Master Thesis Marine Biology

Assessment of benthic aquatic alien species in coastal waters of the southern Baltic Sea with respect to the European Marine Strategy Framework Directive

1st April to 12th October 2011

Handover date: 12th October 2011

By Anne Katharina Juliane Wittfoth

Born on 6th June 1987

Registration number: 209206203

University of Rostock

1. Supervisor: Dr. Michael Zettler

Leibniz-Institut für Ostseeforschung Warnemünde
Biologische Meereskunde
Seestrasse 15
D-18119 Rostock
Phone: +49 381 5197 236
Fax: +49 381 5197 440
E-Mail: michael.zettler@io-warnemuende.de

2. Supervisor: Dr. rer. nat.Wolfgang Wranik

Universität Rostock
Institut für Biowissenschaften
Albert-Einstein-Str. 3b
D-18051 Rostock
Phone: +49 381 498 6060
Fax: +49 381 498 6052
E-mail: wolfgang.wranik@uni-rostock.de

Table of contents

Zusammenfassung

Eingewanderte Arten sind ein immer wichtiger werdender Faktor für die Ökologie und Gesundheit eines Ökosystems. Es sind Fallbeispiele bekannt, in denen die Neozoen einen negativen Einfluss auf das heimische Ökosystem haben und zu wirtschaftlichen Folgen führen. Die Europäische Union hat daher in der europäischen Meeresstrategie-Rahmenrichtlinie (RICHTLINIE 2008/56/EG) beschlossen, dass alle Länder den Anteil und die Auswirkungen vorhandener Neozoen beurteilen sollen. Ein wichtiger Verbreitungsvektor für eingewanderte Arten ist hierbei der Schiffsverkehr, sowie Kanäle und Wasserstraßen.

Daher soll das Warnowästuar als Handelshafen und das Oderhaff als Mündung einer großen Wasserstraße mit dem Hafen Stettin untersucht werden. Weiterhin stellt die Darß-Zingster Boddenkette als dazwischen liegendes Küstengewässer ein interessantes Gebiet dar. Zur Erfassung der Daten wurden drei Beprobungen zu verschieden Zeitpunkten durchgeführt. Jeweils drei quantitative Sedimentkerne wurden pro Station entnommen und ein qualitativer Kescherfang durchgeführt. Die Daten wurden anschließend ausgewertet, um die Artenzusammensetzung und den Anteil der Neozoen zu bestimmen. Weiterhin wurden der ökologische Status der jeweiligen Gebiete mit Hilfe des M-AMBI und deren Beeinträchtigung durch Neozoen nach Olenin *et al.* (2007) ermittelt.

Die Auswertung der Daten hat ergeben, dass das Oderhaff und das Warnowästuar eine relativ hohe Anzahl an Neozoen beherbergen. So besitzt das Oderhaff 13 verschiedene eingewanderte Arten, deren gemeinsamer Anteil der Gesamtabundanz von 0,3 bis 36 % schwankt. Im Warnowästuar wurden nur 11 verschiedene eingeschleppte Arten gefunden, deren Anteil bei wenigen Prozent (1-3 %) liegt. Nur die Probenstation Peetzer Bach hat einen höheren Anteil von 29 %, vermutlich aufgrund des speziellen Habitats. Die Darß-Zingster Boddenkette besitzt die wenigsten Neozoen (6), diese haben aber eine hohe Abundanz (9-71 %). Weiterhin erreicht dieses Gebiet den höchsten Beeinträchtigungsgrad durch Neozoen von allen drei Gebieten (Level 3). Eine Ursache könnte die isolierte Lage des Gebietes sein. Das Ästuar und das Haff wiesen einen moderaten Einfluss (Level 2) auf das System durch Neozoen auf. Der ökologische Status des Warnowästuars und der Boddenkette ist gut. Der angewendete Index zur Bewertung des Einfluss von Neozoen nach Olenin *et al.* (2007) kann nicht als allgemein anwendbarer Index angesehen werden. Der Index setzt eine große Datengrundlage und viel Erfahrung voraus. Viele Bewertungen sind subjektiv und daher nicht mit anderen Gebieten vergleichbar, was den Index nicht empfehlenswert macht.

Summary

Invading species are a factor for the ecology and health of an ecosystem, which is getting more and more important. There exist cases where non-indigenous species have had a negative impact on the native ecosystem, as well as economic consequences. The European Union has decided, in the marine strategy framework directive, that all countries should assess the amount and impact of their aquatic alien species (DIRECTIVE 2008/56/EC). An important vector for spreading such invaders is ship traffic, canals, and waterways.

That is the reason why in this study, the Warnow Estuary, an important harbor, and the Szczecin Lagoon, an important waterway containing the habor Szczecin, were chosen for assessment. The Darß-Zingst-Bodden-Chain, which is located between these two areas, indicates how far the invaders have spread. For the evaluation of these areas, replicates were taken three times. Each time three quantitative sediment samples and one qualitative haul with a landing net were successfully completed. After the evaluation of the samples the biodiversity and amount of non-indigenous species were calculated. Furthermore, the ecological status was calculated with the help of the M-AMBI and the biological pollution of each area was assessed and evaluated according to Olenin *et al.* (2007).

The analysis of the data has revealed that the Warnow Estuary and Szczecin Lagoon were found to have a relatively high number of alien species. In the Szczecin Lagoon 13 different alien species were found, the percentage of all alien species together varies from 0.3 to 36 %, most of them are from the pontocaspian region. In the Warnow Estuary only 11 species were counted, most of them had a low percentage of 1 %, but the sampling station Peetzer Bach had an amount of alien species of the total species number of 29 %, probably because of its special habitat. The Darß-Zingst-Bodden-Chain has the lowest number of invading species (6), but they have the highest abundance of all assessd areas (9-71 %). Furthermore, this area has the highest biological pollution level of all three areas, namely level 3 (high level). A reason could be its isolated location and low native diversity. The other two areas have a moderate pollution and reach only a level two. The ecological status of the Warnow Estuary and the Bodden-Chain is good on average. The applied biological pollution index by Olenin *et al.* (2007) could not be recommended as an universal assessment tool for alien species, because it requires a lot of data and experience. Most ratings are subjective and make a comparison with other assessed areas difficult.

1. Introduction

The Baltic Sea is a young and brackish, epicontinental sea in northern Europe, including the Kattegat, it has a surface of 415,000 km² and a depth up to 459 m. In its history, the physical and chemical conditions have alternated from fresh to marine, and from well temperate to glacial. Around 7,000 years ago, the Baltic Sea became as it is today. As a result of the last glaciation, after the Weichselian glacial period, which ended 12,000 years ago, most animals are postglacial immigrants and many of the species live close to their salinity tolerance. The salinity can rise up to 20 – 24 practical salinity units (psu) in the Kattegatt and decrease to only 1-2 psu in the inner parts of the large gulfs (e.g. Gulf of Finland). The temperature differs from boreal Atlantic in the southwest to sub-Arctic in the northern most part of the Baltic Sea. These horizontal and vertical gradients influence the native and non-native species distribution.

The concepts to determine the invading species vary not only among countries, but also among scientists. There is a shift in terminology, noticeably from "introduced species" or "non-indigenous species" in the beginning of the 1990s, to "invasive species" or "aquatic alien species" at the end of 1990s and early 2000s. The IUCN introduced the following definition of alien species in 1999: "Alien species" (non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon , existing outside of its natural range (past or present) and its dispersal potential (i.e. outside the range it occupies naturally, or could not occupy without direct or indirect introduction, or care by humans) and includes any part, gametes or propagule of such species that might survive, and subsequently reproduce." With the awareness of these species and the discussion of the consequences of their introduction, another phrase rises up that describes this topic. "Biological pollution" has been used recently to discuss problems caused by aquatic alien species. Olenin *et al.* (2007) modified a definition of Elliot (2003) and described this dictum as follows:

Biological pollution describes "the impacts of alien invasive species efficiency to disturb ecological quality by having significant effects on:

- an individual (internal biological pollution by parasites or pathogens),
- a population (by genetic change, i.e. hybridisation),
- a community (by structural shift),
- a habitat (by modification of physical–chemical conditions),
- an ecosystem (by alteration of energy and organic material flow).

The biological and ecological effects of biological pollution may also cause adverse economic consequences.“

The immigrations of alien species are differentiated between primary and secondary introductions. If the species exists for the first time in a locality, which is different to the biological province, it is called a primary introduction. More then one primary introduction can occur at the same time. Secondary introduction is used if the species expands from this first location. There exist many possible vectors for species to immigrate to a new location (Fig. 1). In our modern trading society infiltration of alien species by shipping plays a prominent role. Ships transport a wide range of sessile species, platonic organisms (free living stage) or buried in the sediment and associated individuals. This occurs usually via the ships’ hull fouling or ballast water, and its sediments.

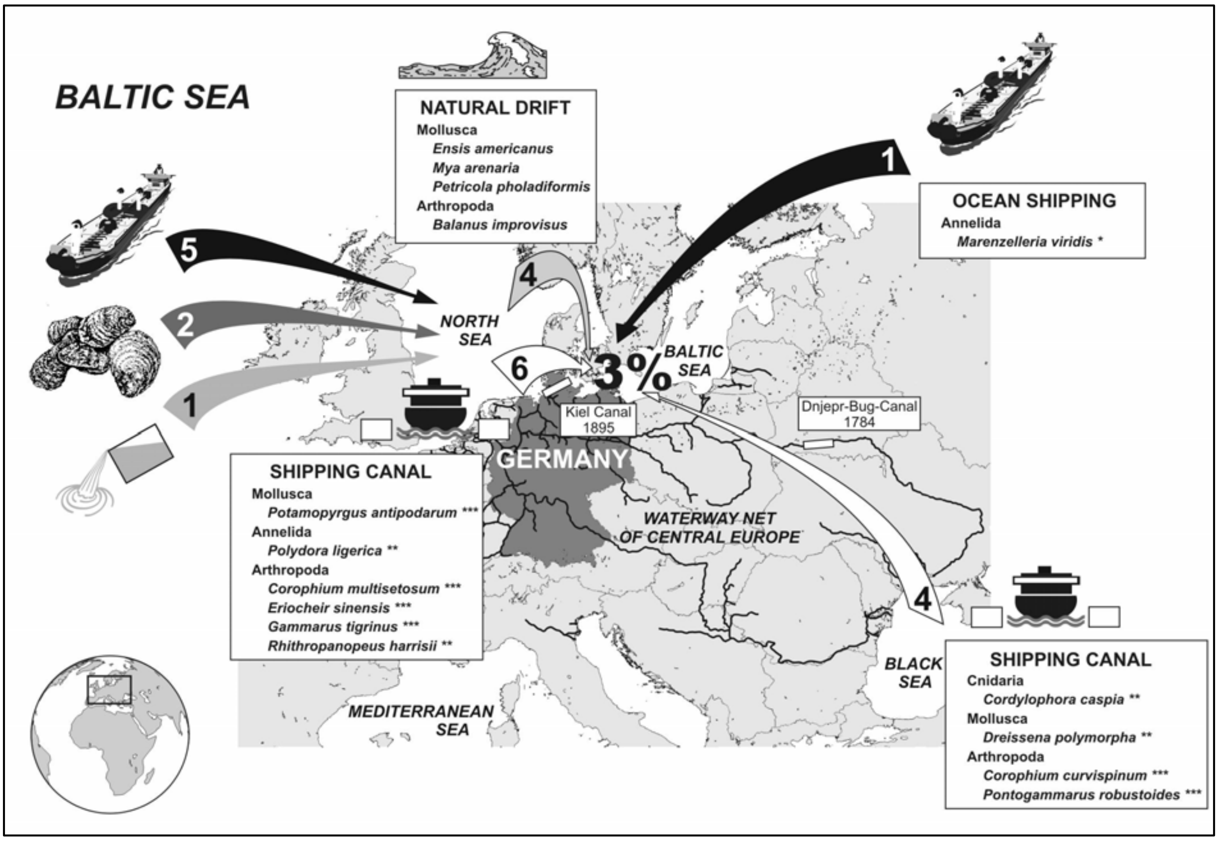

Figure 1 Introduced macrozoobenthic species on the German Baltic Sea coast from Nehring (2001)
Known or probable introduction vectors (* ballast water, ** hull, *** hull or active migration), number of introduced species and their amount on total species number (in percent), important canals and their opening date.

Another probable vector becoming economically more important is the aquaculture. Except for the frequent cultivation of non-native species, continued existence of these living animals leads to an infiltration of phytoplankton, phytobenthos, as well as, diseases and parasites. For example, the cultivation of the king crab *Paralithodes camchaticus* in Russia, in the 1960s, precipitates to the establishment and expansion of this crab in Norway, which occurred through active migration of escaped crabs and pelagic larvae. A further problem is the trade with living species, which could take diseases with them. An additional factor is the natural dispersal, once a species is established, it could potentially increase its range through a pelagic phase or active migration, and could become increasingly wide spread.

Other vectors are marine algae that are used as packing material (e.g. for lobster). Epibionts and other associated organisms could spread like that around the world. Another problem could also be the discarding of non-indigenous live fishing baits without regard to their ability to establish in the area. Important man-made vectors are the waterways and canals, because of the construction of new connections through different waters, new invasion routes are made possible for some species (Leppäkoski *et al.*, 2002).

Most introduced macro invertebrates have established a permanent existence in estuaries. After Nehring (2002) there are four probable reasons.

- Through canals with inland crafts salt tolerant limnic species reach the coast first.
- Most estuaries characterised by intense intercontinental shipping, increases the potential of infection. This is aggravated by the fact that ballast water often has estuarine character.
- Most of the introduced species are genuine brackish water species with a high tolerance of changing environmental condition. That is why they have better chances to be transported alive than marine species.
- Because of the natural autochthonous species are at a minimum in brackish waters, it is easier for introduced species to become established.

If alien species are established they could have an impact and consequences for the ecosystem. The ecological and economic aspects of introduced species are insufficiently studied in the Baltic Sea, because there are no obvious effects on the native environment, and consequently no impacts on human uses. Nevertheless, there are some new ecological functions made by the non-indigenous species. For example, the snail *Potamopyrgus antipodarum* is a surface deposit feeder on the soft bottom, where native species are absent. *Dreissena polymorpha* is a filter feeder in oligohaline freshwater, where native mussels like

Mytilus edulis do not exist. In addition, the empty shells can be used as habitat by other species (microhabitat engineers). Native predators and scavengers do not exist in diluted parts of the inlets, on the German Baltic Sea coast, but the crab *Rhithropanopeus harrisii* can occupy this ecological niche. Studies of recent years show that some species compete with native species for food, and space (e.g. *Cordylophora caspia*, *Gammarus tigrinus*, *Dreissena polymorpha*). Some alien species become numerically dominant (e.g. *Balanus improvisus*, *Mya arenaria*) and could change the energy matter that flows between pelagic and benthic, and modify trophic structures of ecosystems (e.g. *Cordylophora caspia*, *Mya arenaria*). Invading species could also harm the ecosystem by transferring parasites or diseases to local species (e.g. *Coregonous nasus*, *Pacifastacus leniusculus*). The non-native macro invertebrates in the German Baltic Sea have no value of food resources and consequently do not support the commercial fisheries, and the invertebrates could not be harvested for food. All in all, less than 30 % of the introduced species are classified as nuisance organisms, 7 have caused significant damage (e.g. *Cordylophora caspia*, *Dreissena polymorpha*, *Balanus improvisus*). But the economic impact is rarely quantified (Leppäkoski *et al.*, 2002).

The European marine strategy framework directive declares that all European waters should have a good environmental status. Which means that all “non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems” (DIRECTIVE 2008/56/EC). It demands an initial assessment and determination of the ecological status to be completed by July 15, 2012. In 2015, the development of a program of measurements designed to achieve or maintain a good environmental status will be completed. Therefore an “inventory of the temporal occurrence, abundance and spatial distribution of non-indigenous, exotic species or, where relevant, genetically distinct forms of native species, which are present in the marine region or sub region.” will be completed (DIRECTIVE 2008/56/EC).

That is why an inventory and assessment of the aquatic alien species in three selected areas of the German southern Baltic Sea coast will be completed in this master thesis. The areas, which should be evaluated, are the Warnow Estuary, the Darß-Zingst-Bodden-Chain and the Szczecin Lagoon. The hypotheses are that the Estuary and the Lagoon will probably have the highest number of invading species, and a corresponding relatively high impact. As a harbor, the majority of alien species in the Warnow Estuary presumably will have a transatlantic origin. The most non-indigenous species of the Lagoon probably originated from the Caspian Sea, so it is likely that the Bodden-Chain, in the middle of these areas, is influenced by both origins. Certainly the number of species will be inferior to the other two areas, that is why it is assumable that they have less impact in contrast to the remaining two areas.

2. Materials and methods

2.1 Study area

Altogether, three costal waters were studied. These three estuaries and lagoons belong to the German Baltic Sea coast and are all characterized by a salt-gradient. The westernmost study area is the estuary of the Warnow. East of this water body is the Darß-Zingst-Bodden-Chain located, and at the border to Poland, the Szczecin Lagoon is situated (Fig. 2). The main infiltration route of pontocaspian species is via the river Oder. The Szczecin Lagoon was chosen as a study site, because of its connection to the Oder and the Baltic Sea. Apart from transcontinental waterways, capacious harbors are also exposed to immigrating species. That is the reason why the Warnow Estuary and the Szczecin Lagoon were investigated, because it holds the biggest harbor in Mecklenburg-Western Pomerania and Szczecin in Poland. The Darß-Zingst-Bodden-Chain is an interesting study area because it is an intermediate location between the Warnow Estuary and Szczecin Lagoon. The only possibilities for the spreading of non-indigenous species here are small pleasure crafts, boats, and active migration.

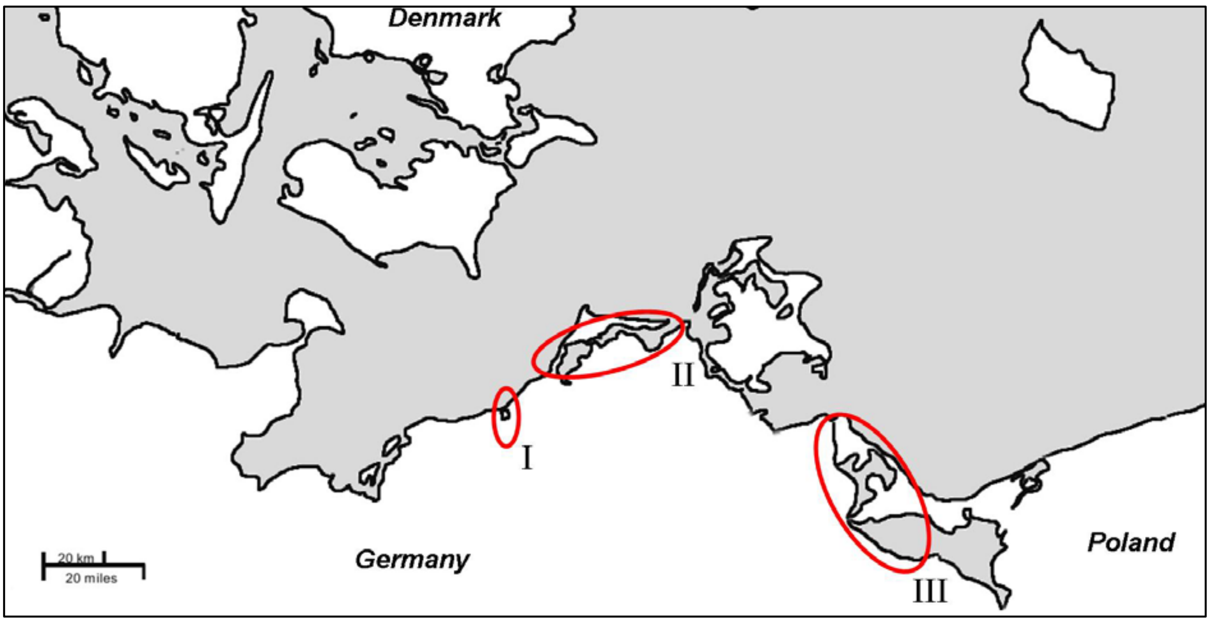

Figure 2 Investigated areas of the southern Baltic Sea
The study areas are circled in red and named:
I Warnow Estuary
II Darß-Zingst-Bodden-Chain
III Szczecin Lagoon

Figure 3 A typical example of a sample area with reed is the station Gehlsdorf of the Warnow Estuary

The particular stations were chosen to cover the entire study area and to minimize the logistical effort. All study areas can be reached by car and are characterised by reed (Fig. 3). Some of them possess another hard substrate like stones or sheet pilings (Tab. 1).

Table 1 Habitat of selected sampling stations
WE - Warnow Estuary DZBC - Darß-Zingst-Bodden-Chain SL - Szczecin Lagoon

Station	Study area	Reed	Stones/ Rubble	Stakes/ Sheet piling
Barth	DZBC	x		x
Bellin	SL	x	x	
Gehlsdorf	WE	x	x	x
Mönckebude	SL	x	x	x
Neuendorf	DZBC	x	x	
Oldendorfer Fähre	WE	x	x	x
Petridamm	WE	x	x	x
Schnatermann	WE	x	x	
Ziemitz	SL	x	x	x

The Unterwarnow (Fig. 4) is the estuary of the river Warnow, which flows through the city of Rostock. The estuary has a width of around 500 m and gets wider in the north. This lagoon is called Breitling and has a breadth of 3,000 m. The present connection of the Unterwarnow to the Baltic Sea is a human made canal, which was built in 1903 and is nearly 13 m deep. All in all, six sample sites were chosen here. In the south, Petridamm (Fig. 4a) is located near the start of the Unterwarnow. Downstream Gehlsdorf (Fig. 4b), Oldendorfer Fähre (Fig. 4c) and Schmarl (Fig. 4d) follow. In the Breitling two stations were sampled, the Peetzer Bach (Fig. 4e) and Schnatermann (Fig. 4f). In April it was impossible to take samples at Peetzer Bach, because of heavy construction. For that reason Peetzer Bach were only sampled two times (in May and July).

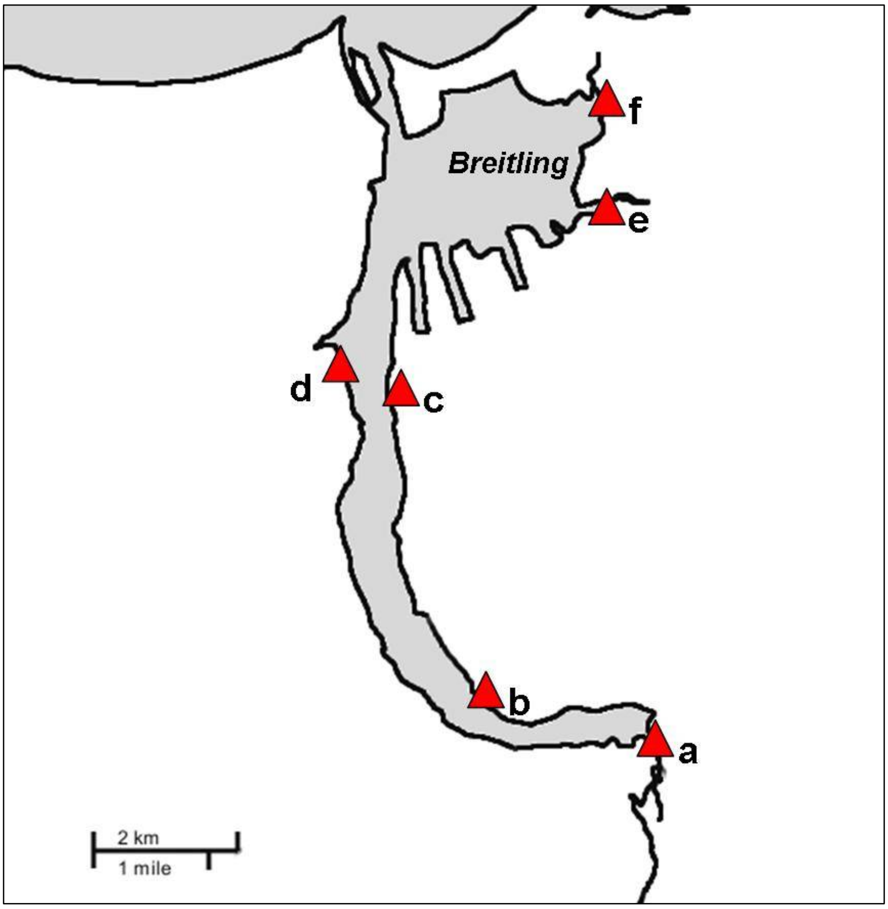

Figure 4 Study area I: The Warnow Estuary consisting of the Unterwarnow and the Breitling
The probed stations are shown as red triangles and named as follows:
a Petridamm b Gehlsdorf c Oldendorfer Fähre d Schmarl
e Peetzer Bach f Schnatermann

The Darß-Zingst-Bodden-Chain (Fig. 5) is located in the east, between Rostock and Stralsund. It consists of several lagoons, which the peninsula Fischland-Darß-Zingst separates from the Baltic Sea. The water area is 197 km² in size and only two meters deep on average. The big lagoons of the Bodden-Chain are the Saaler Bodden, Bodstedter Bodden, Barther Bodden and Grabow. The rivers Recknitz and Barthe flow into the

Darß-Zingst-Bodden-Chain. The only connections to the Baltic Sea are the Gellenstrom and a little gap between Großer Werder und Kleiner Werder. Former connections, such as the Prerowstrom, were closed by man. To evaluate these areas six sampling places were chosen to be investigated. The station with the lowest salinity is Dierhagen (Fig. 5a), which is located in the Saaler Bodden, like the second place Neuendorf (Fig. 5b). In the Bodstedter Bodden Bliesenrade (Fig. 5c) is situated as the only station in this lagoon. The sampling sites Barth (Fig. 5d) and Müggenburg (Fig. 5e) belongs to the Barther Bodden. The last station with the highest salinity, named Nisdorf, is located in the lagoon Grabow (Fig. 5f).

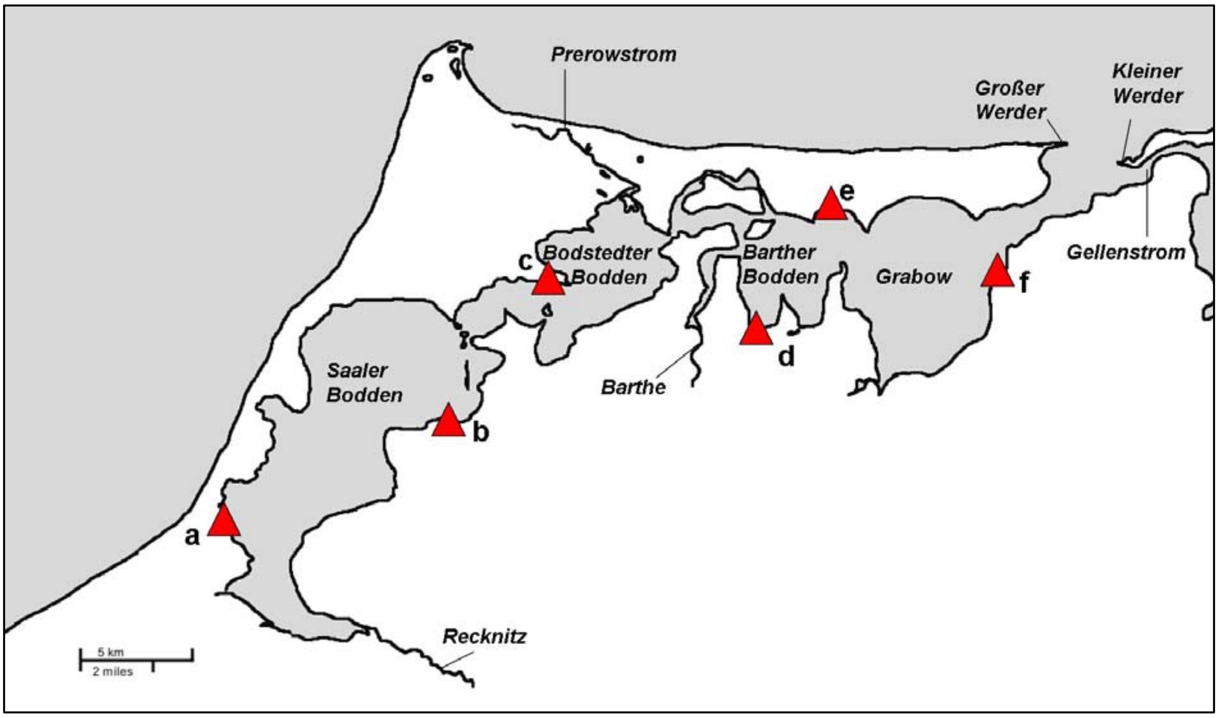

Figure 5 Study area II: Darß-Zingst-Bodden-Chain consisting of the Saaler Bodden, Bodstedter Bodden and the Barther Bodden
The six examined stations are shown as red triangles:

a Dierhagen b Neuendorf c Bliesenrade d Barth
e Müggenburg f Nisdorf

The last study area is the Szczecin Lagoon (Fig. 6). It is a coastal water with the estuary zone of the Oder and Peene, and has an average deep of 3.8 m. In this study only the German side of the lagoon was investigated, but the adjoining waters Peenestrom and Achterwasser were included. The Peenestrom separates the island Usedom from the mainland. It is the westernmost connection of the Szczecin Lagoon to the Baltic Sea. The Peenestrom has more or less large bays, for example the Achterwasser. The station in the Peenestrom with the highest salinity is Ziemitz (Fig. 6a). In the Achterwasser the sample sites Lütow (Fig. 6b), Loddin (Fig. 6c), and Gieglitz (Fig. 6d) are situated. Further upstream the examined station Lassan (Fig. 6f) is located. At this location, only in April sampling was possible, because the area became closed as a private property. For this reason in the months of May and July the station Warthe (Fig. 6e) was investigated. At the origin of the Peenestrom there is the sampling site Zecherin (Fig. 6g). In the Szczecin Lagoon itself four sampling stations were investigated, they are named Gummlin (Fig. 6h), Kamminke (Fig. 6i), Mönkebude (Fig. 6j) and Bellin (Fig. 6k). For a better overview in Table 2 all stations of the Warnow Estuary, Szczecin Lagoon and Darß-Zingst-Bodden-Chain were listed in alphabetic order and added with the longitudes and latitudes.

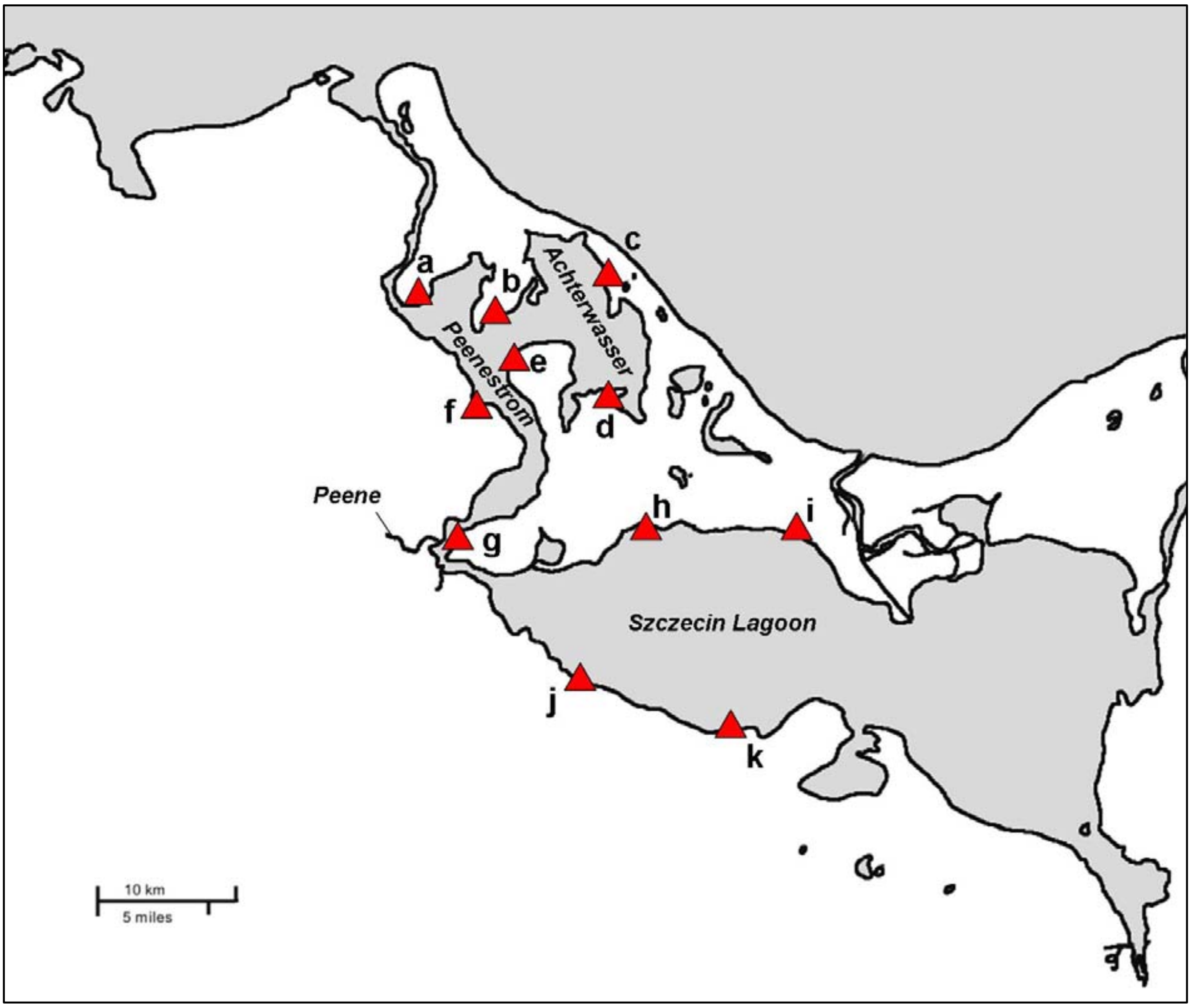

Figure 6 Study area III: Szczecin Lagoon composed of the Szczecin Lagoon (German side), the Peenestrom and the Achterwasser
The following eleven sampling sites were selected for this study and illustrated as red triangles:

a Ziemitz	b Lütow	c Loddin	d Gieglitz
e Warthe	f Lassan	g Zecherin	h Gummlin
i Kamminke	j Mönkebude	k Bellin	

Table 2: Geographic coordinates of each station of all study areas

Stations	Water	Study area	Latitude	Longitude
Barth	Barther Bodden	Darß-Zingst-Bodden-Chain	54° 22.546 N	12° 43.197 E
Bellin	Szczecin Lagoon	Szczecin Lagoon	53° 44.213 N	14° 07.438 E
Bliesenrade	Bodstedter Bodden	Darß-Zingst-Bodden-Chain	54° 23.387 N	12° 35.826 E
Dierhagen	Saaler Bodden	Darß-Zingst-Bodden-Chain	54° 17.500 N	12° 22.000 E
Gehlsdorf	Unterwarnow	Warnow Estuary	54° 06.006 N	12° 06.857 E
Gieglitz	Achterwasser	Szczecin Lagoon	53° 57.545 N	14° 00.142 E
Gummlin	Szczecin Lagoon	Szczecin Lagoon	53° 52.168 N	14° 01.136 E
Kamminke	Szczecin Lagoon	Szczecin Lagoon	53° 52.066 N	14° 12.453 E
Lassan	Peenestrom	Szczecin Lagoon	53° 57.001 N	13° 51.487 E
Loddin	Achterwasser	Szczecin Lagoon	54° 01.402 N	14° 00.194 E
Lütow	Achterwasser	Szczecin Lagoon	54° 00.619 N	13° 52.959 E
Mönkebude	Szczecin Lagoon	Szczecin Lagoon	53° 46.385 N	13° 58.296 E
Müggenburg	Barther Bodden	Darß-Zingst-Bodden-Chain	54° 25.020 N	12° 46.845 E
Neuendorf	Saaler Bodden	Darß-Zingst-Bodden-Chain	53° 57.545 N	14° 00.142E
Nisdorf	Barther Bodden	Darß-Zingst-Bodden-Chain	54° 22.975 N	12° 53.095 E
Oldendorfer Fähre	Unterwarnow	Warnow Estuary	54° 07.757 N	12° 05.949 E
Peetzer Bach	Breitling	Warnow Estuary	54° 09.616 N	12° 08.589 E
Petridamm	Unterwarnow	Warnow Estuary	54° 05.481 N	12° 09.227 E
Schmarl	Unterwarnow	Warnow Estuary	54° 08.110 N	12° 05.337 E
Schnatermann	Breitling	Warnow Estuary	54° 10.600 N	12° 08.200 E
Warthe	Peenestrom	Szczecin Lagoon	53° 59.142 N	13° 54.184 E
Zecherin	Peenestrom	Szczecin Lagoon	53° 51.914 N	13° 49.887 E
Ziemitz	Peenestrom	Szczecin Lagoon	54° 01.070 N	13° 46.939 E

2.2 Data collection

For a sufficient data basis the examined areas were investigated three times, first in early April, second at the end of May, and last at the beginning of July. The benthic invertebrates were recorded qualitative and quantitative in a water depth ranging half to one meter.

Quantitative sampling:

To get a sufficient statistical base at each station three sediment cores were taken. The cores were 30 cm high and the sampled area measured 78.5 km². Next the sample was sifted directly in the field with a mesh size of 1 mm. Then the residues were packed in 1 litre kautex bottles and fixed with 3 % formol. These samples were called Hols.

Qualitative sampling:

To evaluate the epibenthic invertebrates, a landing net was dredged for 30 minutes through the water. Furthermore, bank structures like stones, wood or reed were scraped off. The obtained samples were collected in 1 litre kautex bottles and fixed with 3 % formol. These samples were called Dredge.

After collecting, the samples were evaluated with the binocular microscope. The invertebrates were counted and weighed (only Hols). The identification was completed, when possible at species level. Otherwise the next higher taxonomic level was chosen. For a better differentiation of tissues sometimes the invertebrates were stained with methylene blue. After counting the individuals of the Dredge, they were classified in five groups (see Tab.3). The taxa of Bryozoa and Hydrozoa were uncountable and only rated as existing and classified with a 1. A number of specimens were stored in ethanol 95 %. Photographs were taken with an AxioCam ICc3 and the software AxioVision version 4.8.2.0. So all photographs are either formol preserved specimen or individuals, which were preserved in ethanol. These chemicals lead to discoloration of the specimen, so all photographs do not show the true coloring of the individuals.

Table 3 Abundance classification of qualitatively collected species in the Dredge

Group		**Number of individuals**
A	Abundant	> 100
C	Common	51-100
F	Frequent	16-50
O	Occasional	6-15
R	Rare	1-5

2.3 Statistical methods

2.3.1 M-AMBI

To evaluate the ecological status of the studied areas, the index M-AMBI (Muxika *et al.*, 2006) was utilised. Therefore, the AMBI (Borja *et al.*, 2000) must be calculated, so the software version 4.1 and the species list of February 2010 were applied.

The AMBI is the short form of AZTI Marine Biotic Index and a technique used to evaluate soft bottom benthic of European estuaries and costal waters. The index is deduced of the ratio of the abundance of five ecological groups. These groups are graded according to sensitivity and tolerance towards an ecological stress gradient.

“- Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous Polychaetes.

- Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.
- Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic richment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous Spionids.

- Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized Polychaetes: subsurface deposit-feeders, such as Cirratulids.
- Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in reduced sediments.” (Borja *et al.*, 2000)

With the abundance of each group a biotic coefficient was calculated. It provides a pollution classification from 0 to 6 (see Borja *et al.*, 2000). Finally, the M-AMBI was applied. This is a multivariate analyses, which uses different metrics (species abundance, Shannon Wiener diversity and AMBI), which fulfil the Water Framework Directive requirements, in assessing ecological quality (Muxika *et al.*, 2006).

2.3.2 Primer

For further statistical analysis of multivariate data the statistical software Primer v. 6 was used (Clarke & Gorley, 2006) to compare the sampling sites among themselves, and to realize which species coexist together. Therefore the data was transformed with the fourth root and a resemblance analysis based on Bray Curtis index followed. For Cluster analysis the complete linkage or group average method was performed. To consider the species, which occurred only in the Dredge, abundance according to the classification (see 2.2) was assigned (Tab. 4).

Table 4 Assigned abundance for only qualitative recorded species
According to their classification a quantitative abundance was assigned for statistical analysis.

Group	Assigned abundance
A Abundant	100
C Common	50
F Frequent	25
O Occasional	10
R Rare	1

2.3.3 Biological pollution index

For the assessment of the non-indigenous species the proposed index of Olenin *et al.* (2007) was applied. The index did not use a numerical calculation, but follows a specific literal-code. First the ADR class (abundance and distribution range) was determined. The species was given a letter from A to E, where A stands for low numbers in one or several localities and E for high numbers in all localities (Tab. 5). Afterwards the impact-code was applied. Therefore the impact on native species and communities (C) (Tab. 6), habitats (H) (Tab. 7) and ecosystem functioning (E) (Tab. 8) was classified from 0 to 4, where zero stands for none and four for a massive impact. After following the code it provided a biological pollution level from zero to four: 0 – No; 1 – Weak, 2 – Moderate, 3 - Strong and 4 – Massive (Fig. 7). For each alien species this index was applied and after evaluating all species, the overall biological pollution level for the assessment unit was determined. The general biological pollution is based upon the greatest impact level of at least one species. So if, for example ten alien species exists and nine get only a level of one, but a single species reaches level three, then the total biological pollution level of the assessed area is three. For detailed information see Olenin *et al.* (2007).

Table 5 Classification of alien species abundance and distribution range according to Olenin *et al.* (2007)

Code	Description
A	An alien species occurs in low numbers in one or several localities.
B	An alien species occurs in low numbers in many localities, or in moderate numbers in one or several localities, or in high numbers in one locality.
C	An alien species occurs in low numbers in all localities, or in moderate numbers in many localities, or in high numbers in several localities
D	An alien species occurs in moderate numbers in all localities, or in high numbers in many localities.
E	An alien species occurs in high numbers in all localities.

Table 6 Classification of alien species impact on native species and communities according to Olenin *et al.* (2007)

Code	Impact	Description
C0	None	No displacement of native species, although alien species may be present. Ranking of native species according to quantitative parameters in the community remains unchanged. Type-specific communities are present.
C1	Weak	Local displacement of native species, but no extinction. Change in ranking of native species, but dominant species remain the same. Type-specific communities are present.
C2	Moderate	Large scale displacement of native species causes decline in abundance and reduction of their distribution range within the assessment unit and/or type-specific communities are changed noticeably due to shifts in community dominant species.
C3	Strong	Population extinctions within the ecosystem. Former community dominant species still present but their relative abundance is severely reduced; alien species are dominant. Loss of type-specific communities occurs within more than one ecological group.
C4	Massive	Population extinction of native keystone species. Extinction of type-specific communities occurs within more than one ecological group.

Table 7 Classification of alien species impact on habitat according to Olenin *et al.* (2007)

Code	Impact	Description
H0	None	No habitat alteration.
H1	Weak	Alteration of a habitat(s), but no reduction of spatial extent of a habitat(s).
H2	Moderate	Alteration and reduction of spatial extent of a habitat(s).
H3	Strong	Alteration of a key habitat, severe reduction of spatial extent of habitat(s); loss of habitat(s) within a small area of the assessment unit
H4	Massive	Loss of habitats in most or the entire assessment unit, loss of a key habitat.

Table 8 Classification of alien species impact on ecosystem functioning according to Olenin *et al.* (2007)

Code	Impact	Description
E0	None	No measurable effect.
E1	Weak	Measurable, but weak changes with no loss or addition of new ecosystem function(s).
E2	Moderate	Moderate modification of ecosystem performance and/or addition of a new, or reduction of existing, functional group(s) in part of the assessment unit.
E3	Strong	Severe shifts in ecosystem functioning in part of the assessment unit. Reorganisation of the food web as a result of addition or reduction of functional groups within trophic levels.
E4	Massive	Extreme, ecosystem-wide shift in the food web and/or loss of the role of a functional group(s).

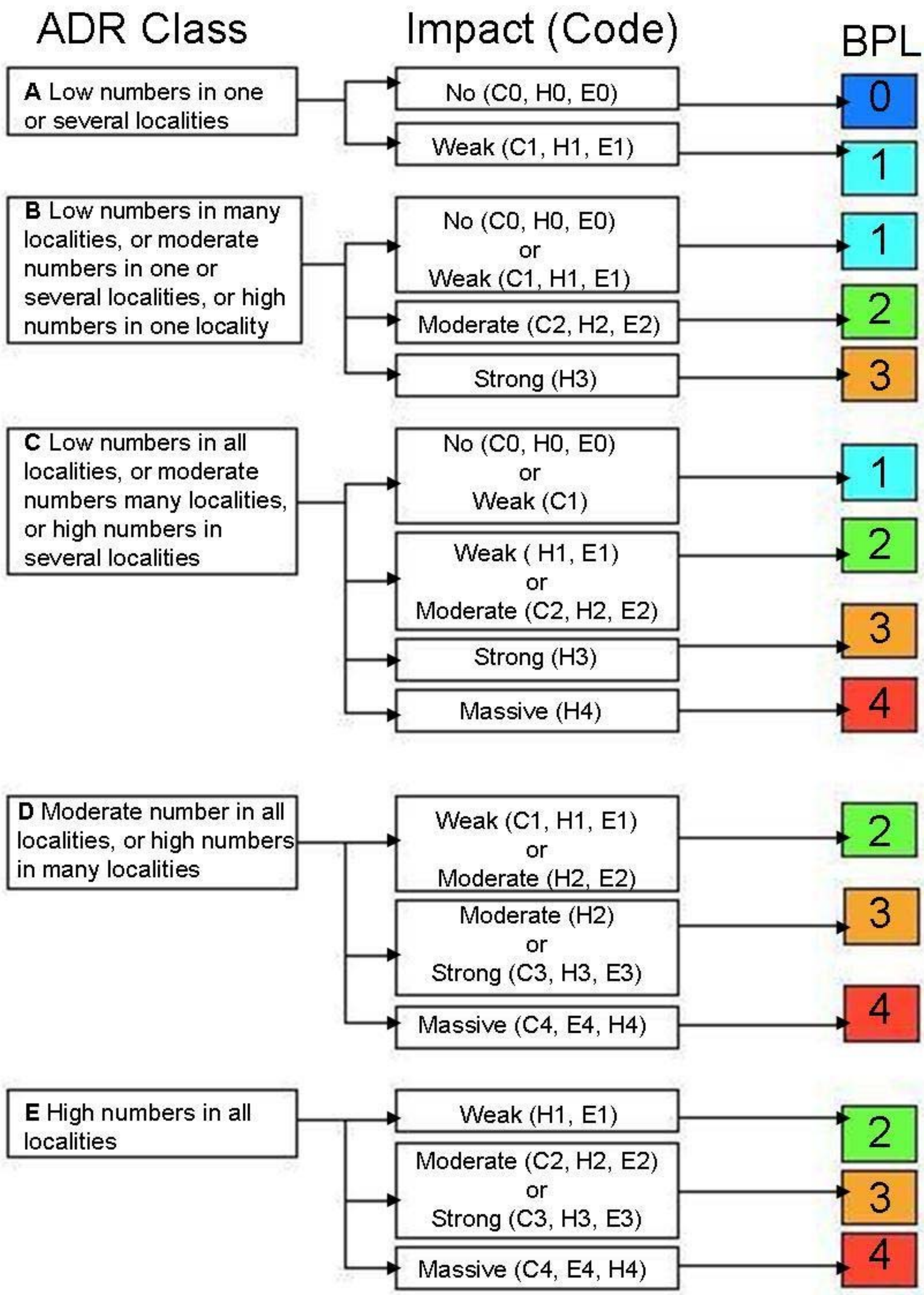

Figure 7 The decision support scheme for assessment of biological pollution level (BPL) according to Olenin *et al.* (2007)

3. Results

3.1 Assessment of data

When all three sampling times were added together, 90 different species were specified in the Szczecin Lagoon. Somewhat lower (80) was the number of species found in the Warnow Estuary. The lowest biodiversity found, was the Darß-Zingst-Bodden-Chain with 55 species. This ratio also shows a long-term dataset. The databank dates from the year 1871 to 2011 and was provided by courtesy of the Leibniz Institute for Baltic Sea Research Warnemünde.

After a comparison with this database, it has become apparent that 42-52 % of species were not encountered (Fig. 8). This is probably a result of taxonomic and sample collecting reasons. For one thing, Chironomids and Oligochaets were not classified at a species level, in addition, not all possible substrates and salinities were sampled. Furthermore, in the long-term database species are listed, which existed only at one time in an area. However 8-15 % new species could be collected. This also may have taxonomical reasons, because in contrast with older identifications, the order Trichoptera was identified to species level.

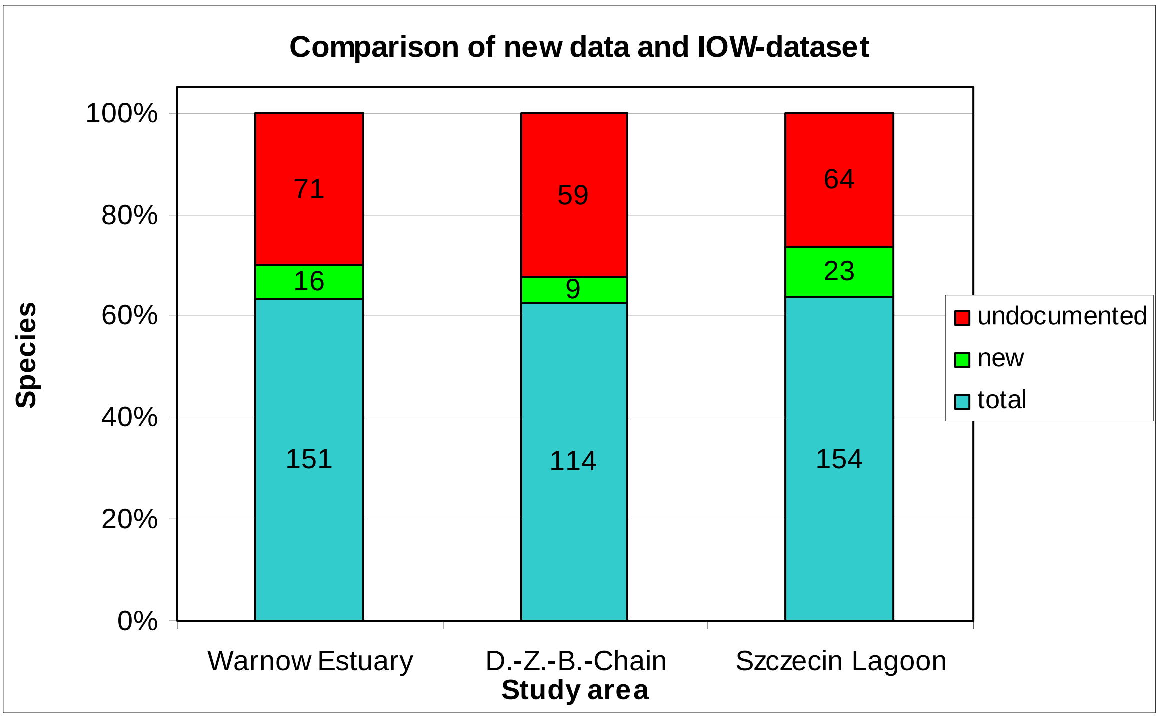

Figure 8 Comparison between new gathered data and historical records
The blue bars shows the total number of species which were ever identified in the area. Number of species, which were not found in the actual study, are shown by a red bar. The last bar (green) shows new species, which were not listed in the historical database.

3.2. Distribution of aquatic alien species in the study areas

In the assessed areas 17 aquatic alien species were found, which belong to 9 different orders (Tab. 9). In the Szczecin Lagoon 13 different alien species exist, whereas in the Warnow Estuary only 11 species were counted. The lowest number of non-indigenous species was found in the Darß-Zingst-Bodden-Chain with only 6 species. On the following pages their amount of the total observed abundance and their distribution pattern should be studied.

Table 9 Observed non-indigenous species-list with habitats
WE – Warnow Estuary DZBC – Darß-Zingst-Bodden-Chain
SL – Szczecin Lagoon x – existing

Order	**Species**	**Study area**		
		WE	**DZBC**	**SL**
Hydrozoa	*Cordylophora caspia*	x	x	x
Cirripedia	*Balanus improvisus*	x	x	
Isopoda	*Proasellus coxalis*			x
Amphipoda	*Chelicorophium curvispinum*	x		x
	Dikerogammarus haemobaphes			x
	Dikerogammarus villosus			x
	Gammarus tigrinus	x	x	x
	Obesogammarus crassus			x
	Orchestia cavimana	x		x
	Pontogammarus robustoides			x
Mysida	*Limnomysis benedeni*			x
Decapoda	*Rhithropanopeus harrisii*	x		
Bivalvia	*Dreissena polymorpha*	x		x
	Mya arenaria	x	x	
Gastropoda	*Potamopyrgus antipodarum*	x	x	x
Polychaeta	*Marenzelleria neglecta*	x	x	x
	Marenzelleria viridis	x		
Total	17			

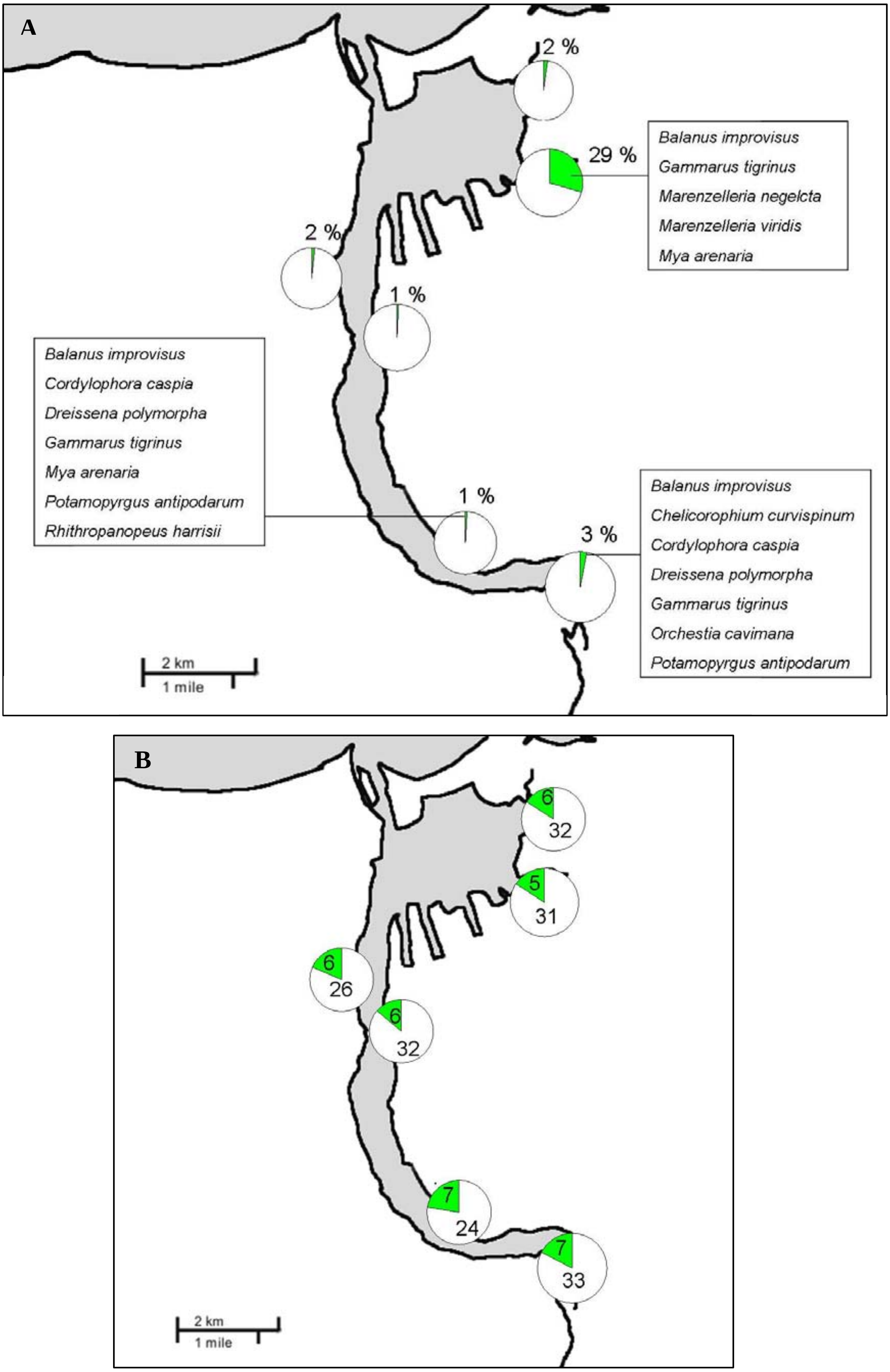

Figure 9 Distribution of non-indigenous species in the Warnow estuary.
A Shown is the percentage of the total abundance of non-native species and their composition exemplarily.
B Shown is the number of species and non-native species in the assessed area. Green indicates the invaded species.

Generally speaking, the Warnow Estuary has a low percentage of alien species (Fig. 9A). The only exception is the station Peetzer Bach with an amount of 29 % of non-indigenous species, but a comparatively low diversity of non-indigenous species. The compositions of the species vary from south to north. For example the mussel *Dreissena polymorpha* exists only in the southernmost stations Petridamm and Gehlsdorf, the stations with the lowest salinities. Whereas *Marenzelleria neglecta* inhabits only the areas with salinity at least around 9 psu (Schmarl, Peetzer Bach, Schnatermann). Some species are really rare, for example *Orchestia cavimana* and *Chelicorophium curvispinum* appear only at the station Petridamm.
Each station has five to seven different alien species and between 24 and 33 native species (Fig. 9B). The station with the highest diversity of native species is the sampling site Petridamm, but there also exist the highest number of non-indigenous species. The lowest number of non-native species has the sampling station Peetzer Bach (5). At the station Gehlsdorf, seven non-native species could be found, but only 24 native species.

The situation is different with the Darß-Zingst-Bodden-Chain (Fig. 10A). It appears like the amount of alien species increases with lower salinity or larger distance from the Baltic Sea. Except for Nisdorf, with the highest salinity and Dierhagen with the lowest, the composition of species is uniform. Nisdorf is the station with the highest diversity of non-indigenous species and is the station with the lowest amount as well. Nisdorf has some species, which only exist at this station, for example *Balanus improvisus* and *Mya arenaria*. The highest percentage of invaded species has the station Bliesenrade with 71 %. Only two non-native species could be recorded in Dierhagen, but their total amount increases up to 56 %.
At the sampling sites of the Darß-Zingst-Bodden-Chain 2 to 6 different alien species per station could be observed, whereas 20-55 native species per station exist in this area (Fig. 10B). Dierhagen is the station with the lowest number of native species and also have the least number of alien species of all sampling sites in this area. The maximum number of different native species exists in the sampling station Barth. The highest number of alien species (6) exists in Nisdorf. These species coexist with a relatively high number of native species (27).

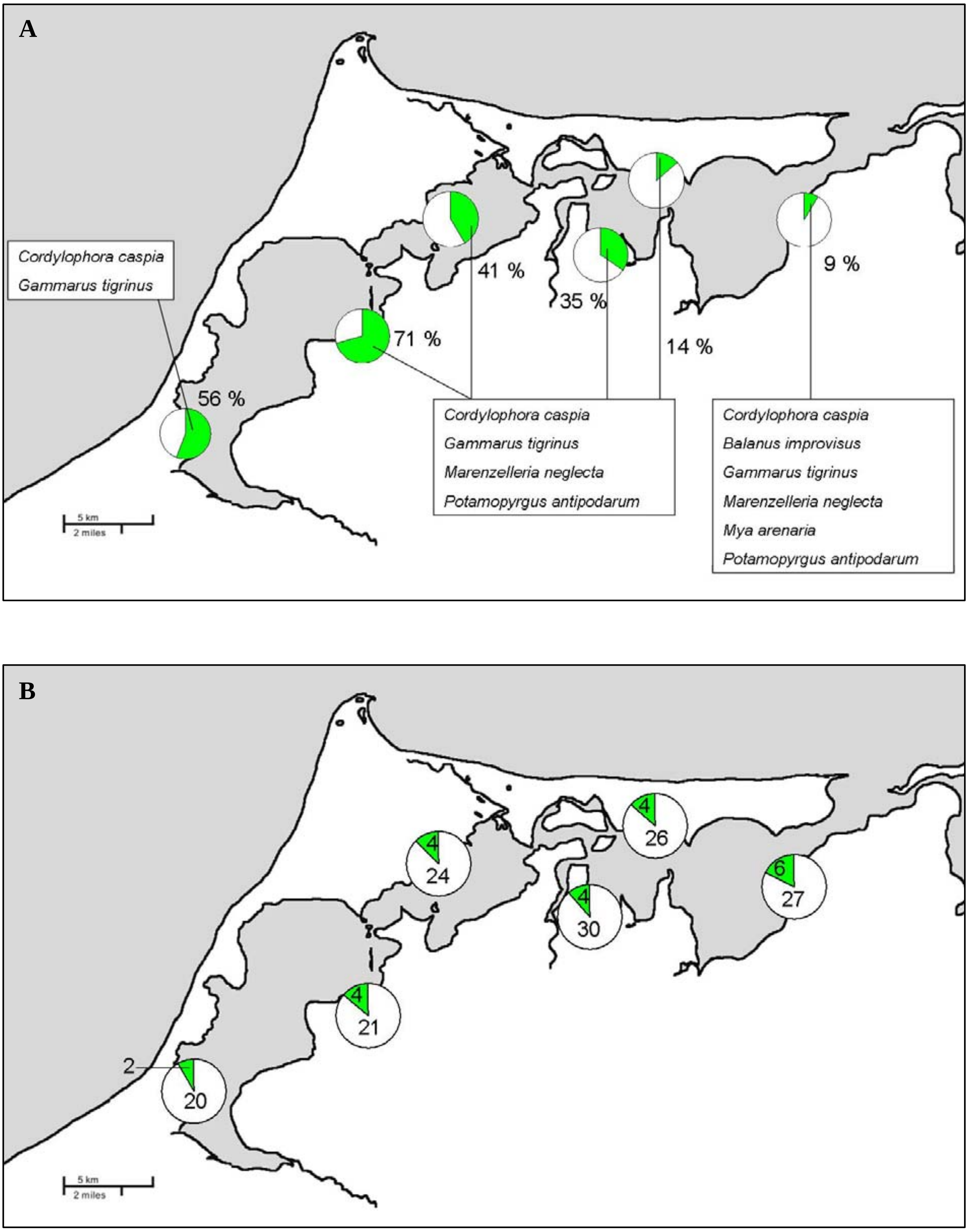

Figure 10 Distribution of non-indigenous species in the Darß-Zingst-Bodden-Chain.
A Shown is the percentage of the total abundance of aquatic alien species and their composition of each station**.**
B Shown is the number of species in the assessed area. Green indicates the invaded species.

The Szczecin Lagoon has no obvious distribution pattern (Fig. 11A). The Lagoon itself has a relatively high percentage of alien species up to 30 %. An exception is the station Kamminke with only 3 %. Similarly low amounts have been found at the station Lassan in the Peenestrom and Gieglitz in the Achterwasser. But this does not mean that they have a low diversity of non-native species, they also inhabit six different alien species. In contrast, the remaining stations have more or less a high abundance of alien species. Many species are really rare and exist only at a few stations, such as *Dikerogammarus haemobaphes, Chelicorophium curvispinum*, *Obesogammarus crassus*, *Orchestia cavimana,* and *Proasellus coxalis*. In the Szczecin Lagoon between 20 and 55 native species, and 6 and 8 alien species exist per station (Fig. 11B). The station with the lowest native diversity, Zecherin, also has a high number of alien species (8). The sampling site Ziemitz is inhabited by nine different alien species, the highest number of this study area. The highest diversity of native species has the station Gieglitz, but it also has a relatively high number of alien species (7).

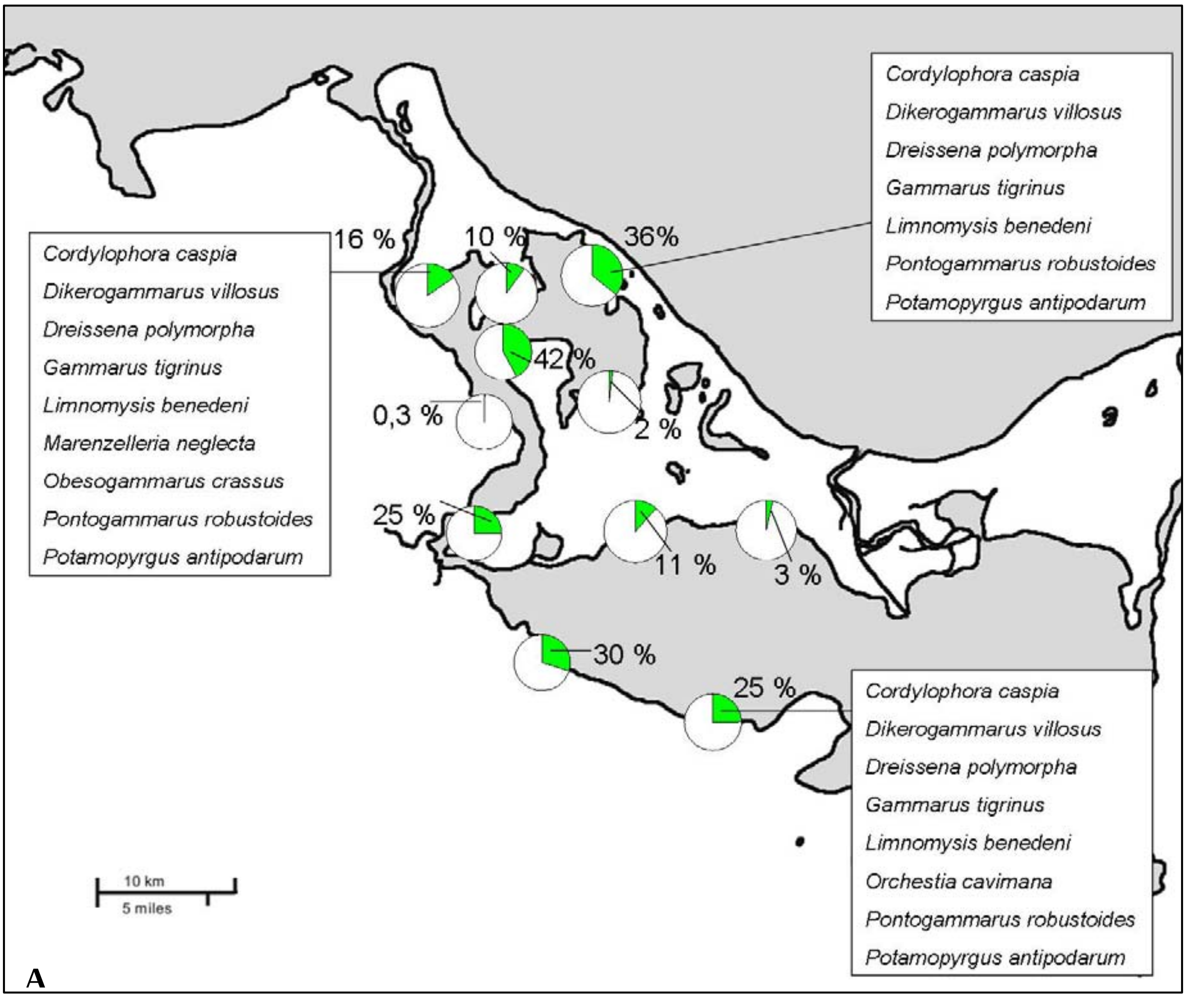

Figure 11 Distribution of non-indigenous species in the Szczecin Lagoon.
A Shown is the percentage of the total abundance of non-indigenous species and their composition exemplarily.

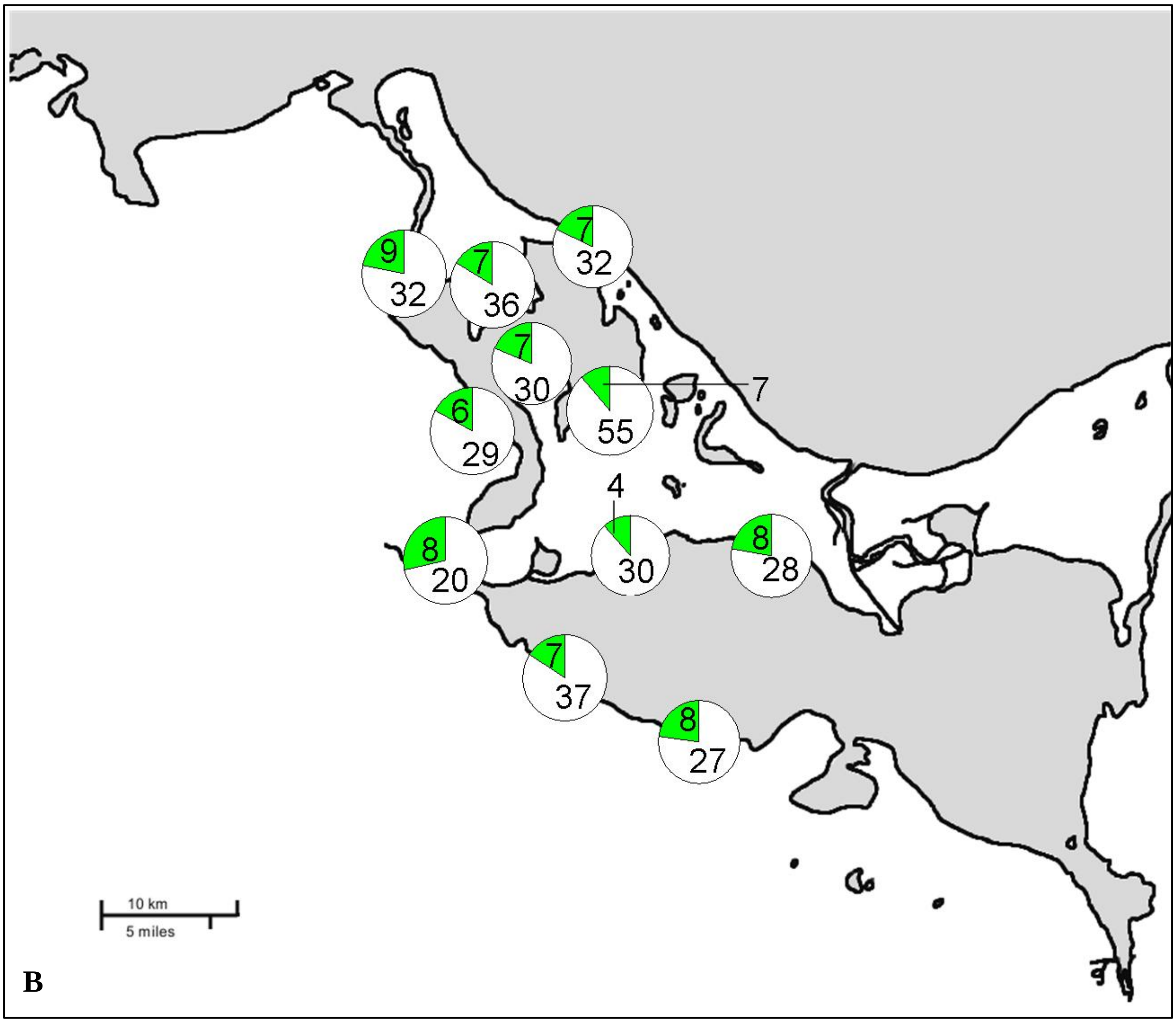

Figure 11 Distribution of non-indigenous species in the Szczecin Lagoon.
B Shown is the number of species in the assessed area. Green indicates the invaded species.

3.3 Profiles of recorded alien species

On the following pages a profile of the alien species is given to get a better understanding of their ecology and mode of life. Therefore basic data on their habitat and nutritional preferences, as well as their reproduction cycle are summarized. In addition, their current distribution and known ecological tolerances are stated. Where possible, the Common name of a species in English and German are listed. The profiles were arranged according to their taxonomic order and within alphabetical order.

3.3.1 Hydrozoa

Cordylophora caspia (Pallas, 1771)

Figure 12 ***Cordylophora caspia*** **from Neuendorf (Darß-Zingst-Bodden-Chain)**

Common name: Freshwater hydroid (English)
Keulenpolyp, Affenhaar (German)

Distribution: The origin of this species is the Black and Caspian Sea. Now this hydroid is known in temperate and tropical coastal waters of every continent and in many fresh waters. It was first observed in the Baltic Sea in 1803 (Arndt, 1989).

Morphology: The stem can get 10 cm high and has a light brown color and basally ringed branches on alternated sites. The hydranths are terminal and white or pale pink (Hayward & Ryland, 1990) (Fig. 12).

Ecology: *C. caspia* has a wide range of salinity (0-35 psu) and temperature (5-35°C) tolerance.

Nutrition: They feed on small planktonic organisms.

Reproduction: Each branch bears one to three gonophores with six to ten eggs. The larvae leave as planulae state. But also asexual reproduction is known, for example budding or building a stolon.

Habitat: It can be found on various substrates. The species prefers shade and brackish to nearly fresh water areas (Olenin, 2006).

3.3.2 Cirripedia

Balanus improvisus Darwin, 1854

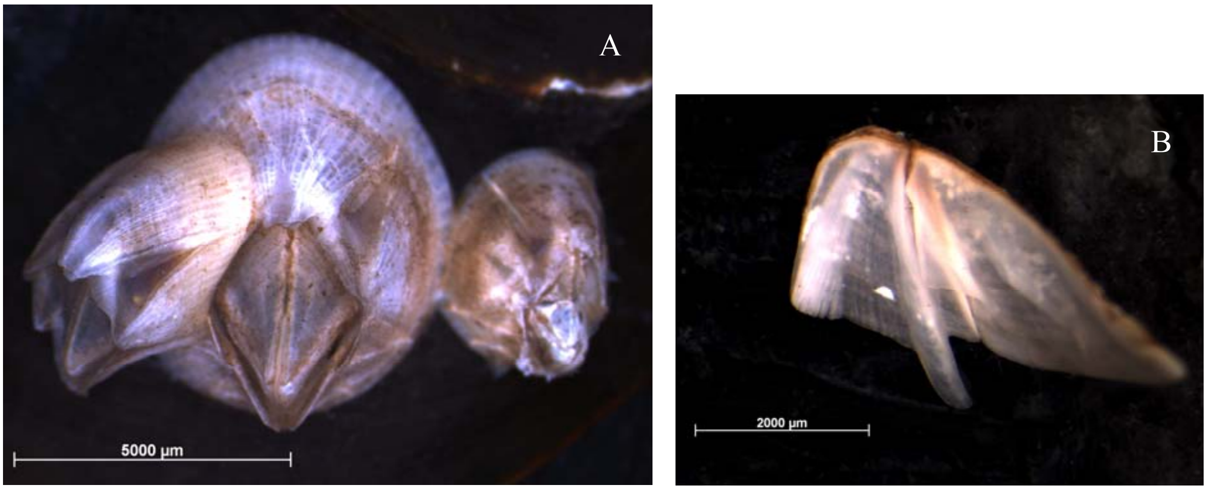

Figure 13 *Balanus improvisus* on *Mytilus edulis*-shell from Warnemünde (Warnow estuary)
A Habitus
B Tergum and Scutum of *Balanus improvisus*

Common name: Bay barnacle, acorn barnacle (English)
Brackwasser-Seepocke (German)

Distribution: The area of origin of *Balanus improvisus* is probably located in sub-tropical-temperate waters, assumedly North-America. Now it is wide spread around the world. In 1844 it was first described in the Baltic Sea (Gislen, 1950).

Morphology: The barnacle is moderated sized, up to 10 rarely 15 mm and is white or cream in color. The shell wall has six narrow plates and the orifice is tight and diamond shaped (Fig. 13A). The tergum possesses a long notch (Fig. 13B).

Ecology: The bay barnacle is extremely euryhaline and eurythermal.

Nutrition: Suspensions feeder (Appeltans *et al*., 2011).

Reproduction: Hermaphroditism and self-fertilisation are also known. Fertilised eggs develop in the ovisac, located in the mantle cavity. After that, free swimming nauplial larvae hatches. After six nauplial stages the transformation to the cyprid larvae occurs. These larvae stage settle on hard substrate and develop into a barnacle (Olenin, S., 2006).

Habitat: Living in the sub-littoral, it prefers stony and rocky bottoms. Sometimes it is attached to crabs, mussels or algae (Zaiko, A., 2005).

3.3.3 Isopoda

***Proasellus coxalis* (Dollfus, 1892)**

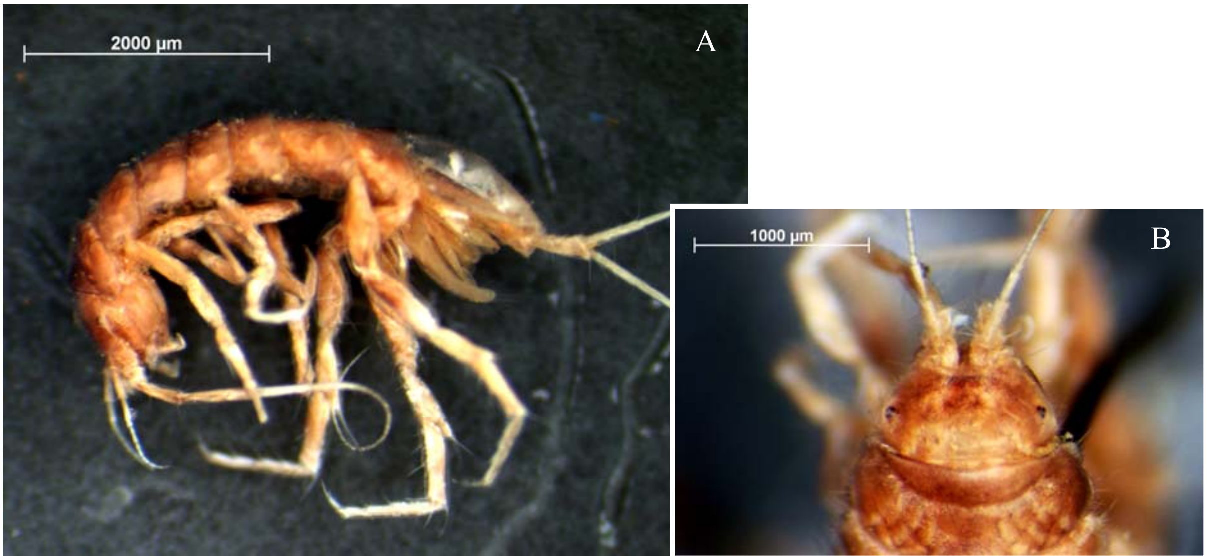

Figure 14 *Proasellus coxalis* from Müritz-Elbe-Wasserstraße
A Habitus
B Head without white points

Common name: -

Distribution: The region of origin of this Isopoda lies in the Mediterranean.

Morphology: The body is long-oval and barley-plenty three times long as wide. The surface is fine and short bristled (Gruner, 1965). In contrast to *Asellus aquaticus* this specie has no white spots behind the head (Fig. 14B).

Ecology: *P. coxalis* is very salt-tolerant and ubiquitous. Without sunlight it loses its pigmentation fast.

Nutrition: This species feeds on living or dead plants, sometimes filamentous algae or detritus.

Reproduction: no data

Habitat: They inhabit all kinds of running waters and often springs (Nehring & Leuchs, 1999).

3.3.4 Amphipoda

Chelicorophium curvispinum (G.O. Sars, 1895)

Figure 15 *Chelicorophium curvispinum* from Zecherin (Szczecin Lagoon)

Common name:	Caspian mud shrimp (English) Süßwasser-Röhrenkrebs (German)
Distribution:	This amphipod has his origin in the area of the Black Sea and Caspian Sea. It exists widely across Europe, in the rivers on the continent and Britain, the Baltic and the North Sea. It is also invading the Great Lakes of the United States and Canada. It invaded the Baltic Sea in 1900 (Gruszka, 1999).
Morphology:	*C. curvispinum* grow up to 9 mm and has a yellowish color. Especially in adult males the second antennae are very large (Fig. 15). The urosom is segmented.
Ecology:	As a result of the salt-tolerance (up to 6 psu) it also populates estuaries. They build tubes out of hard materials like stones and wood. During daylight this species hide itself and is only active during the night.
Nutrition:	They are active filter-feeder on detritus and plankton (Eggers & Martens, 2001).
Reproduction:	The reproduction occurs from April till September, with 12-20 °C. So three generations occur in a year.
Habitat:	This species live in slow-flowing rivers or lakes and prefers fine-grained soil (Tittizier, 1996).

***Dikerogammarus haemobaphes* (Eichwald, 1841)**

Figure 16 *Dikerogammarus haemobaphes* from Zecherin (Szczecin Lagoon)

Common name:	Kleiner Höckerflohkrebs (German)
Distribution:	The species are originally a pontocaspien species. It was first observed in the Baltic Sea in 1997 (Jazdzewski *et al*., 2004).
Morphology:	*D. haemobaphes* reaches a body size up to 18 mm. The tubercles of the urosom are short and conical (Eggers & Martens, 2001) (Fig. 16).
Ecology:	*D. haemobapphes* has a wide ecological tolerance, e.g. it occurs in salinities from freshwater up to 8 psu and in temperatures ranging from 6 to 30 °C (Grabowski *et al.*, 2007).
Nutrition:	It is an omnivore species.
Reproduction:	The reproductive period is from April till October and spawns three generations (spring, summer, autumn). The mean brood size ranges from 28 to 39 eggs per female (Bącela *et al.,* 2009).
Habitat:	They prefer stony habitats of rivers.

Dikerogammarus villosus **Sowinsky, 1894**

Figure 17 ***Dikerogammarus villosus*** **from Kammike (Szczecin Lagoon)**

Common name:	Killer shrimp (English) Großer Höckerflohkrebs (German)
Distribution:	The Killer shrimp has its origin in the rivers, which flows into the Black Sea. Now the shrimp is found in almost every Western European large river and the Baltic Sea since 1999 (Jazdzewski & Konopacka, 2002).
Morphology:	The body size can be up to 21 mm and the tubercles of the urosom are raised and cylindrical (Fig. 17). The color varies, there exists plain grey or brown individuals, as well as fawn striped ones.
Ecology:	*D. villosus* is an euryhaline species and can tolerate a wide range of temperatures, but prefers a temperature around 20°C.
Nutrition:	This amphipod is omnivore and a predator of *Gammarus tigrinus*.
Reproduction:	They can reproduce, if the water temperature is above 13°C, with a mean fecundity of 27.3 eggs per female (Devin & Beisel, 2006). This species has three generations per year.
Habitat:	*D. villousus* prefer habitats with stones where they can hide. Regularly they are between *Dreissena polymorpha*-colonies (Eggers & Martens, 2001).

***Gammarus tigrinus* Sexton, 1939**

Figure 18 *Gammarus tigrinus* from Kamminke (Szczecin Lagoon)

Common name:	Tiger shrimp (English) Tigerflohkrebs (German)
Distribution:	Originally from North America, now it exists in the Netherlands, Ireland, and Great Britain. In 1975 it was also found in the Baltic Sea (Bulnheim, 1976).
Morphology:	The species has a length up to 12 mm and the color varies from green or yellowish (male) to more blue (female). The significance are the transverse banding, which are pale green with deep blue or black with gold colored (Lincoln, 1979) (Fig. 18).
Ecology:	*G. tigrinus* can live in a wide range of salinity and temperature, from freshwater to 25 psu and from 0°C to 35°C (Pinkster, 1975).
Nutrition:	They are omnivore and feed on small animals, algae, plants, and detritus (Tittizier, 1996).
Reproduction:	This species need a temperature from 5°C to reproduce. The ideal temperature is 20°C, in that case the eggs needs only nine days to hatch. After 27 days the new generation is fertile (Pinkster, 1975).
Habitat:	They were found in fresh water of high ion content, as well as river, lakes, and coastal brackish waters (Koop *et al.*, 1990). *G. trigrinus* selects phytobenthos of hard substrate as suitable habitat.

***Obesogammarus crassus* (G.O. Sars, 1894)**

Figure 19 *Obesogammarus crassus* from Ziemitz (Szczecin Lagoon)

Common name:	-
Distribution:	The origin of this species is found on the coasts of the Caspian Sea and Black Sea, and their rivers. Nowadays it exists in Lithuania, Poland, and Germany (*Grabowski et al*, 2007). It was first observed in the Baltic Sea in 1962 (Gasiunas, 1964).
Morphology:	They have short antennae and on ursom segment II they have two or less spines (Fig. 19). This species has a maximum length of 12 mm.
Ecology:	This Amphipoda is an euryhaline species.
Nutrition:	It is an omnivour species.
Reproduction:	no data
Habitat:	It prefers oligohaline waters and hard bottom areas.

Orchestia cavimana Heller, 1865

Figure 20 *Orchestia cavimana* from Kamminke (Szczecin Lagoon)

Common name:	Süßwasser-Strandfloh (German)
Distribution:	Originally this species occurs in the east Mediterranean. Now it is found in the Black Sea, Red Sea, Atlantic coast of North Africa, and Europe to southern North Sea. In 1950 it was first observed in the Baltic Sea (Ezhova *et al.,* 2005).
Morphology:	This species can get up to 22 mm and has a dark brown color (Lincoln, 1979). The antenna1 is very short (Fig. 20) and the males have a special shaped gnathopod.
Ecology:	They are nocturnal and good swimmers. They can live for extended periods under water and are very salt-tolerant. If they are in danger, they show the conspicuous jumping behaviour.
Nutrition:	*O. cavimana* feeds on washed up plant matter.
Reproduction:	After copulation in Mai the hatched young animals remain in the marsupium from June till August. The adults live till September, only the new generation winters in groups (Kinzelbach, 1972).
Habitat:	It populates the wet lands of standing and slow running waters, as well as gravel banks (Eggers & Martens, 2001).

Pontogammarus robustoides (Sars, 1894)

Figure 21 ***Pontogammarus robustoides*** **from Kamminke (Szczecin Lagoon)**

Common name:	-
Distribution:	The areas of origin of this species are the coastal zones of the Black Sea and Caspian Sea. Now this species are invasive in several Baltic countries. It was first observed in the Baltic Sea in 1962 (Gasiunas, 1964).
Morphology:	The specimens can grow up to 18 mm and have short antennae (Eggers & Martens, 2001). On urosom segment II they always have more than 2 spines (Fig. 21).
Ecology:	They tolerate salinity from freshwater to 7 psu.
Nutrition:	*P. robustoides* is an omnivour species (Berezina & Panov, 2003)
Reproduction:	There are three generations per year, so the reproduction lasts from March/April until October (Gabrowski, 2006).
Habitat:	They prefer remains of plants as habitat, but *P. robustoides* can be also found on stony or sandy bottom.

3.3.5 Mysida

<u>*Limnomysis benedeni* Czerniavsky, 1882</u>

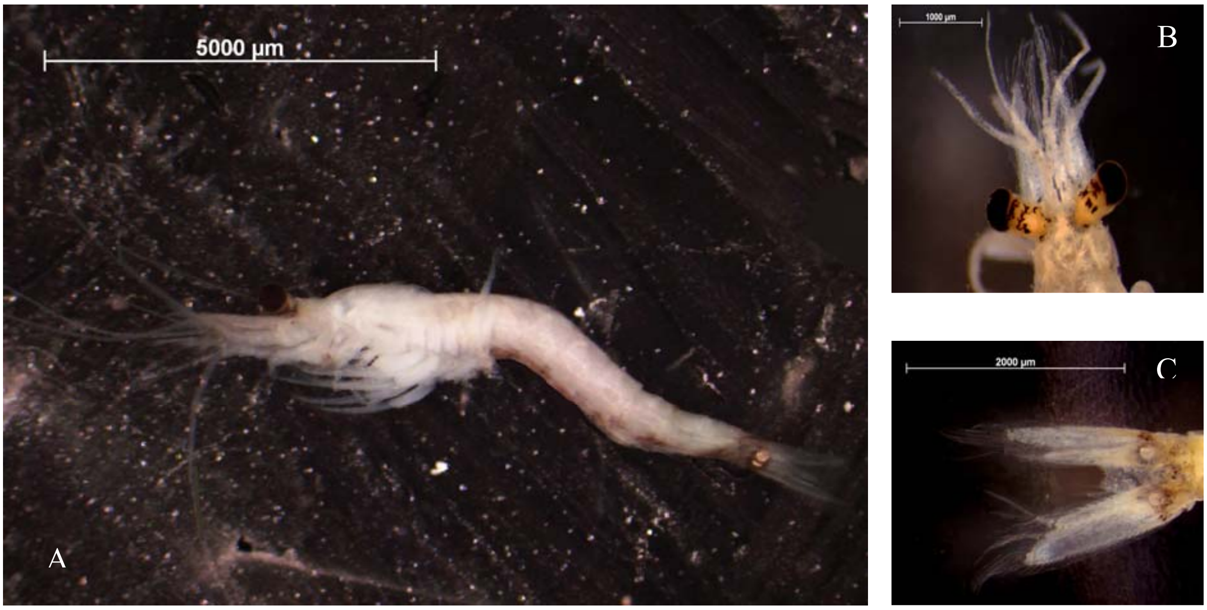

Figure 22 *Limnomysis benedeni* from Kamminke (Szczecin Lagoon)
A Habitus
B Head with antenna scales
C Indented Telson

Common name: Donau-Schwebgarnele (German)

Distribution: *L. benedeni* originate from the pontocaspian region. Now it is found in almost all European river systems. Since 1962 it can be found in the Baltic Sea (Gasiunas, 1964).

Morphology: They can grow up to 15 mm and the telson is indented (Fig. 22B). The antenna scales are rectangular (Fig. 22C).

Ecology: This Mysida is an euryhaline species, which can survive in deoxygenated waters.

Nutrition: This species feeds on detritus and filters phytoplankton.

Reproduction: They have a spring and summer generation, whereas the spring generation (~20) has twice the embryos in their marsupium then the summer generation.

Habitat: The species prefers standing or slow running waters with highly structured habitats like stones covered with *Dreissena polymorpha* and macrophyths (Gergs *et al*., 2008).

3.3.6 Decapoda

***Rhithropanopeus harrisii* (Gould, 1841)**

Figure 23 *Rhithropanopeus harrisii* from Schnatermann (Warnow Estuary)

Common name:	Zuiderzee crab, dwarf crab (English) Zuiderzeekrabbe, Brackwasserkrabbe (German)
Distribution:	The origin area of this species is the North American Atlantic. Now the species has been introduced the south Baltic, Dutch and other European estuaries. In 1936 it was first observed in the south Baltic Sea (Nikolaev, 1951).
Morphology:	The carapace is flat with four teeth on anterior-lateral edge and has a yellowish green color with black spots (Fig. 23). The typical length of a male carapace is 12 mm (Hayward & Ryland, 1990).
Ecology:	*R. harrisii* is a brackish water species and tolerates a wide range of salinity, but it prefers oligo- and mesohaline waters.
Nutrition:	The crab subsists of Mysidacea, snails and plants. Cannibalism can occur after the moulting.
Reproduction:	In the end of June the females lay up to 16,000 eggs in the soil. After one month the first free-living larvae state hatches (Nehring & Leuchs, 1999).
Habitat:	It prefers estuaries and lakes with muddy and sandy substrate. The species usually associates with shelter providing structures like vegetation and stones (Keith, 2006).

3.3.7 Bivalvia

Dreissena polymorpha (Pallas, 1771)

Figure 24 *Dreissena polymorpha* from Kamminke (Szczecin Lagoon)

Common name:	Zebra mussel (English) Dreiecksmuschel, Zebramuschel (German)
Distribution:	The area of origin is the region of the Black Sea and Caspian Sea. They were introduced into the Baltic Sea in 1803 (Schlesch, 1937). Nowadays they can be found in various parts of Europe.
Morphology:	*D. polymorpha* has a triangular shell shape and is yellowish colored with often serrated brown lines (Fig. 24). They can obtain a size up to 50 mm.
Ecology:	The mussel tolerates temperatures from -2 to 40°C. They also tolerate salinity up to a certain degree (7 psu). With a gland they produce bysuss filaments and baste on hard substrate (Zaiko & Olenin, 2006).
Nutrition:	*D. polymorpha* is a filter feeder on microscopic plankton organisms and organic particles (Reinhold & Tittizier, 1996).
Reproduction:	The Zebra Mussel has separated sexes. The breeding takes place in spring, when the water temperature rises up to 16-18°C. During the veliger stage the species occurs eight days in plankton, during May till September (Kothé 1973).
Habitat:	This species lives in lakes or slow running rivers and prefers stones, wood or other mussels as substrate (Reinhold & Tittizier, 1996).

Mya arenaria Linnaeus, 1758

Figure 25 ***Mya arenaria*** **from Schmarl (Warnow Estuary)**

Common name:	sand gaper, softshell calm (English) Sandklaffmuschel (German)
Distribution:	The origin area of this species is the North American Atlantic. Now it exists circumboreal but does not reach the Mediterranean. It was first observed in the Baltic Sea in 1245 (Hessland, 1946).
Morphology:	The shell is oval and dirty white or fawn in color. Large individuals can get a length from 12 to 15 cm (Fig. 25).
Ecology:	*Mya arenaria* is an euryhaline species, which burrows up to 50 cm deep in the sediment. With the siphons it holds connection to the surface and they can be totally withdrawn into the shell, up to a specific size. They normally live up to 10–12 years.
Nutrition:	This mussel is a suspension feeder on plankton and detritus.
Reproduction:	The reproduction happens from June to September. One female can have up to 3 million eggs. The larvae are 2 weeks free-living in the pelagial (Willmann, 1989).
Habitat:	The species lives on sandy and muddy soils. Sometimes it can be found to a depth of 192 metres and also in estuaries (Tyler-Walters, 2003).

3.3.8 Gastropoda

***Potamopyrgus antipodarum* (J.E. Gray, 1843)**

Figure 26 *Potamopyrgus antipodarum* from Neuendorf (Darß-Zingst-Bodden-Chain)

Common name:	Jenkins' spire snail, New-Zealand mudsnail (English) Neuseeländische Zwergdeckelschnecke (German)
Distribution:	Originally this species is from New-Zealand. Now it colonized Australia, Europe, and North America. Since 1887 it can be observed in the Baltic Sea (Nikolaev, 1951).
Morphology:	The shell has six tumid whorls and ear-shaped or oval aperture. Sometimes a spiral keel is present with or without periostracal bristles (Fig. 26).
Ecology:	The species has a wide tolerance range, it can tolerate a salinity up to 24 psu and a temperature up to 30°C.
Nutrition:	The snail feeds on detritus, algae and rotting parts of plants.
Reproduction:	In Europe only parthogenetic reproduction was recognized (development of unfertilized eggs). They can reproduce the whole year.
Habitat:	The snail lives in freshwater areas and prefers muddy sediments, but also sand and hard soils as well as plants were occupied (Jagnow & Gosselck, 1987).

3.3.9 Polychaeta

Marenzelleria neglecta Sikorski & Bick, 2004

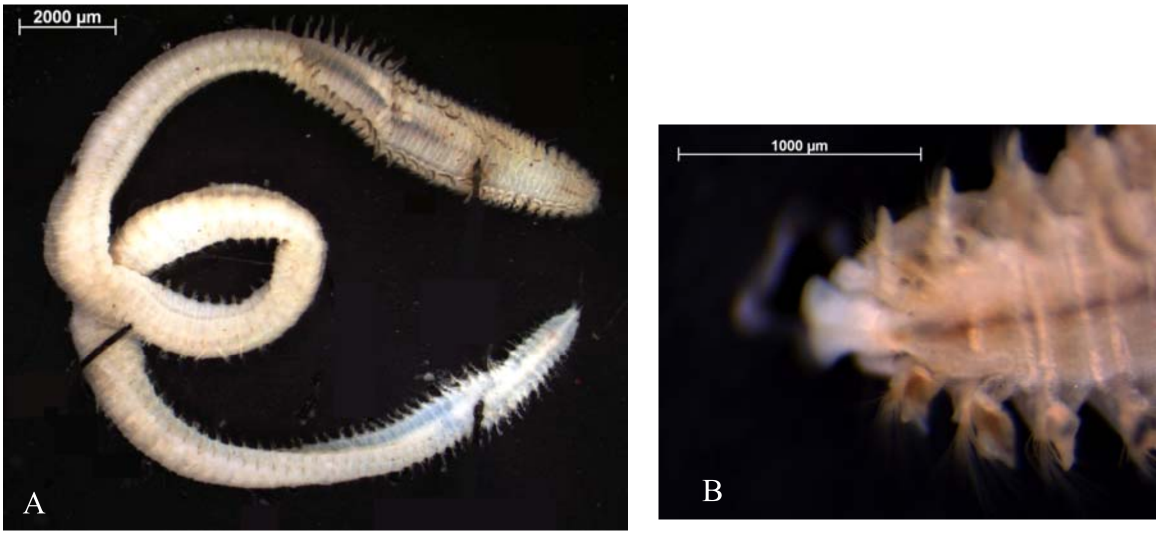

Figure 27 ***Marenzelleria neglecta*** **from Bliesenrade (Darß-Zingst-Bodden-Chain)**
A Habitus
B Head with nuchal organ

Common name:	Red-gilled mud worm (English) (also used for *M. virdis*)
Distribution:	The worm originally occurs in North America. The species has spread to most estuaries and coastal waters of Europe. It is restricted to the northern Hemisphere and was first observed in 1985 in the Baltic Sea (Bick & Burckhardt, 1989).
Morphology:	They can get over 12 cm long. The color is variable from red to light brown and even dark green (Fig. 27A). The length of the nuchal organ can go up to setiger 4 (Fig. 27B). (Sikorski & Brick, 2004)
Ecology:	*M. neglecta* has a salinity tolerance from freshwater to over 30 psu. They build tubes into the sediment out of sand and mud up to a depth of 45 cm. It can cope with low oxygen levels. (Zettler *et al*., 1994)
Nutrition:	The worm is feeding on sediment particles, for example sedimented plankton particles or other organic matter.
Reproduction:	After developing the gametes in Mid-May, they reach their maturity after 20 weeks and spawn in autumn. The larvae state lasts 4 to 12 weeks. (Bochert, 1997)
Habitat:	This species inhabits soft bottom areas of estuaries.

Marenzelleria viridis (Verrill, 1873)

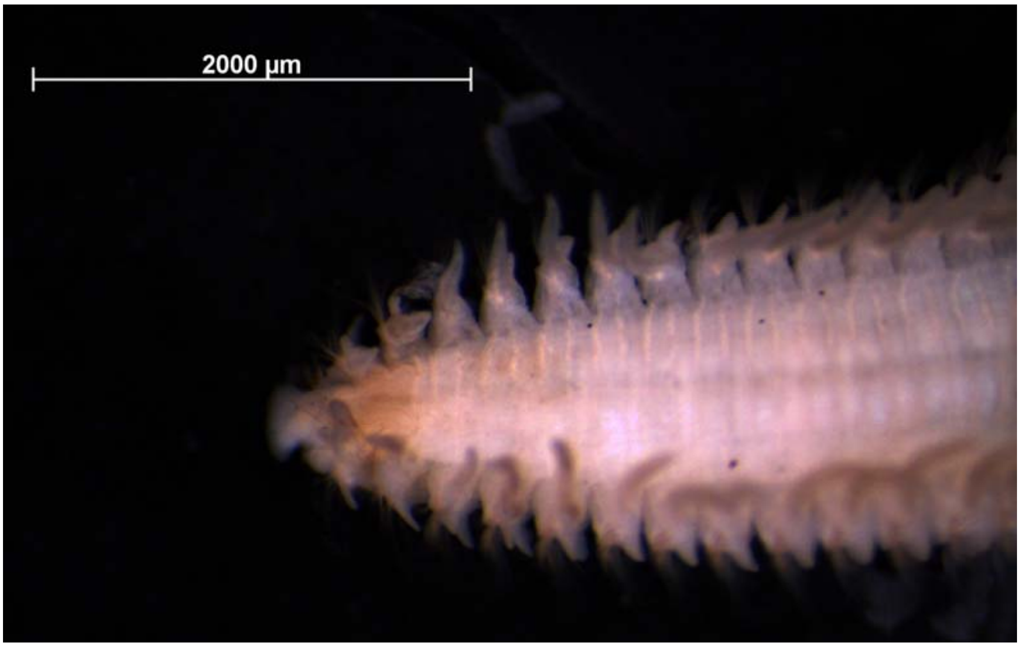

Figure 28 *Marenzelleria viridis* from Barth (Darß-Zings-Bodden-Chain)

Common name:	Red-gilled mud worm (English) (also used for *M. neglecta*)
Distribution:	The origin areas are the estuaries of the North American coast. Nowadays it exists in the United Kingdom, North Sea, and since 2005 in the Baltic Sea in 2005 (Bastrop & Blank, 2006).
Morphology:	They reach a length of 120 mm. The length of the nuchal organ can go up to setiger 2 (Fig. 28).
Ecology:	The worm lives in vertical branched and branchless tubes up to 35 cm deep. At night juvenile and adult worms rise to the Pelagial. It is a oligo- mesohaline species and tolerates 0.5 up to 18 psu (Zettler, 1996, 1997).
Nutrition:	*M. viridis* is a selectively substrate feeder.
Reproduction:	The Reproduction occurs in March to April. The larval development is entirely pelagic for 4 to 12 weeks. (Bochert, 1997)
Habitat:	The species lives in the Litoral in sandy and muddy soils.

3.4 Resemblances of the stations

For comparison of the resemblance of the stations the datasets were transformed with the fourth root. The resemblance analysis was performed on the basis of Bray Curtis. The cluster analysis was done with a complete linkage compare (Fig. 29). The comparison of stations average biodiversity shows that the three study areas cluster well together. Between two big groups can be distinguished, the more limnic and the more brackish marine stations.

As for the Warnow Estuary, the station Petridamm is apart from the other Warnow stations. The marine brackish stations Schmarl, Oldendorfer Fähre and Schnatermann are very similar, about 70 %. The station Peetzer Bach is a marine station also, but it stands out. Gehlsdorf has only a resemblance of 45 % with the other stations in its cluster. The Darß-Zingst-Bodden-Chain structures into two groups. One group consists of the stations Müggenburg, Barth, and Nisdorf, and the other one of the stations Bliesenrade, Neuendorf, and Dierhagen.

The Szczecin Lagoon divides in three clusters. One group are the stations of Achterwasser and the station Gummlin. The second is the rest of the Szczecin Lagoon and Zecherin, which represents the entrance to the Peenestrom. The last cluster summarizes Lassan and Ziemitz of the Peenestrom and the Warnow station Petridamm.

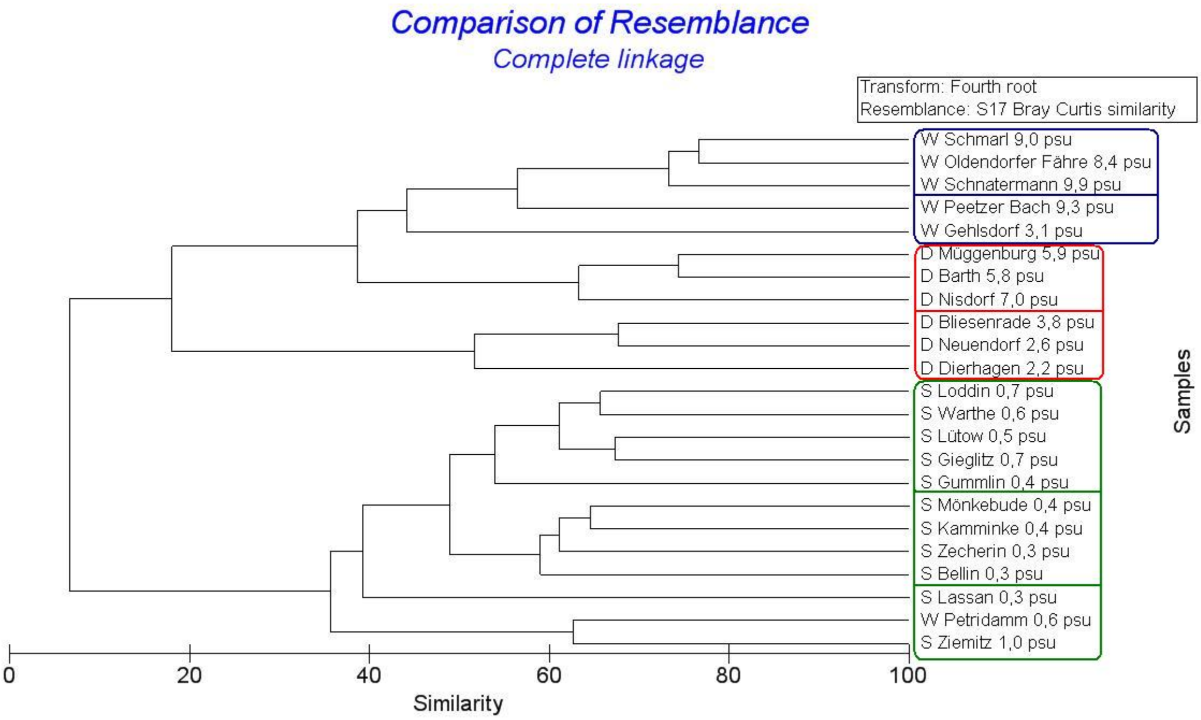

Figure 29 Comparison of all stations
In this cluster analysis the resemblance of all stations were compared. For this purpose the average of all three sampling times was taken. After every station the average salinity in psu is shown.
W – Warnow Estuary D – Darß-Zingst-Bodden-Chain S – Szczecin Lagoon

3.5 Formation of communities

For comparison of the species the datasets were transformed with the fourth root. The resemblance analysis was completed on the basis of Bray Curtis, and the cluster analysis itself was performed with a group average comparison. The diagram shows which species exist together very often or rare.

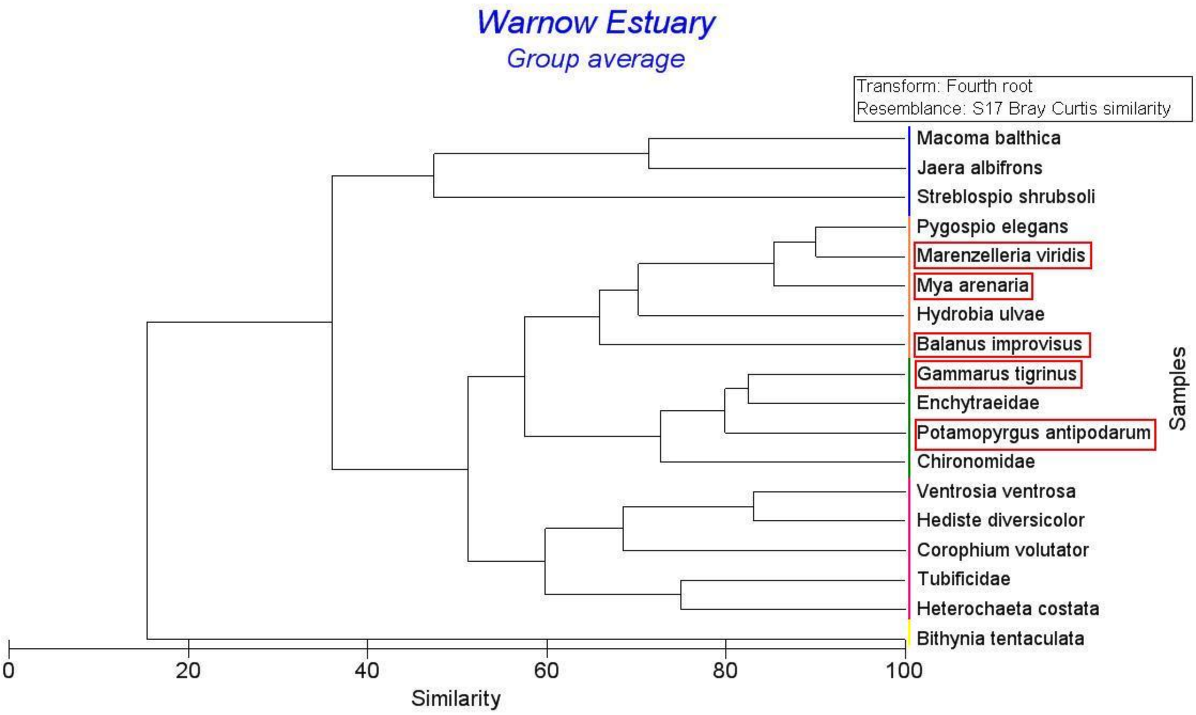

Figure 30 Analysis of specie composition of the Warnow Estuary
This cluster analysis shows, which species coexist. In this figure only species are shown, which exist in more than one station and have at least at one station an abundance with more than 100 individuals per m² in average. The alien species are framed red.

The result of the Warnow Estuary is shown in Figure 30, for a better overview the species list was shortened. To be shown in this graph the species must exist in more than one station and must have an abundance with more than 100 individuals per m² at least at one sampling site. In this cluster analysis the snail *Bithynia tentaculata* is separated from the other species. Except for this snail, all other species divide in two main groups, where one group only consist of three species, *Macoma balthica*, *Jaera albifrons*, and *Streblospio shrubsolii* (indicated in blue). The second group contains all alien species, which fulfil the imposed conditions. The group split up in three branches (shown in orange, green, and pink). Whereby, for example *Marenzelleria virids, Mya areanaria and Pygospio elegans* coexist with a relatively high probability.

In Figure 31 the result of the Darß-Zingst-Bodden-Chain is shown. For a better overview the species list was shortened. To be shown in this graph the species must exist in more than one station and must have an abundance with more than 50 individuals per m² at least at one sampling site. All of the shown species have a relatively high possibility to be found together. The cluster first splits up after a similarity of 50 %. Two main groups exist, which are divided in different branches. One group contain the two alien species *Gammarus tigrinus* and *Marenzelleria neglecta*, which fulfil the above mentioned conditions.

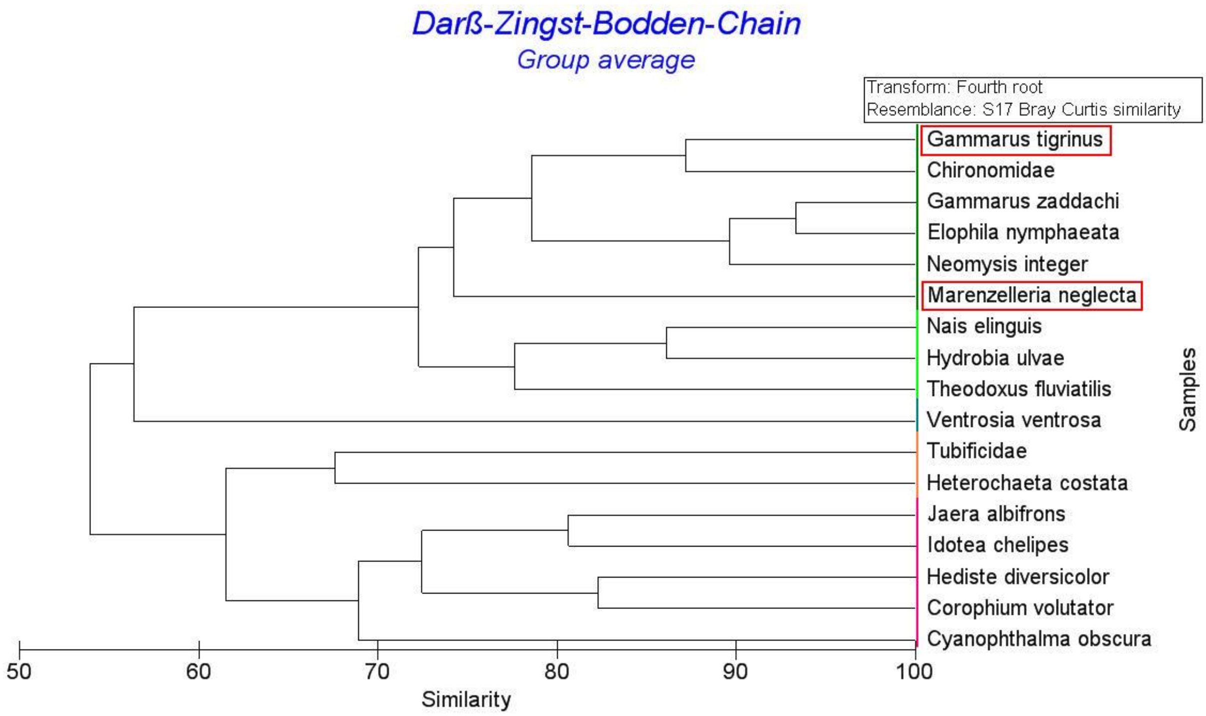

Figure 31 Analysis of specie composition of the Darß-Zingst-Bodden-Chain
This cluster analysis shows, which species coexist. In this figure only species are shown, which exist in more than one station and have at least at one station an abundance with more than 50 individuals per m² in average. The alien species are framed red.

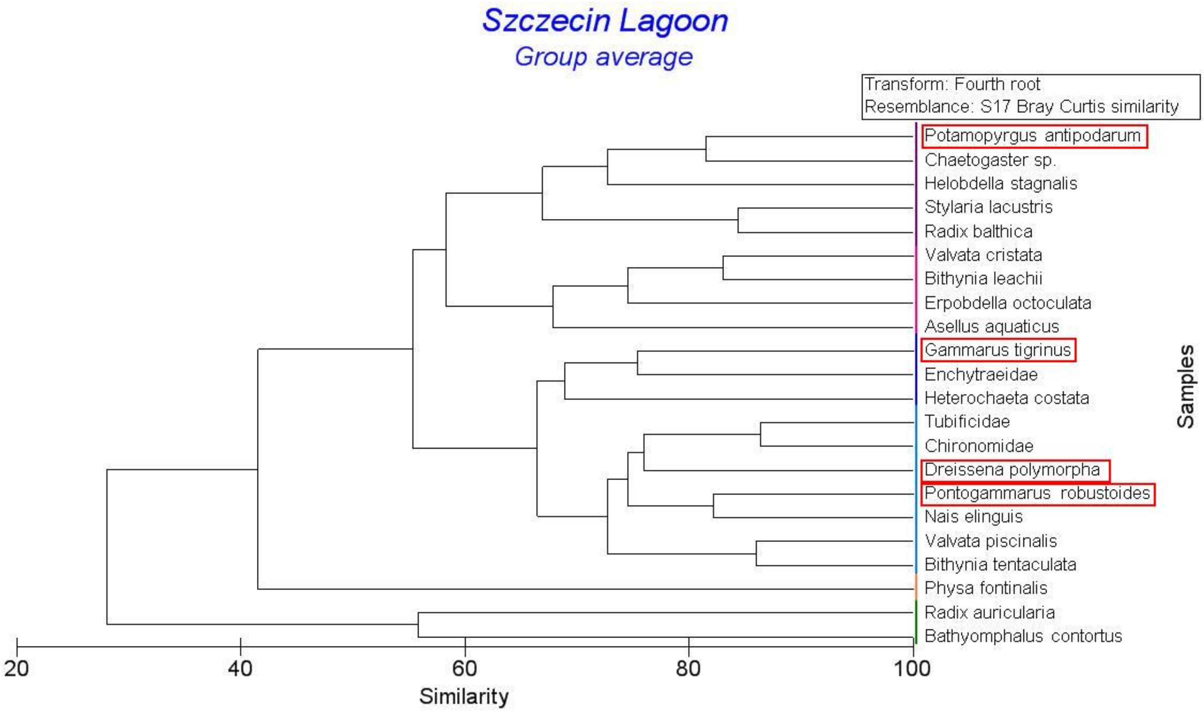

Figure 32 Analysis of specie composition of the Szczecin Lagoon
This cluster analysis shows, which species coexist. In this figure only species are shown which, exist in more than one station and have at least at one station an abundance with more than 100 individuals per m² in average. The alien species are framed red.

The result of the Szczecin Lagoon is shown in Figure 32, for a better overview the species list was shortened. To be shown in this graph the species must exist in more than one station and must have an abundance with more than 100 individuals per m² at least at one sampling site. First the snails *Bathyomphalus contortus* and *Radix baltica* separate from the main cluster, as well as *Physa fontinalis*. After that, two main branches exist. One branch consist generally of snails and leechs (shown in pink and purple), except for *Asellus aquaticus*. Both pontocaspian invaders *Dreissena polymorpha* and *Pontogammarus robustoides* group together closely in the second branch (light blue).

3.6 Assessment of the ecological status

To verify the ecological status of the study systems, the M-AMBI was calculated with the average abundance of all species through the three sampling times (Borja *et al.*, 2000; Muxika *et al.*, 2006) (see also 2.3.1). The status could not be generated for the Szczecin Lagoon, because the dominating limnic species in this area were not classified for the M-AMBI system. Adding an own classified list for this species was impossible, because of the time limitations.

As shown in Figure 33 the ecological quality of the Warnow Estuary is good on average. The Station Gehlsdorf has a good ecological quality, but has the lowest result in this area. No station reached the best status, which is level "high". From station Peetzer Bach only one sampling time could be evaluated, because in May too many species existed, which were not classified. The differences between minimum and maximum were enormous, partly the results decreased by one or two levels. The result of the station Gehlsdorf alternates the most, whereas Oldendorfer Fähre has the smallest variation.

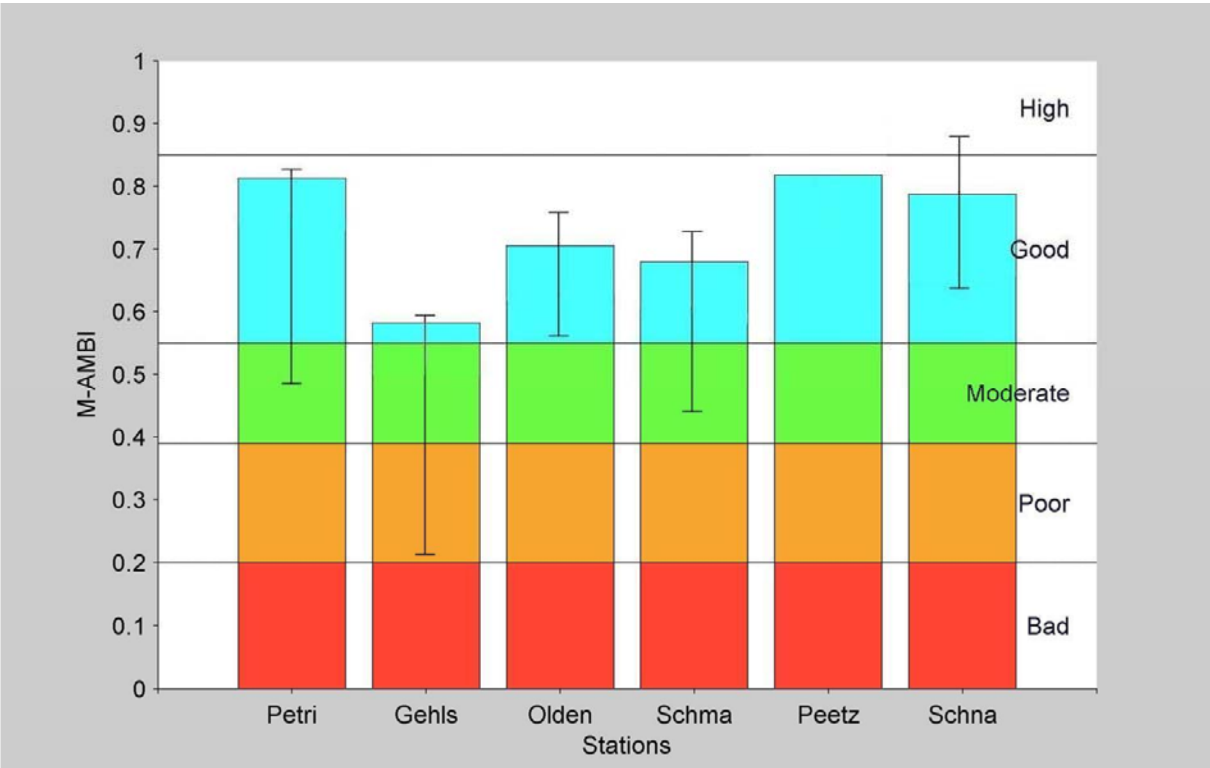

Figure 33 Ecological status of each station of the Warnow estuary by utilisation of the MAMBI-analysis
Status assessed by classifying each species to one of five ecological groups and further multivariate analysis. In this figure the average of all three sampling times is shown. The variability is indicated by error bars. The station Peetzer Bach has no error bars, because only one sampling time could be evaluated.
Petri - Petridamm Gehls - Gehlsdorf Olden - Oldendorfer Fähre Schma - Schmarl
Peetz - Peetzer Bach Schna - Schnatermann

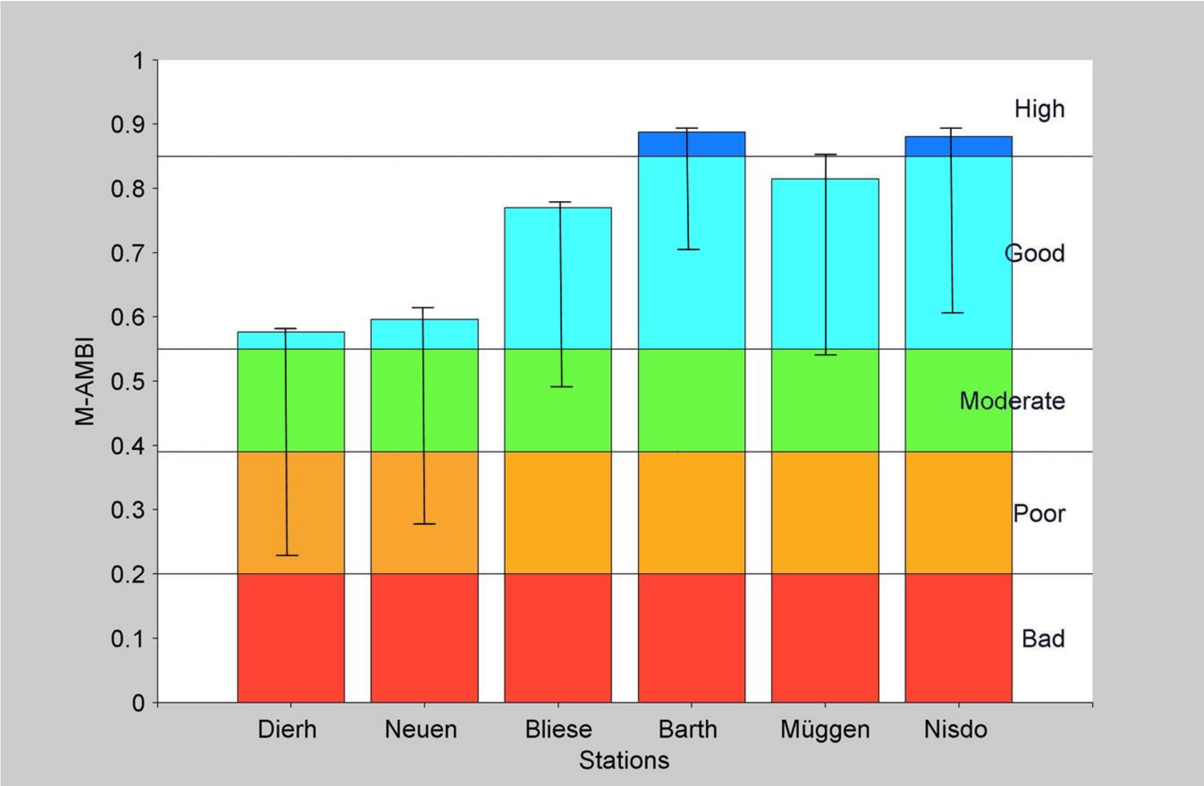

Figure 34 Ecological status of each station of the Darß-Zingst-Bodden-Chain by utilisation of the MAMBI-analysis
Status assessed by classifying each species to one of five ecological groups and further multivariate analysis. In this figure the average of all three sampling times is shown. The variability is indicated by error bars.
Dierh - Dierhagen Neuen - Neuendorf Bliese - Bliesenrade Müggen - Müggenburg
Nisdo - Nisdorf

The difference of the minimum and maximum in the Darß-Zingst-Bodden-Chain (Fig. 34) is greater than the Warnow Estuary. The results alternate, for example, at the station Dierhagen by two levels, from good to poor. The lowest variation has the station Barth. Collectively, the Bodden-Chain has a good ecological status. The highest level could be reached on two occasions (Barth, Nisdorf). The station with the lowest level is Dierhagen, the innermost station of the Bodden-Chain. It seems like the ecological status increases, the more the station gets closer to the connection to the Baltic Sea.

3.7 Evaluation of the biological pollution

To assess the impacts of the non-native species the biological pollution index from Olenin *et al.* (2007) was applied (see also 2.3.3). After the range of abundance and distribution was determined, the influence on habitat, community, and ecosystem functioning were estimated and evaluated. The result is shown in Table 10.

According to the index the Warnow Estuary has a moderate biological pollution level. The determining species are *Balanus improvisus* and *Marenzelleria viridis*, which reach a level of two, because they exist in moderate numbers in many localities, but their impact is weak. More than half of the species have no impact on the ecosystem, because they are relatively rare. Furthermore, only three species have a weak effect.

Table 10 Assessment of the three study areas with the biopollution index (Olenin *et al.*, 2007)
ADR-Class: Abundance and Distribution Range
Impact (Code): C – Community, H – Habitat, E – Ecosystem functioning
BPL: Biopollution level

Study area	Species	ADR-Class	Impact (Code)	BPL
Warnow Estuary	Balanus improvisus	C	C0, H1, E1	2
	Chelicorophium curvispinum	A	C0, H0, E0	0
	Cordylophora caspia	A	C0, H0, E0	0
	Dreissena polymorpha	A	C0, H0, E0	0
	Gammarus tigrinus	C	C1, H0, E0	1
	Marenzelleria neglecta	A	C0, H0, E0	0
	Marenzelleria viridis	C	C1, H1, E1	2
	Mya arenaria	C	C1, H0, E0	1
	Orchestia caviaman	A	C0, H0, E0	0
	Potamopyrgus anitpodarum	C	C1, H0, E0	1
	Rhithropanopeus harrisii	A	C0, H0, E0	0
Total				2 Moderate
Darß-Zingst-Bodden-Chain	Balanus improvisus	A	C0, H0, E0	0
	Cordylophora caspia	C	C0, H0, E0	1
	Gammarus tigrinus	D	C1, H1, E1	2
	Marenzelleria neglecta	D	C2, H2, E2	3
	Mya arenaria	A	C0, H0, E0	0
	Potamopyrgus antipodarum	B	C0, H0, E0	1
Total				3 Strong
Szczecin Lagoon	Chelicorophium curvispinum	A	C0, H0, E0	0
	Cordylophora caspia	B	C1, H1, E1	1
	Dikerogammarus haemobaphes	A	C0, H0, E0	0
	Dikerogammarus villosus	C	C1, H0, E0	1
	Dreissena polymorpha	C	C1, H1, E1	2
	Gammarus tigrinus	B	C0, H0, E0	1
	Limnomysis benedeni	C	C0, H0, E0	1
	Marenzelleria neglecta	A	C0, H0, E0	0
	Obesogammarus crassus	A	C0, H0, E0	0
	Orchestia cavimana	A	C0, H0, E0	0
	Pontogammarus robustoides	C	C1, H0, E0	1
	Potamopyrgus antipodarum	B	C0, H0, E0	1
	Proasellus coxales	A	C0, H0, E0	0
Total				2 Moderate

The Darß-Zingst-Bodden-Chain, with the lowest diversity of alien species has the highest pollution of all three study areas. Especially the influence of the species *Marenzelleria neglecta* is significant and results in a strong pollution. The other species have hardly any or only weak effects except for *Gammarus tigrinus.*

The moderate pollution of the Szczecin Lagoon is affected through the high abundance of *Dreissena polymorpha* and its consequences. Here also, by half of the species have no considerable effects on the system. The other species have only a weak impact level and result in biological pollution level one.

4. Discussion

4.1 Methods criticism

Sample-taking

It might be necessary that the number of sediment cores per station must be increased for more correct results. Furthermore, a tighter station network, which covers every possible habitat, will be a benefit. In this case the water body itself should be sampled in increased depth, for example by boat. It would be an advantage if the haul with the landing net could be completed in a quantitative way, for example every time a defined transect with known surface could be sampled.

M-AMBI

The results alternate heavily. A reason could be that three parallels are not enough. Possibly in some stations the sampled areas via sediment corer are insufficient, because of a low density of species. The index was developed for impacts of abiotic factors like organic matter input. That is the reason why it probably does not react on aquatic alien species. So it is not an adequate tool for evaluating alien species. Under special circumstances it could be useful as an early warning system, because a bad ecological status of a water system affects the native ecosystem and can make it prone for stress. That could result in a lower competitive power of the native species and make it easier for alien species to establish. So areas with a high potential to be invaded like harbors could use this tool to assess their status and locate presumable problem areas. If these areas threaten to a better status, the native species have a higher chance to hold down the invader.

Biological pollution index

The index is probable for every area practical, but needs a lot of data and especially the evaluation of the impact of the species requires a lot of experience. Many ratings are very subjective and make a comparison with other assessed areas difficult. Partly for some areas it would be difficult to get enough historical data to estimate the effect on native species or their extinction. Another problem is, what it has with most indices in common, that the impact of species can only be assumed if it has a long and stable establishment. New species will have always a small effect and no predictions are possible. A general aspect is that it assesses all effects of alien species as negative. For positive changes by an invading species no formula exists. For example an invaded ecological engineer could be a benefit for an area. In addition, *Marenzelleria neglecta* could loosen and aerate the soil and make it easier for other species to settle in this area. So the invading of this species would be a benefit for the area. An advantage of this index is that it is directly comprehensible, which species leads to the "problem". In this way arrangements can be adapted to the invading species and its vectors.

4.2 The assessed areas

Warnow Estuary

In the Warnow Estuary 80 different species were found. Among them are 11 alien species from 7 different orders, the majority of the invading species has their origin in North America. In average a stations holds 6 aliens species and 28 native species. The majority of the sampling sites only have a small percentage of alien species, the amount varies from 1 to 3 %. A reason for the low percentage could be the strength of the natural community against species competition and the good ecological status. An exception is the station Peetzer Bach with 29 % non-native species, which only contain 5 different species. The composition of the alien and native species changes with the course of the area. A reason is the salinity gradient. Consequently the station Petridamm with its low salinity, nearly freshwater characteristics, has a different species composition compared to the other marine stations. For example the snail *Bithynia tentaculata* or the invader *Dreissena polymorpha* only exist at this station. Another outstanding station is Peetzer Bach. Probably because of its special habitat (turf) and the frequent ship traffic in this area, the species composition is different to the other more marine influenced stations. The location, close to the commercial harbor, may be a reason for the high percentage of non-indigenous species. The invaded species adapted to the natural community. So for example the invaders *Marenzelleria viridis*, *Mya arenaira* and the native polychaete *Pygospio elegans* coexist as a soft bottom community. But the mussels *Mya arenaria* and *Macoma balthica* do not exist together. Studies indicated that there are interspecific interactions causing a decreasing abundance of *M. balthica* were *M. arenaria* reaches high numbers (Obolewski & Piesik, 2005). Nevertheless the non-native species have a moderate impact on the native species.

Darß-Zingst-Bodden-Chain

The Darß-Zingst-Bodden-Chain has the lowest number of species of all three assessed areas (55), a probable reason could be the low salinity of 2-7 psu. The critical salinity of 5-8 psu is called “horohalinicum”. It is the range where limnic species could not exist, but the salinity is too low for most of the marine species (Remane, 1934). The biodiversity of the area contains 6 alien species of 6 different orders. At a station 4 alien species and 25 native species exist averagely. The percentage of the invaded species varies from 9 to 71 %, apparently the number of non-native species decreases with increasing salinity. The alien species have a strong impact on the native community. Such a great impact has the species *Marenzelleria neglecta*. In most sampling sites it has the highest number of individuals of all polychaetes. The only comparable worm is *Hediste diversicolor*, but this species has only a low abundance. Studies proved that *M. neglecta* has a negative influence on *H. diversicolor* and a competition occurs between this two species (Kotta et al. 2004). The majority of the invaders are originally from North America, so presumably the influence of the Warnow Estuary is higher than the Szczecin Lagoon. It looks like the alien species of the Warnow Estuary spread throw the Bodden-Chain, whereas the non-native species of the Lagoon do not migrated to this point. A reason could be that the Darß-Zingst-Bodden-Chain has no big freshwater areas. Most of the invaders of the Szczecin Lagoon prefer limnic habitats. Regarding the species composition the area can be distinguished between more marine influenced stations Müggenburg, Barth and Nisdorf and the more limnic-brackish influenced Bliesenrade, Neuendorf and Dierhagen. This division matches with differences in salinity and geographical location. So are Müggenburg, Barth and Nisdorf mesohaline stations and the other three oligohaline. Despite the low possibilities of the water exchange with the Baltic Sea and the high pollution with nutrients, the Bodden-Chain has a good ecological status.

Szczecin Lagoon

The Szczecin Lagoon inhabits 90 different species, whereby 13 species of 7 orders are non-native. Most of the stations are occupied by 7 alien species and 35 native species on average. Three stations only have a low percentage of alien species of 0.3-3 % (Gieglitz, Lassan, Kamminke), but most stations have a higher percentage between 10 % and 42 %. The invaded Amphipoda makes almost 100% of the total amphipods diversity, probably because native amphipods cannot tolerate the low salinity of this area. The majority of the alien species have their origin in the pontocaspian region. The cluster analysis of stations (see 3.4) approximates that the three hydrological components (Szczecin Lagoon, Peenestrom, Achterwasser) of this study area are different regarding their species composition. The impact of the alien species on the native community is moderate. The highest impact has the mussel *Dreissena polymorpha*, this species is a boon and bane at the same time. On one hand it builds a habitat for many Oligochaeta or snails, in so doing it increases the biodiversity (for example shown in Fenske, 2003), but on the other hand native mussels, belonging to the genera *Unio* or *Anodonta,* are co-oped by the zebra mussel as hard substrate. That way the other mussels are effectively starved, because *D. polymorpha* disturb the filter feeding (Böhmer *et al.*, 2001).

4.3 Future challenges

To get the situation under control, easy and comparable measurements and indices to assess biological invaders are needed. Regular monitoring to notice changes in the ecological status and species-richness play an important role by controlling the invaders. Then quick actions are possible. Therefore it will be necessary to work together globally, to profit from other countries experiences. With such a global network neighbouring countries could not only learn, but also warn each other early if new species spread. In most cases invaded species could not be removed. The only way is to limit their vectors and strengthen the native ecosystems. Therefore global arrangements are necessary, for example the handling with ballast water must be regulated. To achieve this goal, global laws and agreements must be developed and the execution of them must be controlled. Furthermore, it will be important to strengthen the native ecosystems by obtaining a good ecological status or better, therefor extensive monitoring must be undertaken and corresponding measures like renaturation has to be initiated. For this purpose it is essential to make people and governments to be aware of this problem and to understand the vital necessity to react.

5. References

Appeltans W, Bouchet P, Boxshall GA, Fauchald K, Gordon DP, Hoeksema BW, Poore GCB, van Soest RWM, Stöhr S, Walter TC, Costello MJ. (eds), 2011. World Register of Marine Species. Accessed at http://www.marinespecies.org on 2011-09-09

Arndt E.A., 1989. Ecological, physiological and historical aspects of brackish water fauna distribution. In: Ryland J.S. & P.A.Tyler (Eds). Proc. 23th European Marine Biology Symposium. Olsen&Olsen, Fredensborg, Denmark: p. 327-338

Bącela K., Konopacka A., Grabowski M., 2009. *Reproductive biology of Dikerogammarus haemobaphes: an invasive gammarid (Crustacea:Amphipoda) colonizing running waters in Central Europe*. Biol. Invasions 11 (9): p. 2055–2066

Bastrop R., Blank M., 2006. Multiple invasions - a polychaete genus enters the Baltic Sea. Biological Invasions, 8 (5): p. 1195-1200

Berezina, N. A., Panov, V. E., 2003. Establishment of new gammarid species in the eastern Gulf of Finnland (Baltic Sea) and their effects on littoral communities. Proceedings of the Estonian Academy of Sciences, Biology and Ecology 52 (3): p. 284-304

Bick A., Burckhardt R., 1989. Erstnachweis von Marenzelleria viridis (Polychaeta, Spionidae) fur den Ostseeraum, mit einem Bestimmungsschlussel der Spioniden der Ostsee. Mitteilungen des Zoologischen Museums Berlin, 65: p. 237-247

Bochert, R., 1997. *Marenzelleria viridis* (Polychaeta: Spionidae): a review of its reproduction. Aquatic Ecology 31: p. 163-175

Böhmer, H.J., Heger, T., Trepl, L., 2001. Fallstudien zu gebietsfremden Arten in Germanland – Case sudieds on Alien Species in Germany. – Texte des Umwelbundesamtes 2001 (13): 126 pp.

Borja, A., Franco, J., Pérez, V., 2000. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. *Marine Pollution Bulletin*, 40 (12): p. 1100-1114

Bulnheim, H.P., 1976. Gammarus tigrinus, ein neues Faunenelement der Ostseeforde Schlei. Schr. Naturw. Ver. Schlesw.-Holst., 46: p. 79-84

Clarke, KR, Gorley, RN, 2006. PRIMER v6: User Manual/Tutorial. *PRIMER-E*, Plymouth

Devin, S., Beisel, J.-N.,2006. *Dikerogammarus villosus*. In Delivering Alien Invasive Species Inventories for Europe. Accessed at http://www.europe-aliens.org/pdf/ Dikerogammarus_villosus.pdf on 2011-09-09

Didžiulis, V., 2006. NOBANIS – Invasive Alien Species Fact Sheet – *Marenzelleria neglecta.* – From: Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS. Accessed at www.nobanis.org on 2011-09-13

Eggers, T. O., Martens, A., 2001. Bestimmungsschlüssel der Süßwasser-Amphipoda (Crustacea) Germanlands. *Lauterbornia*, 42: p. 1-68

Elliott, M., 2003. Biological pollutants and biological pollution – an increasing cause of concern. Marine Pollution Bulletin 46: p. 275-280

European Parliament and Council, 2008. DIRECTIVE 2008/56/EC. establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) Official Journal of the European Union 164: p. 19-40

Ezhova E., Zmudzinski L. and Maciejewska K., 2005. Long-term trends in the macrozoobenthos of the Vistula Lagoon, southeastern Baltic Sea. Species composition and biomass distribution. Bulletin of the Sea Fisheries and biomass distribution. Bulletin of the Sea Fisheries Institute, 1 (164): p. 55-73

Fenske, C., 2003. Die Wandermuschel (Dreissena polymorpha) im Oderhaff und ihre Bedeutung für das Küstenzonenmanagement. Inauguraldissertation, Ernst-Mortiz-Arndt Universität Greifswald: 43 pp.

Gasiunas I., 1964. Acclimatisation of forage crustaceans into the Kaunas waterpower plant reservoir and possibility of their migration into other waters of Lithuania [Aklimatizacija kormovykh rakoobraznykh v vodokhranilische Kaunasskoj GES i vozmozhnost ikh migracii v drugije vodojemy Litvy. Trudy Ak.Nauk Lit.SSR, Serija B, 1 (30)

Gergs, R., Hanselmann, A.J., Eisele, I. & Rothhaupt, K.-O., 2008. Autecology of *Limnomysis benedeni* Czerniavsky, 1882 (Crustacea: Mysida) in Lake Constance, Southwestern Germany. Limnologica 38 (2): p. 139-146

Gislen T., 1950. On the invasion and distribution of *Balanus improvisus* along the Swedish coasts. Fauna och Flora, 45: p. 32-37

Grabowski, M.., 2006. NOBANIS – Invasive Alien Species Fact Sheet – *Pontogammarus robustoides*. – From: Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS Accessed at www.nobanis.org on 2011-09-23

Grabowski M., Jażdżewski K., Konopacka A., 2007. Alien Crustacea in Polish Waters – Amphipoda. *Aquatic Invasions* 2 (1): p. 25-38

Gruner, H.-E. ,1965. Krebstiere oder Crustacea. V: Isopoda. – In: DAHL, F. (Hrsg.), Die Tierwelt Germanlands und der angrenzenden Meeresteile nach ihren Merkmalen und nach ihrer Lebensweise, Teil 51 und 53. Verlag G. Fischer, Jena: 380 pp.

Gruszka, P., 1999. The river Odra estuary as a gateway for alien species immigration to the Baltic Sea Basin. Acta hydrochimica et hydrobiologica, 27 (5): p. 374-382

Hayward, P.J., Ryland, J.S.,1990. The Marine Fauna of the British Isles and North-West Europe. Oxford University Press Inc, New York: 119-120: p. 547-549

Hessland I., 1946. On the Quaternary Mya period in Europe. Arkiv for Zoologi, 37A (8): p. 1-51

IUCN, 1999. IUCN guidelines for the prevention of biodiversity loss duet biological invasions. Newsletter of the Species Survival Commission

Jagnow, B., Gosselck, F., 1987. Bestimmungschlüssel für die Gehäuseschnecken und Muschel der Ostsee. Mitt. Zool. Mus. Berlin 63: p. 191-268

Jazdzewski K., Konopacka A., 2002. Invasive Ponto-Caspian species in waters of the Vistula and Oder Basins and the Southern Baltic Sea. In: Leppakoski E., Gollasch S. and Olenin S.(eds), Invasive Aquatic species of Europe - distribution impacts and management. Kluwer Academic Publishers, Dordrecht, Boston, London: p. 384-398

Jazdzewski K., Konopacka A., Grabowski M., 2004. Recent drastic changes in the gammarid fauna (Crustacea, Amphipoda) of the Vistula River deltaic system in Poland caused by alien invaders. Diversity and Distributions, 10: p. 81-87

Keith, D. E, 2006. Harris mud crab. Tarleton State University. Accessed at http://www. frammandearter.se /0/2english/pdf/Rhithropanopeus_harrisii.pdf on 2011-09-13

Kinzelbach, R., 1972. Zur Verbreitung und Ökologie des Süßwasser-Strandflohs *Orchestia cavimana* Heller, 1865 (Crustacea: Amphipoda: Talitridae). Bonner zoologischer Beitrag 23 (3): p. 267-282

Koop, J., Pörtner, H.O., Grieshaber, M.K., 1990. Verbreitungsbestimmende Aspekte der Ionenregulation von *Gammarus tigrinus* (Sexton) in salzbelasteten Fließgewässern (Werra, Weser Rhein). German. Gesell. Limnol. (Hrsg.), Erweiterte Zusammenfassung der Jahrestagung 1990 in Essen. DGL: p. 387-392

Kothé, P. 1973. Die Verbreitung des Makrozoobenthos im Nord-Ostsee-Kanal und ihre Abhängigkeit vom Salzgehalt. II. Organismenverbreitung und biologische Indikation des Seewassereinflusses. Dt. Gewässerkund. Mitt. 17: p. 21-26

Kotta, J., Orav-Kotta, H., Sandberg-Kilpi, E., 2004. Changes in the feeding behaviour of benthic invertebrates: effect of the introduced polychaete *Marenzelleria viridis* on the Baltic calm *Macoma balthica*. Proc. Estonian Acad. Sci. Biol. Ecol. 53: p. 269-275

Leppäkoski, E., Gollash, S., Olenin, S. (eds.), 2002. Invasive Aquatic Species of Europe. Distirbution, Impacts and Management. Kluwer Academic Publishers: p. 66-75; 183-192; 253-259

Lincoln, R.J.,1979. British marine Amphipoda: Gammaridea. British Museum (Natural History). London: p. 254, 658

Muxika, I., Á. Borja and J. Bald, 2006. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. *Marine Pollution Bulletin,* 55: p. 16-29

Nehring, S., Leuchs, H., 1999. Neozoa (Makrozoobenthos) an der Germanen Nordseeküste: Eine Übersicht. Bundesanstalt für Gewässerkunde, Koblenz, BfG-1200

Nehring, S., 2001. Estuaries as a habitat: On the status of introduced macro invertebrates on the German North and Baltic Sea coast. – In: Secretariat of the Convention on Biological Diversity (Hrsg.), Assessment and Management of Alien Species that threaten Ecosystems, Habitats and Species. CBD Technical Series no. 1: p. 55-57

Nehring, S., 2002. Estuaries: The habitat for alien macro invertebrates in German coastal waters. Aliens 15: p. 14-15

Nikolaev I.I., 1951. On new introductions in fauna and flora of the North and the Baltic Seas from distant areas [O novyh vselencach v faune i flore Severnogo morja i Baltici iz otdalennyh rajonov]. Zoologicheskij Zhurnal., 30: p. 556-561

Obolewski, K., Piesik, Z., 2005. *Mya arenaria* (L.) in the Polish Baltic Sea coast. Baltic Coastal Zone 9: p. 13-27

Olenin, S., 2006. *Balanus improvisus* Darwin, 1854. In: Delivering Alien Invasive Species Inventories for Europe. Accessed at http://www.europealiens.org/pdf/Balanus_ improvisus.pdf on 2011-09-09

Olenin, S.,2006. *Cordylophora caspia* (Pallas, 1766) In: Delivering Alien Invasive Species Inventories for Europe. Acessed at http://www.europe-aliens.org/pdf/ Cordylophora_ caspia.pdf on 2011-13-09

Olenin, S., Minchin, D., Daunys, D., 2007. Assessment of biological pollution in aquatic ecosystems. *Marine Pollution Bulletin* 55: p. 379-394.

Pinkster, S., 1975. the introduction of the alien Amphipod Gammarus tigrinus Sexton, 1939 (Crustacea, Amphipoda) in the Netherlands and its competition with indigenous species. Hydrobiol. Bull. 9: p. 131-138

Remane, A., 1934. Die Brackwasserfauna. Zool. Anz. (Suppl.) 7: p. 34-74

Reinhold, M., Tittizier, T., 1997. Zur Rolle von Schiffen als Vektoren beim Faunenaustausch Rhein/Main/Main-Donau-Kanal/Donau. Dt. Gewässerkund. Mitt. 41: p. 199-205

Sikorski, A.V., Bick, A., 2004. Revision of Marenzelleria Mesnil, 1896 (Spionidae, Polychaeta). SARSIA vol 89 (4): p. 253-275

Schlesch H., 1937. Bemerkungen uber die Verbreitung der Susswasser- und Meeresmollusken im ostlichen Ostseegebiete. Tartu Loodusuurijate Seltsi Aruanded, 43: p. 37-64

Tittizier, T., 1996. Vorkommen und Ausbreitung aquatischer Neozoen (Makrozoobenthos) in den Bundeswasserstraßen. In: Gebhardt, H., Kinzelbach, R., Schmidt-Fischer, S. (Hrsg.). Gebietsfremde Tierarten. Ecomed, Landsberg: p. 49-86

Tyler-Walters, H., 2003. *Mya arenaria*. Sand gaper. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Accessed at http://www.marlin.ac.uk/speciesinformation.php?speciesID=3839 on 2011-09-18

Willmann, R., 1989. Muscheln und Schnecken der Nord- und Ostsee. Neumann-Neudamm, Melsungen: 310 pp.

Zaiko, A., 2005. Balanus improvisus. In: Baltic Sea Alien Species Database. Olenin,S., Leppakoski, E. and Daunys, D. (eds.). Accessed at http://www.corpi.ku.lt/nemo/mainnemo.html on 2011-09-09

Zaiko, A.,Olenin, S., 2006. *Dreissena polymorpha* (Pallas, 1771). In: Delivering Alien Invasive Species Inventories for Europe. Accessed at http://www.europe-aliens.org/pdf/Dreissena_polymorpha.pdf on 2011-09-12

Zettler, M.L., Bochert, R., Bick, A., 1994. Röhrenbau und Vertikalverteilung von *Marenzelleria viridis* (Polychaeta: Spionidae) in einem Küstengewässer der südlichen Ostsee. Rostocker Meeresbiologische Beiträge 1994 (2): p. 215-225

Zettler, M.L., 1996. Ökologische Untersuchungen am Neozoon *Marenzelleria viridis* (Verrill, 1873) (Polychaeta: Spionidae) in einem Küstengewässer der südlichen Ostsee. PhD Thesis, University of Rostock: 149 pp.

Zettler, M.L., 1997 Population dynamics, growth and production of the neozoon M*arenzelleria viridis* (Verrill, 1873) (Polychaeta: Spionidae) in the southern Baltic Sea. Aquatic Ecoglogy 31: p. 177-186

6. Appendix

6.1 Materials

In the following all used materials, chemicals and appliances are listed.

Appliances: Conductivity meter

ProfiLine Cond 1970i Waterproof Conductivity Meters

Conductivity: 0.0 uS/cm to 500 mS/cm in 5 measuring ranges or autorange, 0.00 uS/cm to 19.99 uS/cm (for K=0.1 cm^{-1}), 0.000 uS/cm to 1.999 uS/cm (for K=0.01 cm^{-1})

Temp: 23 to 221 Â°F (-5.0 to +105.0 Â°C)

Salinity: 0.0 to 70.0

TDS: 0 to1999 mg/l

Accuracy: *Conductivity:* $\pm$ 0.5% of value

Temperature: $\pm$ 0.1 K

Sediment corer:

IOW

Ø 100 mm x 500 mm length

weight: 2 kg

surface: 78,5 cm^2

Landing net:

IOW

length: 240 cm

weight: 1 kg

mesh size: 1 mm

Stake scraper:

IOW

length: 160 cm

mesh size: 0,5 mm

Hand sieve:

IOW

Ø 180 mm

weight: 0,2 kg

mesh size: 1 mm

Kautex bottles:

Omnilab

1 litre

Microscope:

M3Z Discussion Stereomicroscope

Stand: Wild Typ 439168

Crossbar: Wild Typ 479887

Lens: Wild M3Z

Eyepiece Base: Leica

Eyepiece: Wild 10x/21B 445111

Zoom Range: 8x to 80x

ZEISS Microscope Axio Lab.A1

ZEISS SteREO Dicsovery.V8

Light source:

ZEISS CL 1500 ECO

Schott KL 2500 LCD

Camera

AxioCam ICc3

resolution: 2028 x 1540 pixels

Forcep set

Laboratory trays

pan of sort

Software:

AxioVision:

version 4.8.2.0

AMBI:

version 4.1

species list of February 2010

Primer:

version 6

Chemicals: Formol 35% aqueous solution:

VWR International GmbH

902409010

Methylene blue:

Merck KGaA

159270

Ethanol 95% (v/v) denaturated TECHNICAL:

VWR International GmbH

20827.412

6.2 Data sets

The used datasets are stored on the enclosed electronic storage media at the end of this paper. Only the IOW database is missing, because of legal reasons. In Table 11 a summary of the recorded species is listed.

Table 11 All recorded species are ordered by their group and assigned to the recorded region
WE – Warnow Estuary DZBC – Darß-Zingst-Bodden-Chain SL – Szczecin Lagoon

Group	Species	Study area
Amphipoda	*Apocorophium lacustre*	WE
	Calliopius laeviusculus	WE
	Chelicorophium curvispinum	SL WE
	Corophium volutator	DZBC WE
	Dikerogammarus haemobaphes	SL
	Dikerogammarus villosus	SL
	Gammarus duebeni	DZBC SL WE
	Gammarus locusta	WE
	Gammarus oceanicus	DZBC WE
	Gammarus salinus	DZBC WE
	Gammarus tigrinus	DZBC SL WE
	Gammarus zaddachi	DZBC WE
	Leptocheirus pilosus	WE
	Melita palmata	WE
	Microdeutopus gryllotalpa	WE
	Monocorophium insidiosum	WE
	Obesogammarus crassus	SL
	Orchestia cavimana *Pontogammarus robustoides*	SL WE SL
Arachnida	*Halacaridae*	SL
Bivalvia	*Anodonta anatina*	SL
	Cerastoderma glaucum	DZBC

Group	Species	Study area
Bivalvia	*Cerastoderma glaucum*	WE
	Dreissena polymorpha	SL WE
	Macoma balthica	WE
	Musculium lacustre	WE
	Mya arenaria	DZBC WE
	Mytilus edulis	DZBC WE
	Pisidium nitidum	SL WE
	Pisidium ponderosum	SL
	Unio tumidus	SL
Branchiura	*Argulus foliaceus*	WE
Bryozoa	*Einhornia crustulenta*	DZBC WE
Cirripedia	*Balanus improvisus*	DZBC WE
Coleoptera	*Peltodytes caesus*	DZBC SL
Decapoda	*Crangon crangon*	WE
	Palaemon adspersus	WE
	Palaemon elegans	DZBC WE
	Palaemonetes varians	DZBC
	Rhithropanopeus harrisii	WE
Diptera	*Chironomidae*	DZBC SL WE
	Sialida	DZBC
	Simuliidae	SL
Ephemeroptera	*Ephemeroptera*	SL WE
Gastropoda	*Acroloxus lacustris*	SL
	Anisus vortex	SL
	Bathyomphalus contortus	SL
	Bithynia leachii	DZBC SL WE
	Bithynia tentaculata	DZBC SL WE
	Bithynia troschelii	SL

Group	Species	Study area
Gastropoda	*Hippeutis complanatus*	SL
	Hydrobia ulvae	DZBC SL WE
	Littorina littorea	WE
	Littorina saxatilis	WE
	Lymnaea stagnalis	DZBC SL
	Physa fontinalis	DZBC SL
	Planorbarius corneus	SL
	Planorbis planorbis	SL WE
	Planorbis carinatus	SL
	Potamopyrgus antipodarum	DZBC SL WE
	Radix auricularia	DZBC SL
	Radix balthica	DZBC SL WE
	Stagnicola palustris	DZBC SL
	Theodoxus fluviatilis	DZBC SL
	Valvata cristata	SL WE
	Valvata piscinalis	DZBC SL WE
	Ventrosia ventrosa	DZBC SL WE
	Viviparus contectus	SL
	Viviparus viviparus	SL
Hemiptera	*Nepa cinerea*	WE
Hirudinea	*Alboglossiphonia heteroclita*	SL
	Alboglossiphonia hyalina	SL
	Alboglossiphonia striata	SL
	Dina lineata	SL WE
	Erpobdella monostriata	SL
	Erpobdella nigricollis	SL

Group	Species	Study area
Hirudinea	*Erpobdella octoculata*	SL WE
	Erpobdella sp. (juv./embry.)	SL
	Erpobdella testacea	SL WE
	Glossiphonia complanata	SL
	Glossiphonia concolor	SL
	Glossiphonia sp. (juv./embry.)	SL
	Haemopis sanguisuga	SL
	Helobdella stagnalis	DZBC SL WE
	Pawlowskiella cf. stenosa	SL
	Pawlowskiella stenosa	DZBC SL
	Piscicola cf. annae	SL
	Piscicola geometra	DZBC SL
	Piscicola sp.	DZBC SL WE
Hydrozoa	*Cordylophora caspia*	DZBC SL WE
	Hartlaubella gelatinosa	WE
	Hydra oligactis	SL WE
	Hydra sp.	DZBC SL WE
Isopoda	*Asellus aquaticus*	DZBC SL WE
	Cyathura carinata	WE
	Idotea balthica	WE
	Idotea chelipes	DZBC WE
	Jaera albifrons	DZBC SL WE
	Lekanesphaera hookeri	DZBC WE
	Proasellus coxales	SL
Lepidoptera	*Elophila nymphaeata*	DZBC

Group	Species	Study area
Lepidoptera	*Elophila nymphaeata*	SL
Mysida	*Limnomysis benedeni*	SL
	Neomysis integer	DZBC SL WE
	Praunus flexuosus	DZBC WE
Nemertea	*Cyanophthalma obscura*	DZBC SL WE
Odonata	*Odonata*	DZBC SL WE
Oligochaeta	*Chaetogaster sp.*	DZBC SL WE
	Eiseniella tetraeda	SL
	Enchytraeidae	DZBC SL WE
	Heterochaeta costata	DZBC SL WE
	Nais elinguis	DZBC SL WE
	Paranais litoralis	DZBC SL WE
	Stylaria lacustris	DZBC SL WE
	Tubificidae	DZBC SL WE
Plathelminthes	*Turbellaria*	DZBC SL WE
Polychaeta	*Alitta succinea*	WE
	Fabricia stellaris	DZBC SL
	Hediste diversicolor	DZBC WE
	Marenzelleria neglecta	DZBC

Group	**Species**	**Study area**
Polychaeta	*Marenzelleria neglecta*	SL WE
	Marenzelleria viridis	WE
	Pygospio elegans	WE
	Streblospio shrubsoli	WE
Tanaidacea	*Heterotanais oerstedii*	WE
Trichoptera	*Agrypnia pagetana*	SL
	Cyrnus crenaticornis	SL
	Leptoceridae	DZBC SL WE
	Limnephilus rhombicus	WE
	Mystacides azurea	SL
	Mystacides nigra	SL
	Oecetis lacustris	SL WE
	Oecetis ochracea	SL
	Trichoptera	SL WE

Acknowledgments

I would particularly like to thank Dr. Michael L. Zettler for the provision of the topic of my thesis, the kind support, and the various tips for the success of this work. Also, I want to express my gratitude towards Dr. Wolfgang Wranik for assumption of the evaluation of my thesis, the auxiliary consultations, and helpful criticism of my paper.

Furthermore, I would like to thank Mr. Uwe Jueg for the identification of the leeches and Frank Wolf for his help with the classification of the butterfly larvae. In addition, I want to thank Dr. Ralf Bochert for the identification of the Trichoptera larvae and the encouraging backing. My heartfelt thanks go to my three „Labormäuse“ Ines Glockzin, Nadine Keiser and Jeanette Harder. I would not have accomplished the evaluation of the samples without them. Thank you for all the cherish conversations and heartened words. You embellished my work and day, with so much fun. But I also want to thank Frank Pohl for his energetic assistance on sample taking, for the sufficient cake breaks, and the laughs here and there. Alexander Darr, I am grateful for your introduction in the world of Primer.

Moreover, I like to express my gratitude to Dr. Stefan Nehring for his permission to use his figure. In addition, I want to thank Kevin Nowlin for helping me with the complicated English language. Tobias Lipsewers, I thank you for all the funny coffee breaks, lunch conversations, and your physically taxing assistance by gathering the barnacles.

Most important, with my whole heart, I want to thank my family and my beloved partner in life. I have not come so far without you. I thank you, for all your support and that you always are on my side if I need you. Thank you for your morally and mental relief, for your admonitory words in due times, for backing me up and sharing my thrills. This is also your merit and success. Thank you!

Declaration of academic honesty

Hereby I confirm, that the present paper is independent composed by me and no other resources are used, then the listed ones. I acknowledge that the paper is not submitted in another examination procedure. The written composure conforms to the one on the electronic storage media.

Anne Wittfoth Rostock, 12^{th} October 2011