "Invasive Aquatic Species of Europe - Distribution, Impacts and Management", issued in 2002 (Fig. 1D).

A diversification of invasion biology became apparent in the late 1990s, when a shift occurred from merely descriptive work, to studies on the functional impacts of NIS and from the increasing interest in experimental studies of trophic interactions.The first PhD worldwide based on ballast water sampling of ships was published in Germany by Gollasch (1996), working at the Institute of Marine Research in Kiel. In the Baltic Sea, the first ballast water studies date back to 1998 when ballast water was sampled en-route from St. Petersburg to Lisbon (Olenin *et al*. 2000).

CONCLUDING REMARKS

For the last twenty years, much attention has been paid to the non-native inhabitants of the Baltic Sea and, over last decade, their impacts and roles in the affected parts of the sea's ecosystem. A timeline (Fig. 2) represents the brief history of the as yet quite fragmentary research accomplishments by individual scientists that have their background in well-established hydrobiological sciences (aquatic botany, zoology and ecology), as any formal education in invasion biology is not offered with the exception of short lecture courses at a few universities. Much, however, remains to be done. With NIS, new challenges also for marine biodiversity research and monitoring have been introduced. To sum up, the first twenty years of research into the biogeography and ecology of non-native invaders in the Baltic Sea provide us today with reliable but as yet fragmentary information regarding short-term faunistic and floristic changes, which increasingly elucidate the scales, both spatial and temporal, of human influences on the Baltic Sea.

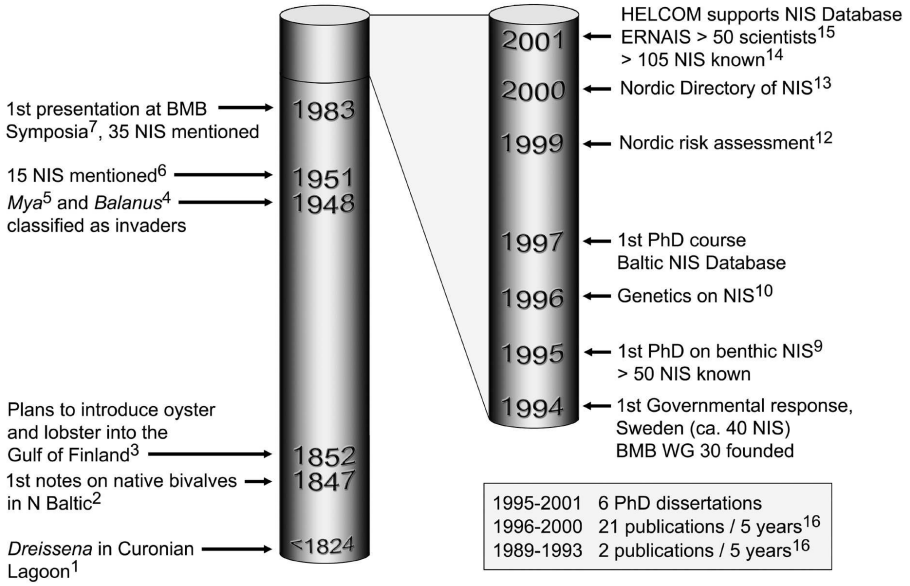

Fig. 2. Timeline of research into invasion biology in the Baltic Sea countries (from Leppäkoski *et al.* 2002 and references therein; modified).

The four steps toward our present awareness can be characterized as follows: (1) Early 1800s: first NIS identified as newcomers, (2) Until the 1970s: only fragmentary notes on NIS occurring in the Baltic; (3) Until the 1990s: focus on distributions; (4) Since the late 1990s: invasion biology is internationalised and diversified with a shift in focus to vectors and the advent of databases and www networks.

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Marine Protected Areas (MPAs) are widely considered to be an essential tool for recovering, protecting and enhancing biodiversity, maintaining productivity and increasing the resilience of ecosystems in the face of a changing climate, and for securing these benefits for current and future generations. Thus MPAs can form the bedrock for a truly Sustainable Blue Economy (see Box 1) for the Baltic Sea â€“ and thereby be the very basis for any future sustainable â€˜Blue Growthâ€™ in the region. ðŸŽ¦ Baltic Sea. Quite the same Wikipedia. Just better.Â In the Middle Ages the sea was known by a variety of names. The name Baltic Sea became dominant only after 1600. Usage of Baltic and similar terms to denote the region east of the sea started only in 19th century. Name in other languages.Â First mentions of amber deposits on the South coast of the Baltic Sea date back to the 12th century.[14] The bordering countries have also traditionally exported lumber, wood tar, flax, hemp and furs by ship across the Baltic. Sweden had from early medieval times exported iron and silver mined there, while Poland had and still has extensive salt mines.