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HERRING Impact Report

Herring spawning areas - present and future challenges

D. Fey, A. Hiller, P. Margonski, D. Moll, H. Nilsson, L. Pongolini, N. Stybel & L. Szymanek

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More information about HERRING can be found on the project website: www.baltic-herring.eu.

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- HERRING -

Joint cross-border actions for the sustainable management of a natural resource

Impact Report

Herring spawning areas - present and future challenges

Content

1. Baltic herring

Baltic herring (*Clupea harengus* (L., 1761) is one of the most important species in the Baltic Sea ecosystem and its fisheries (Rajasilta et al. 2006). Thanks to its ability to adapt to a wide range of water salinity, it inhabits and successfully reproduces throughout nearly the entire Baltic Sea (Ojaveer 1981; Rönkkönen et al. 2004). Baltic herring occurs in two main forms depending on spawning period – spring-spawning and fall-spawning herring (Parmanne et al. 1994; Rajasilta et al. 2001). When appropriate conditions appear, herring migrate to shallow areas close to the coast to spawn. In general, spring- spawning takes place on depths between 0 m to 10 m but deeper spawning has been observed as well (Elmer 1983). The fall-spawning herring are in general described to spawn further out from the coast at depths around 20 m (Elmer 1983). In the northern part of the Baltic Sea, spring-spawning begins in April and May and continues until the end of July, and sometimes even the beginning of August (Rajasilta et al. 1993). In the southern Baltic, herring spawning commences in February and March and continues until the end of June (Krasovskaya 2002; Rajasilta et al. 2006).

Although there are difficulties in distinguishing separate populations of herring in the Baltic Sea, there are variations in size, spawning and feeding habits. Studies have shown that these variations may depend on the environmental differences impacted by factors like temperature and salinity (Rajasilta et al. 2006). ICES has identified 5 different herring stocks in the Baltic Sea (Aho et al. 2009). There are two herring stocks in the Gulf of Bothnia, subdivision 30 and 31 (Fig. 1). In the central Baltic Sea, there are also two herring stocks, one in subdivision 25-29 and 32, and one in the gulf of Riga with subdivision number 28-1 (Fig. 1). The herring stock in the south-western Baltic Sea, subdivision 22-24 (Fig. 1), is treated together with the herring stocks of Kattegatt and Skagerrak due to their migration patterns. These herring stocks are advised to be seen as rough subdivisions of actual herring populations (Parmanne et al. 1994). The every-year assessment is conducted by ICES Baltic Fisheries Assessment Working Group (WGBFAS). This group with collected data from landings and scientific sampling and monitoring, makes estimations of specific fish stocks and provides the base for the scientific advice on sustainable management.

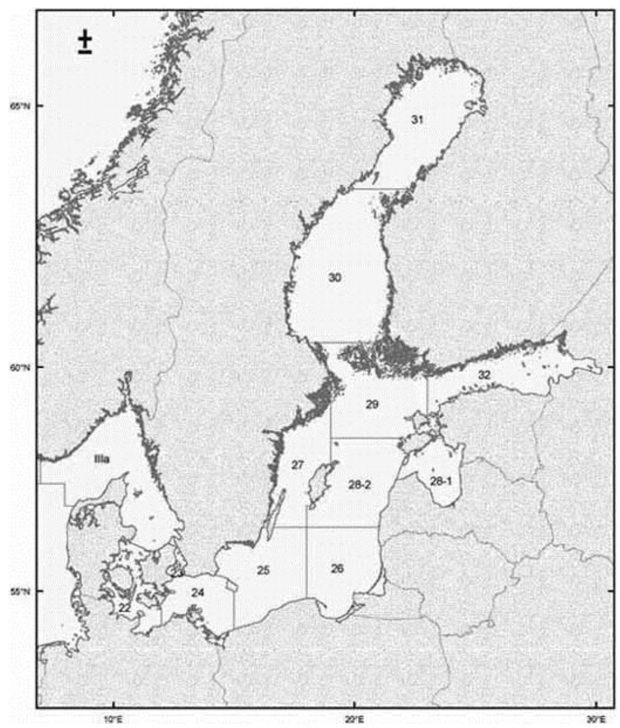


Fig. 1. ICES subdivisions in the Baltic Sea (Source: ICES)

The management units used for stock assessments are, however, a compromise between the knowledge on herring biology and the possibilities of assessing the state of the resources (Tomczak 2006). According to Podolska et al. (2006), the classification used by the ICES does not take into consideration migrations between the stocks in the western and central Baltic, and this could be significant when forecasting biomass and catches. Meanwhile, studies of the presence of larval *Anisakis simplex* indicate that the scale of these migrations could be significant as is suggested by the percentage of infected herring in Polish marine areas (Podolska et al. 2006).

The central Baltic herring stock is the most important stock in the Baltic Sea (Spawning Stock Biomass (SSB) in 2014: 858 kt), followed by the western Baltic spring spawning herring (SSB in 2014: 123 kt).

1.1 Western Baltic spring spawning herring

The western Baltic spring spawning (WBSS) herring migrate annually between their feeding grounds in Kattegat and Skagerrak and their coastal spawning grounds. A decrease of landings, recruitment, and Spawning Stock Biomass (SSB) have been observed since 1990 (Fig. 2). Spawning occurs in various areas of the shallow coastal waters of the western Baltic Sea. This herring stock is considered a meta-population composed of multiple spawning populations. One of the main components of the WBSS stock is the "Ruegen herring," named after the shallow lagoons around the island of Ruegen, including the Greifswald Bay (GWB), which are the main spawning area of this group (Haegele and Schweigert 1985; Barko and Smart 1986; Munkes 2005). It is assumed that there is a certain homing behaviour expressed in the spawning migrations of WBSS herring (Zagarese and Williamson 2001). As a result, regional spawning sites may have an important ecological function in supporting the resilience of the population (Kiørboe et al. 1981). Similar to most spring spawners, the Ruegen herring lays adhesive eggs on submerged substrates (especially macrophyte substrates) in shallow littoral zones. The spawning activity takes place from March until May, and is triggered by water temperatures (Holliday and Blaxter 1960).

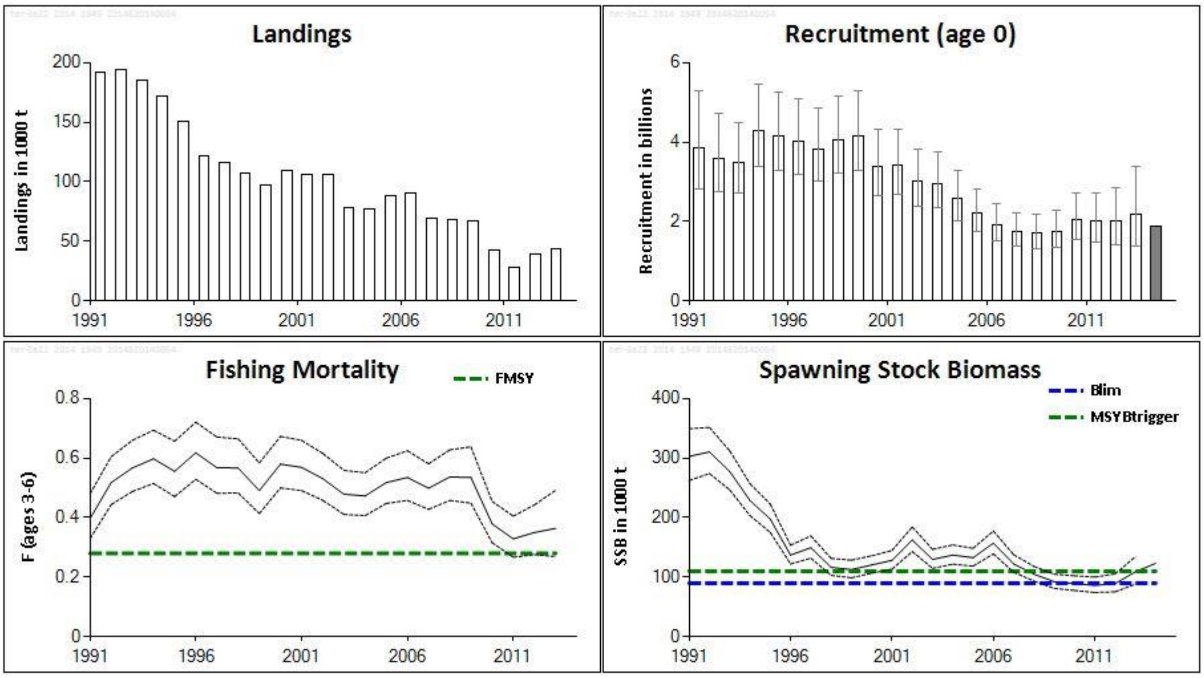


Fig. 2. Western Baltic spring spawning herring. Summary of stock assessment (SSB and recruitment in 2014 predicted) (Source: ICES 2014)

1.2 Central Baltic herring

The central Baltic stock (subdivisions 25–29 and 32, excluding Gulf of Riga herring) contains fast- (southern Baltic) as well as slow-growing (northern Baltic) individuals. The stock comprises mainly spring-spawning herring and a small autumn-spawning population. After spawning (March-May) individuals migrate to the deep basins for feeding. An increase of SSB has been observed since 2001, but in recent years this trend seems to have ceased (Fig. 3). The slight increase in SSB after 2001 was mainly driven by the reduction in fishery mortality (F). The historical decrease is believed to be partly caused by a shift in fishing area from SD 25 and 26 to SD 28.2 and 29 where the average mean weight is lower. The decline in SSB of central Baltic herring was partly caused by a reduction in mean weights-at-age (Parmanne *et al*., 1994; Cardinale and Arrhenius 2000). SSB declined until 2001 and then increased, and has been above MSY $B_{trigger}$ since 2006. Fishing mortality increased until 2000 and then decreased, remaining below F_{MSY} (0.26) since 2003.The increase of the eastern cod stock and decrease in sprat stock should be taken into account in herring management. If the cod stock will continue to increase, also cod predation mortality will augment. This situation is worsened by the decrease of the sprat stock, which is likely increasing the relative predation by cod on herring (ICES WGBFAS 2012).

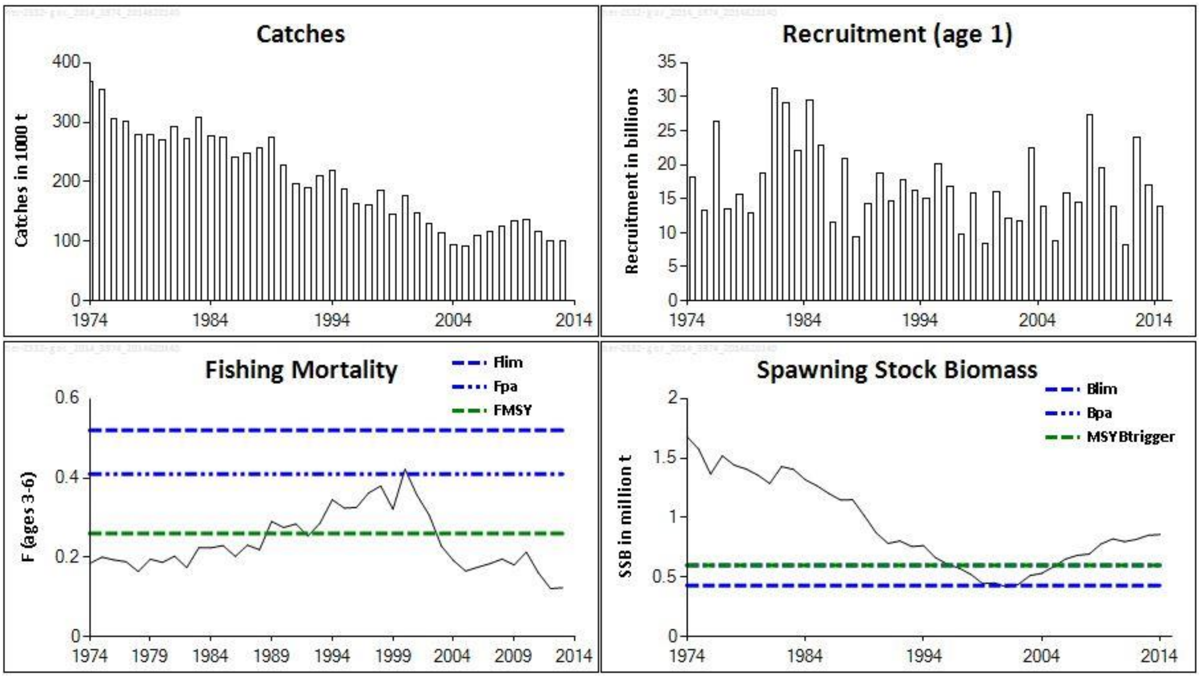


Fig 3. Herring in subdivision 25-29 and 32 (excluding Gulf of Riga herring). Summary of stock assessment (SSB and recruitment in 2014 predicted) (Source: ICES 2014)

2. Case study areas

The case studies in the HERRING project represent some of the most important spawning areas for the Baltic Herring. The Greifswald Bay is the most important spawning area for the western Baltic herring stock. The Vistula Lagoon and the Hanö Bight are some of the most important spawning areas of the central Baltic stock on the Polish and Swedish coast.

2.1 Greifswald Bay

The German coastal case study area of Greifswald Bay (GWB) is a semi-enclosed inshore lagoon, which is considered the major spawning area of the western Baltic spring spawning herring (WBSS) (Holliday and Blaxter 1960). The Bay covers approximately 514 km² and is bounded to the South and West by the coast of the federal state of Mecklenburg-Western Pomerania and to the North by the island of Ruegen (Fig. 4). The bay is characterized by a mean depth of 5.8 m with a maximum depth of 13.6m. The Bay is connected to the Baltic Sea through the narrow Strelasund in the West and a broader but shallower opening to the East. These topographic features and the marginal tidal amplitude in the inner Baltic Sea region (< 10 cm) account for the limited water exchange rate between the lagoon and the Baltic Sea. Thus, the exchange of the entire water body occurs approximately eight times a year (Holliday et al. 1964) and is mainly wind driven (Barko et al. 1986).

With an annual mean salinity of 7.3 (Allen and Wootton 1982), the GWB is a mesohaline ecosystem inhabited by floral and faunal communities composed of a mixture of marine and limnic species. Although these brackish systems are known to be highly productive, they are mostly characterized by a lower biodiversity compared to purely marine or limnic systems (Klinkhardt 1996).

The climate is subject to large seasonal fluctuations in water temperatures. Due to the limited depth, the GWB warms up more quickly in spring and cools down faster in autumn compared to the coastal Baltic Sea. The temperatures range from sub-0 °C surface waters with closed ice coverage in winter to more than 20 °C during summer. Due to the characteristic shallow depth, thermocline formation is a rare event (Barko et al. 1986). The main exceptions occur summer, when intensive solar radiation and reduced wind cause a strong warming of the water's surface (Rannak 1958).

Although the ecosystem is highly eutrophicated, the entire water body is well oxygenated, due to mixing by wind force.

In the shallow littoral zone aquatic vegetation is permanently submerged and dominated by flowering plants such as pondweeds (Potamogetonaceae) or marine eelgrass (*Zostera marina*, L. 1758) in addition to a diverse macro algae community (Holliday and Blaxter 1960).

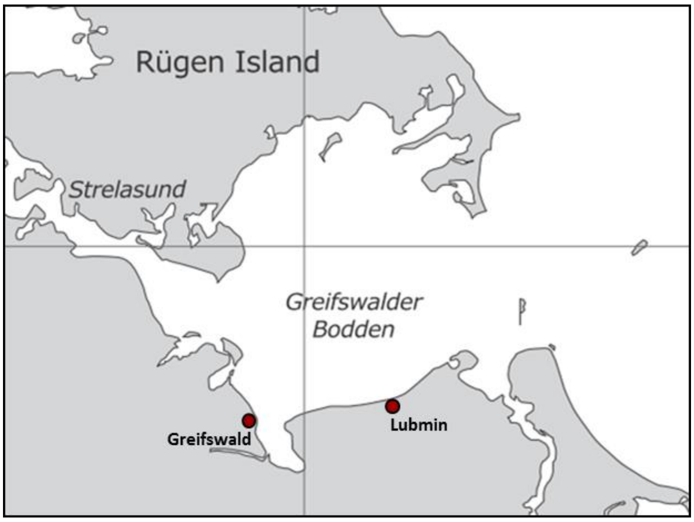


Fig. 4. Case study area Greifswald Bay (Greifswalder Bodden) (Thuenen-Institute of Baltic Sea Fisheries)

2.2 Vistula Lagoon

The Vistula Lagoon (Fig. 5), which is one of the largest coastal basins in the southern Baltic, is currently a very long, narrow, partially-enclosed water body with water exchange between the sea and the lagoon only occurring through the Baltiysk Strait located in the Russian part of the basin. The total surface area of the Vistula Lagoon is 828 km^2, of which 39.6 %, or 328 km^2, lies in Poland, while 510 km^2 is in Russia. The total length of the Vistula Lagoon is approximately 91 km (35 km of the Polish part), and the width ranges from 2 to 11 km. The lagoon is very shallow and the bottom is almost totally flat, predominantly muddy (Żmudziński and Szarejko 1955). The mean depth in the Polish part of the Vistula Lagoon is 2.4 m and the max. depth is 5 m. Since 1915, when the lock constructed on the Nogat River near Biała Góra effectively eliminated the flow of Vistula River waters into the lagoon thus significantly impacting its water budget, the Russian Pregola River has been the principle source of water inflow into the lagoon (Chubarenko and Tchepikova 2001). The most important Polish inflows are from the Pasłęka, Elbląg, Nogat, Bauda, and Szkarpawa rivers (Chubarenko 2008).

The lagoon is a type of transition zone between terrestrial and marine waters in which the marine factors play the predominant role. The impact of winds (generally range in speed from 1 to 4 m/s) on the water surface is a very important in determining water dynamics in the Vistula Lagoon. Storm winds at speeds exceeding 15 m/s occur relatively infrequently, with the largest share in winter (Kwiecień 1975). The impact of winds in the early spring and late fall periods cause the waters of the Vistula Lagoon to mix continually; thus, thermal stratification only occurs during periods of freezing. Moreover, winds often cause surface bottom sediments to be resuspended.

Salinity in the Vistula Lagoon fluctuates both seasonally and spatially (1-5 PSU), and is shaped by the magnitude and reach of Baltic waters. The southwestern regions of the lagoon can periodically be qualified as fresh water, while nearer the border with Russia salinity can reach as much as 6 PSU. The oxygen saturation of the basin's waters is fairly even and oxygen deficits are possible occasionally during warm nights and phytoplankton blooms.

Vistula Lagoon waters are characterized by low visibility with mean Secchi disk visibility of 0.35 – 0.4 m that is linked to both high primary production (mean chlorophyll-a concentrations of approximately 40 mg m^{-3}) and to the morphometry of the basin with its large surface area and shallow depth (Łomniewski 1958; Różańska and Więcławski 1978; Renk et al. 2001). The quality of Vistula Lagoon waters, which are characterized by high nutrient concentrations and organic matter contents, is primarily impacted by pollutants flowing into the basin from rivers, municipal sewage, and pollution from the agricultural areas of the Vistula marshlands (Bogdanowicz 1998; Anonymous 2005). A semi enclosed lagoon with a large drainage area has a high internal potential to eutrophication.

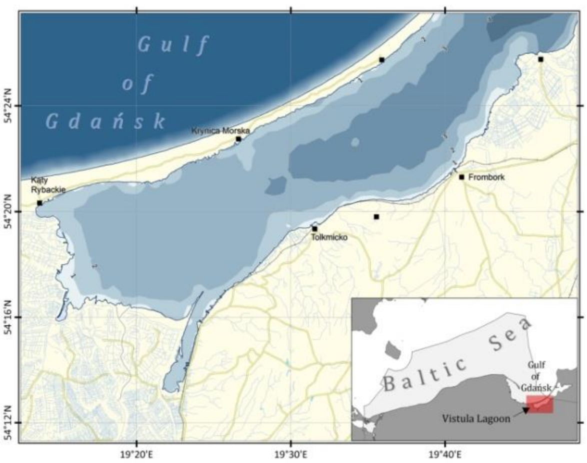


Fig. 5. Polish part of the Vistula Lagoon (Map: Lena Szymanek)

2.3 The Hanö Bight and Blekinge Archipelago

The Hanö Bight stretches from the south east corner of Skåne to the east end of the Blekinge Archipelago (Fig. 6). The combined coastline stretches over 200 km and includes 3 municipalities in Skåne (Simrishamn, Kristianstad and Bromölla) and 4 municipalities In Blekinge (Sölvesborg, Karlshamn, Ronneby and Karlskrona). The marine area covering the borders of all 7 municipalities along this coast is about 5000 km^2. Although the coastal marine area at depths from 0 m to 15 m, which would be most suitable for herring to spawn, covers about 1400 km^2.

The Baltic Sea has in general weak permanent current systems. Because of the high amount of freshwater runoff, the current system is in general characterized by surface water with low salinity having a counter clockwise direction. This creates a surface current running in a southerly direction in Hanö Bight (SMHI, 2011). The hydrodynamics of Hanö Bight are most likely more affected by wind, depending on its direction and speed. The predominant wind direction in the southeast of Sweden is southwesterly or southerly according to wind surveys conducted by SMHI (Swedish Meteorological and Hydrological Institute). A prevailing southerly or westerly wind usually causes upwelling on the east coast of Sweden (SMHI 2009).

Temperatures and salinity in Hanö Bight follow a natural, annual and seasonal variation. In general, the temperature is lower and the salinity higher further out from the seashore in the deeper waters, while further north, closer to the coast and runoff areas the temperature is higher and salinity lower (Hanö Bight Water Conservation Associate). Being an exposed area, the oxygen levels in Hanö Bight are in generally high at over 5 ml/l. (Hanö Bight Water Conservation Associate).

The Hanö Bight is supplied by a large number of rivers and annually receives an average of 4500 tonnes of nitrogen and 95 tonnes of phosphor. About 91% of the nitrogen and 75.5% of the phosphor are transported from the rivers. Only about 5% of the nitrogen and 21.5% of the phosphor come from the industry in the area. The visibility in Hanö Bight varies between 2.7 m and 14 m between different monitored stations and years (Hanö Bight Water Conservation Associate).

In Skåne, the majority of the coast is covered by sandy or rocky beaches and various wetlands in the north. The coast of Blekinge instead goes to an extensive archipelago with several small islands and skerries. The dominant seabed substrate close to shore is gravel and stone or rocks both in Skåne and Blekinge. In Skåne County, the seabed vegetation of Hanö Bight is characterized by the brown algae *Fucus vesiculosus* in the top 3 meters. In the deeper parts, red algae become more dominant with species like *Furcellaria lumbricalis*, *Rhodomela confervoides* and *Polysiphonia fucoides.* In the northern part of Skåne, north of Åhus, there are areas with eelgrass (*Zostera marina*) meadows. The vegetation in the Blekinge archipelago is similar to the southern part of Hanö Bight, although there are more shallow areas with soft seabed with a substrate of sand and clay as well as a high content of organic matter.

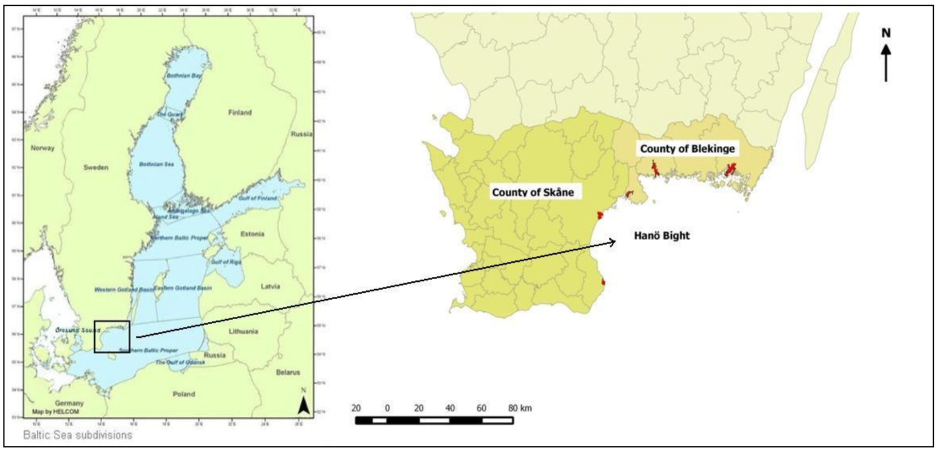


Fig. 6. Case study area, Hanö Bight and Blekinge Archipelago (source: HELCOM, Composed by Lilitha Pongolini

Herring catch in the Vistula Lagoon (photo: Iwona Psuty)

Herring catch in the Vistula Lagoon (photo: Iwona Psuty)

3. Herring spawning

Herring eggs are demersal (Sætre et al. 2002), which means that they are heavier than the surrounding water and they sink and develop on the sea bottom. Herring spawn their eggs in shallow waters most frequently in areas with bottoms featuring rocks, and gravel and overgrown with submerged vegetation (Aneer et al. 1983; Aneer 1989; Rajasilta et al. 2006; Geffen 2009; Ojaveer et al. 2011). The spawning usually take place a few centimetres above the substrate and gametes are released both above, upon, and amongst the vegetation (e.g. Aneer et al. 1983). After spawning, adult herring migrate to the open sea (Parmanne et al. 1994). The eggs hatch after 10-20 days depending on water temperature. The size of larvae at hatch is ca. 5-9 mm. Early herring developmental stages inhabit shallow waters in coastal zones and lagoons until they attain a length of approximately 30 mm (Urho and Hildén 1990). More or less at this time, the herring undergo their metamorphosis: the swim bladder inflates with gas, the dorsal segment darkens, and the body takes on its silvery coloring (Urho 1992). Although fall-spawning herring are widely thought to reproduce far away from the shores in September and the first half of October (Parmanne et al. 1994), early developmental stages are also noted in the Vistula Lagoon (Linkowski et al., unpublished materials, 2001). Zooplankton is the main food source of younger and older larvae, while the diets of juveniles also include macrozooplankton such as Mysidacea and small fish (Arhenius 1995; Casini et al. 2004; Möllmann et al. 2004; Dziaduch 2011).

Herring eggs and larvae (8.0 and 28.0 mm), photo: Katarzyna Horbowa

Sandy bottom with eelgrass habitat
(photo: Wolf Wichmann)

Herring eggs on pondweed
(photo: Philipp Kanstinger)

The environmental conditions have a critical effect on the successful spawning. Suitable bottom structure and vegetation for laying the eggs is necessary. Otherwise the spawning may be limited to small geographical areas only, which will influence the reproduction success. Moreover, appropriate environmental conditions are required for eggs development and larvae growth and survival. Even if the spawning ground is suitable for herring to lay eggs, high or mass mortality of the early life stages will be responsible for low recruitment level.

- Herring spawn on submerged aquatic vegetation. The density, diversity, and distribution of vegetation depend on several abiotic factors including water temperatures, salinity, and turbidity, as well as on habitat characteristics like sediment composition. For example, increased turbidity leads to decreased light availability for submerged aquatic vegetation.
- Ice conditions have a great impact on growth of vegetation. Ice coverage limits light penetration in the water body. This causes a decreased light availability for bottom-dwelling macrophytes. Additionally, ice drifts can impact submerged vegetation through mechanical stress. The duration of ice coverage affects the initiation of growth of macrophytes in spring.
- Herring spawn also on hard-bottom structures like stones or gravel. Thus, bottom type plays an important role when availability of a given area for spawning is considered. Bottom structure changes from sandy to muddy may cause spawning grounds loss.
- Water temperature is one of the most influential factors for herring's reproductive success. Both lower and higher water temperatures, in combination with salinity and oxygen supply, can act as stressors on herring egg and larvae development. Additionally, temperature effect on the growth rate of larvae may influence their survival.
- An increase of water temperature can also change species composition by invasion of non-indigenous species. The ecological impacts of non-indigenous species might have an impact on the reproduction success of herring.
- Furthermore, water temperature is an influential factor triggering herring migration into their spawning areas and spawning activity.
- Salinity plays an important role in the entire ecosystem and has an indirect impact on herring survival. Salinity can act as a direct stressor on the development of herring spawn, with critical salinity levels $\leq$ 4 PSU.
- Oxygen levels can act as a direct stressor on herring egg development. Oxygen deficiency can occur by presence of epiphytes or multilayer eggs. One should also keep in mind that there is a strong relation between water temperature and oxygen supply.
- A decreasing pH-value from 8 to 7 effect the protein biosynthesis of larvae. Low pH-values have a direct impact on herring reproduction.
- Hydrodynamics have not only a direct but also an indirect impact on herring egg - hydrodynamic forcing can lead to mass destruction of macrophytes.

The simplified interactions of four driver complexes impacting the natural ecosystem function are shown in Figure 7. We can define drivers as natural factors which impact the natural environment. The drivers are affected by anthropogenic stressors.

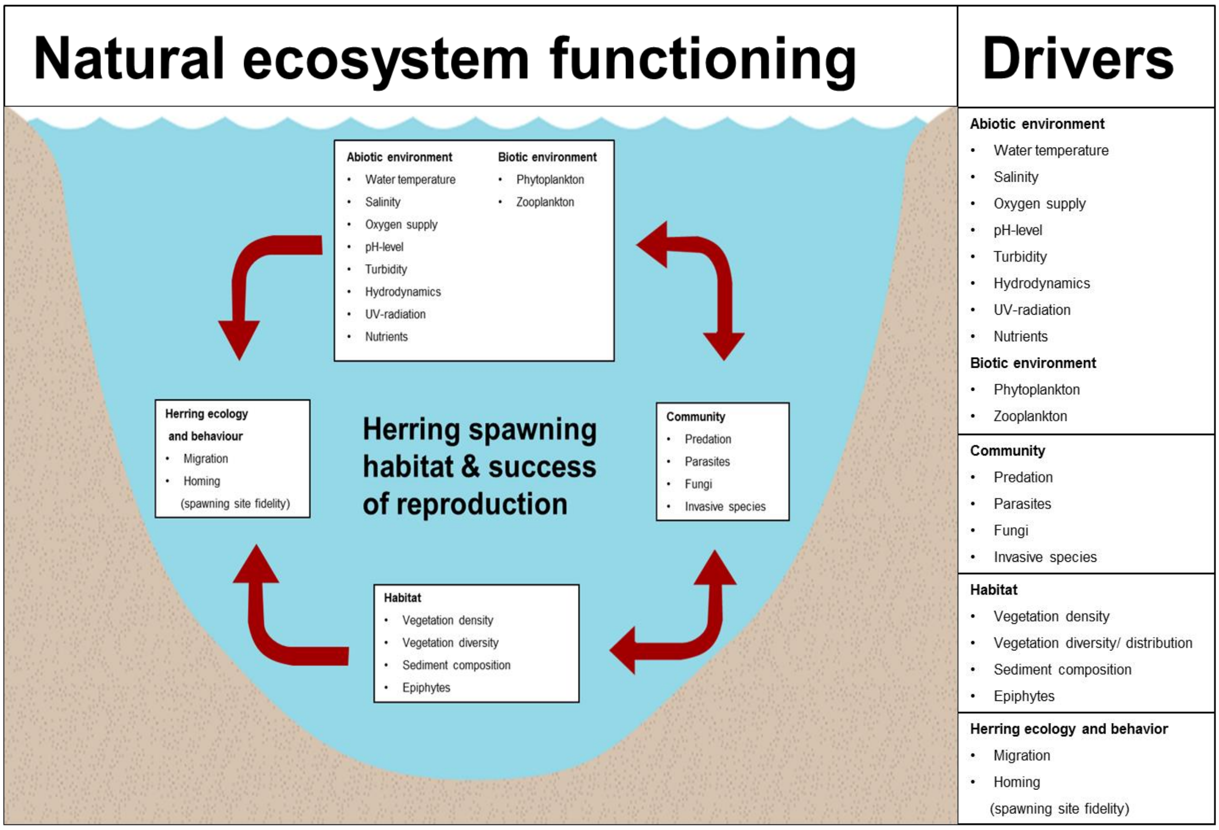


Fig. 7. Overview of important drivers and their interactions on natural ecosystem functioning (Source: TI-OF, Dorothee Moll)

4. Anthropogenic stressors

There are five main categories of anthropogenic stressors impacting natural ecosystem functioning: eutrophication, pollution, coastal modification, species introduction, and climate change (Fig. 8). Each of those activities can affect the natural environment functioning by affecting the drivers (e.g., sediment composition, vegetation, water temperature and salinity, oxygen concentration, pH, water transparency, phytoplankton, zooplankton, predators presence).

Eutrophication

HELCOM (2005) describes eutrophication as a condition of high nutrient concentrations stimulating algae growth leading to an imbalance of the aquatic ecosystem.

High nutrient loads come from river inflow and are caused by agricultural usage in bordering regions. For all three case studies, nitrogen and phosphor loads of municipal sewage plants are small in comparison to nutrient loads caused by agricultural uses. A considerable amount of phosphor is accumulated in muddy sediments, with a high potential for resuspension – it is a problem especially for Vistula lagoon and Greifswald Bay. Although external phosphor inflow decreased in the last years, these internal reservoirs have the potential to slow down any improvement.

Pollution

Pollutants are produced and emitted by human use of resources, infrastructural and industrial development, agricultural fertilizer and pesticide use, and tourism. The major contaminants are persistent organic pollutants, nutrients, oils, radionuclides, and heavy metals. In coastal regions the concentration of selected heavy metals and organic contaminants are much higher than in open waters, because these pollutants are discharged into coastal waters. These pollutants accumulate in coastal sediments with high persistence on one hand and high potential for resuspension on the other.

After agriculture and direct discharge of sewage, there are many diverse sources polluting ecosystems, such as shipping, shipbuilding, recreational crafts, industry, and power stations.

Coastal modification

Coastal modification is the mobilization of coastal sediments, causing increased turbidity and sedimentation in addition to the resuspension of nutrients and pollutants formerly accumulated in sediments. Coastal modification can radically change and impair communities both in the shallow littoral zone and in deeper regions. In this context, dredging of fairways, construction of industrial ports, beach nourishment, construction of gas pipelines can be seen as a form of coastal modification.

Species introduction

The increase of shipping worldwide holds the main potential for the introduction of non-indigenous species. Empty sea-going vessels often store ballast water for stabilization. This water contains organisms, such as phytoplankton, zooplankton, jellyfish larvae, and other species which are transported from one ecosystem to another. Another example of species introduction is ship hull fouling, where organisms colonize the ship’s outer surface. Finally, the non-indigenous species may travel through the rivers system and may also be directly introduced as part of bioengineering or biomanipulation projects. If environmental conditions are suitable, these non-indigenous species are able to settle down and change the natural ecosystem functioning.

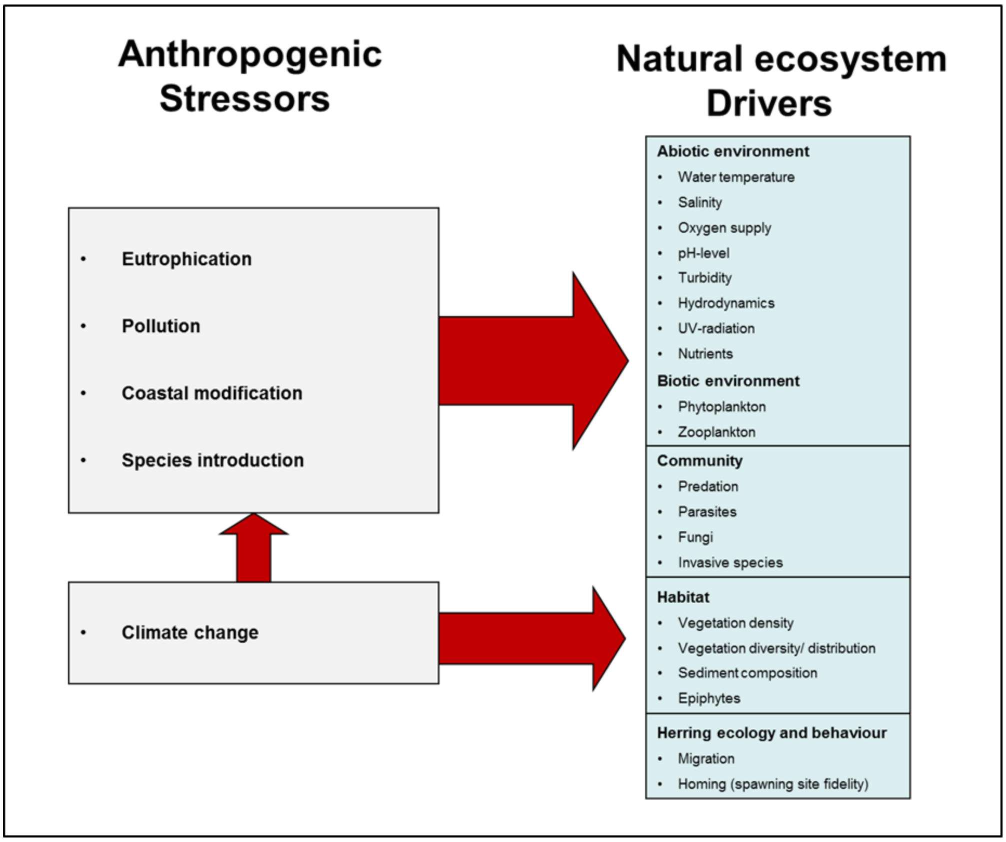


Fig.8.Anthropogenic stressors influence natural ecosystem drivers (Source: TI-OF, Dorothee Moll)

5. Human uses

The described above anthropogenic stressors are resulting from numerous human activities. The most important of them are:

- Commercial fishing
- Recreational fishing and angling
- Marine transport
- Recreational boating
- Marinas, harbours
- Touristic uses
- Energy supply (wind plant, pipelines, power plants)
- Dredging, channeling, sand extraction
- Bordering land use – agriculture
- Bordering land use – industry

When analyzing the possible effect of different types of human activities, geographical distribution of a given activity as well as the time within year of its occurrence should be also taken into account. From this point of view, equally important it is to have a knowledge about not only timing of herring spawning but also about spawning sites distribution. Interaction of multiple anthropogenic effects are responsible for numerous modifications of the environmental conditions, which may have a significant effect on the loss of spawning sites and recruitment success (Fig. 9).

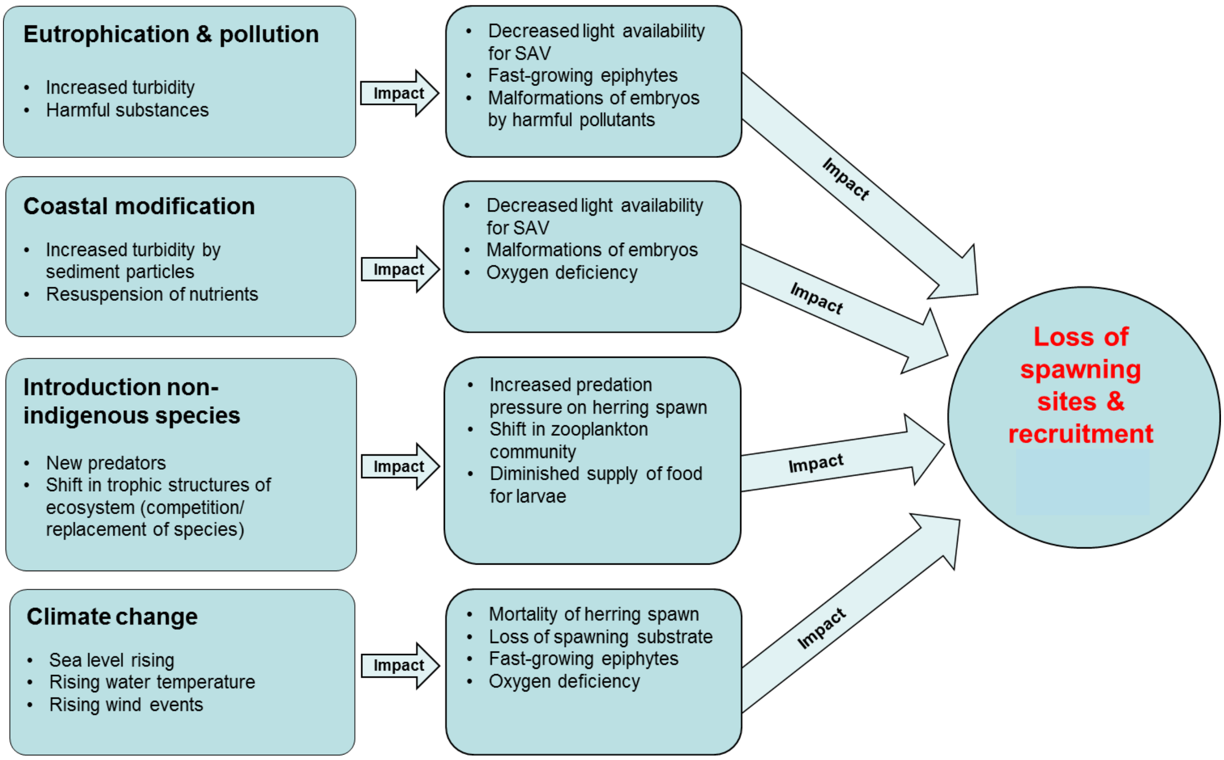
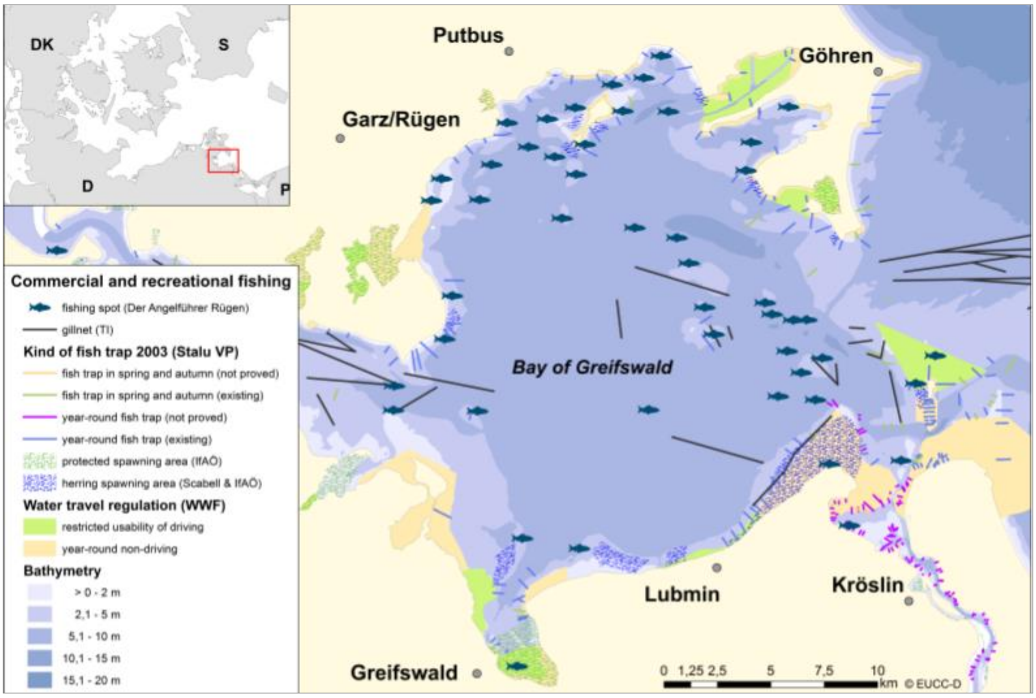


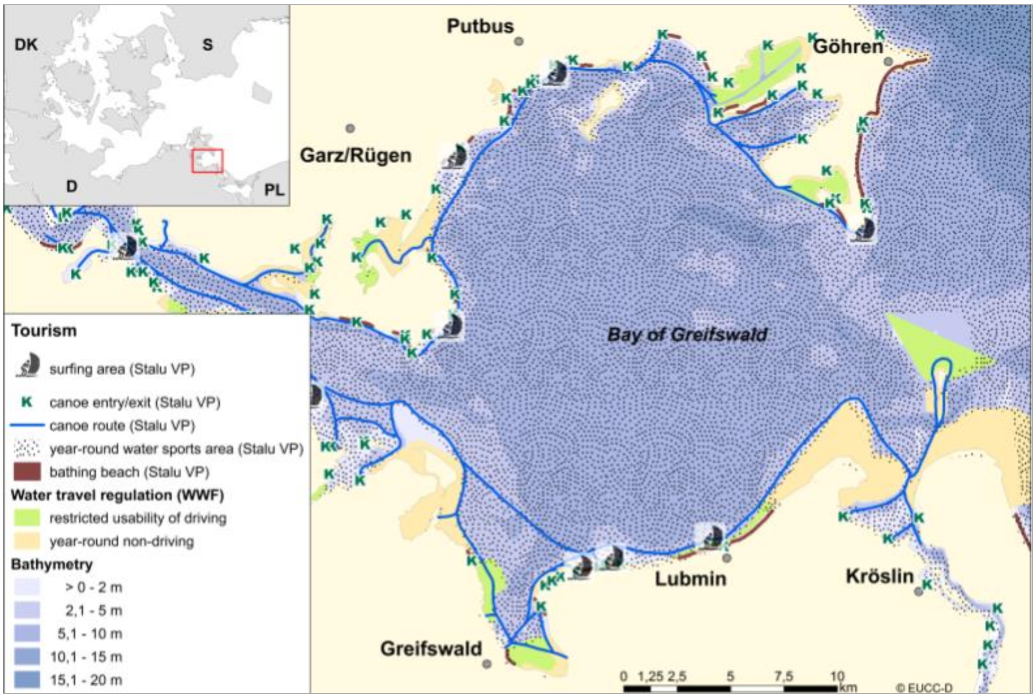
Fig. 9. Interaction of multiple anthropogenic effects (source: Dariusz Fey)

The human activities – their distribution and intensity – were described in details in the Coastal Case Study (CCS) Reports (www.baltic-herring.eu), for the Greifswald Bay, the Vistula Lagoon, and the Hanö Bight and Blekinge Archipelago. Maps describing the distribution of human activities in those CCS areas are presented below.

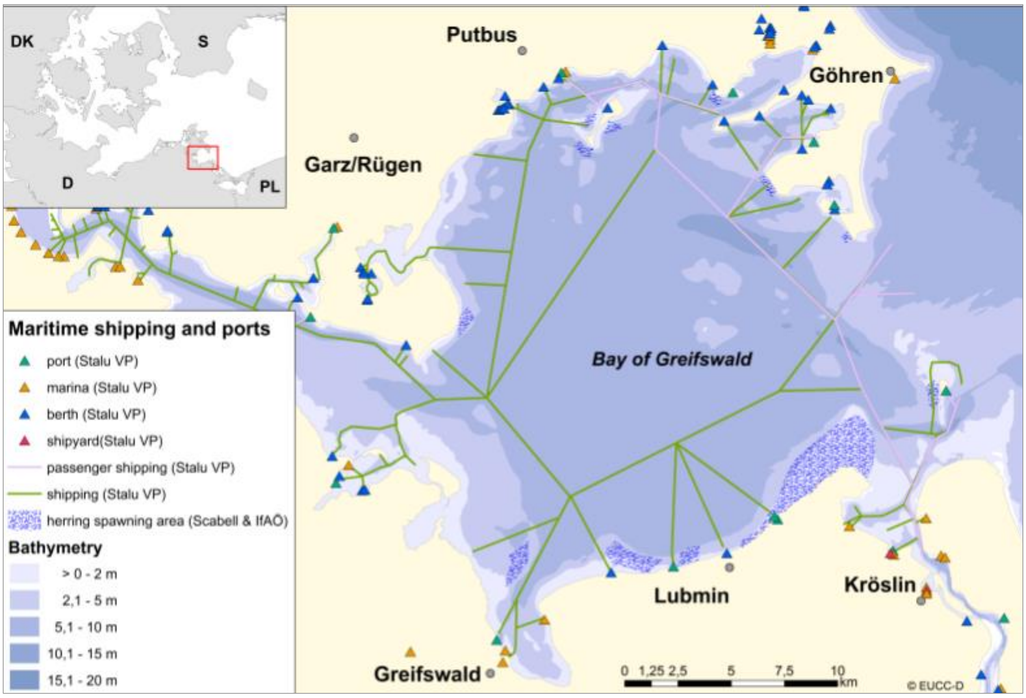
5.1 Germany - Greifswald Bay



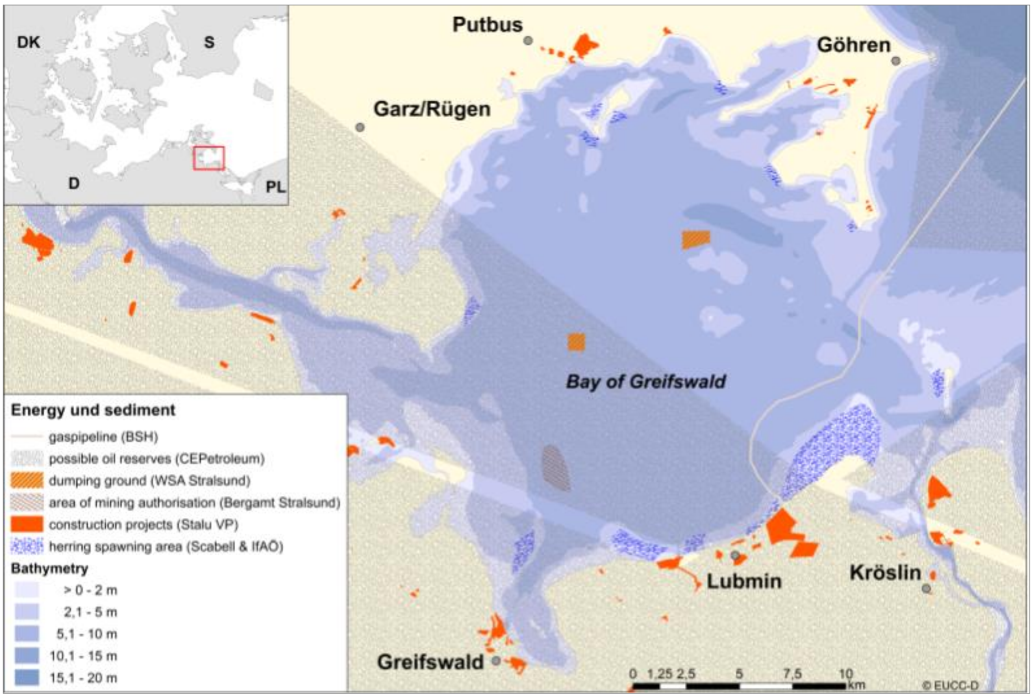
Commercial and recreational fishing in the Bay of Greifswald (EUCC-D, Anne Hiller)



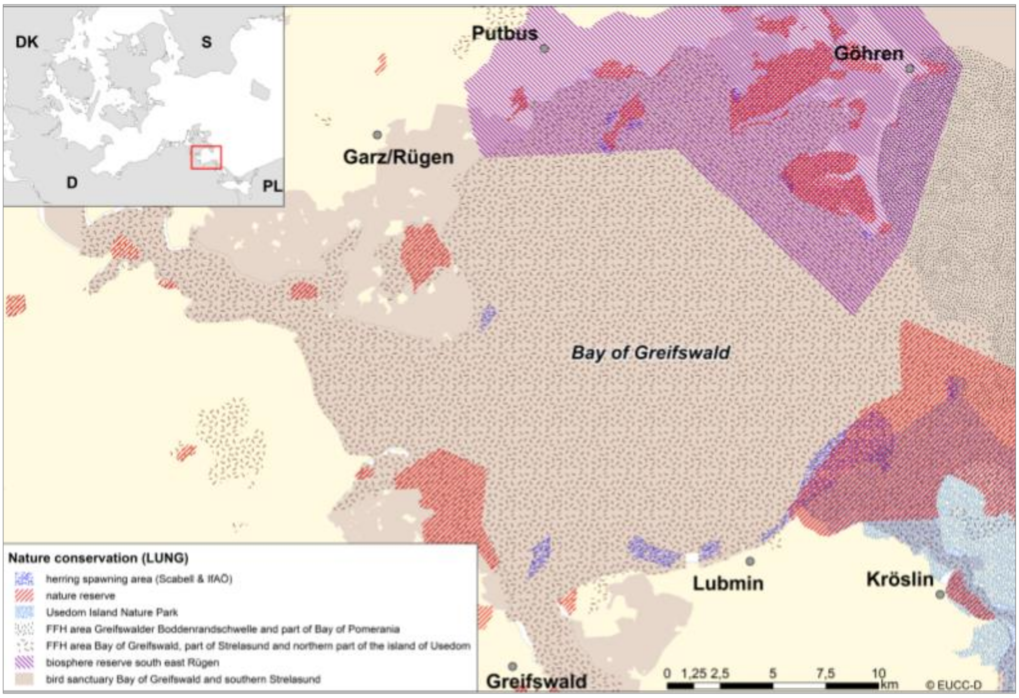
Touristic uses in the Bay of Greifswald (bathing sites, water sport area, canoe and kayak routes) (EUCC-D, Anne Hiller)



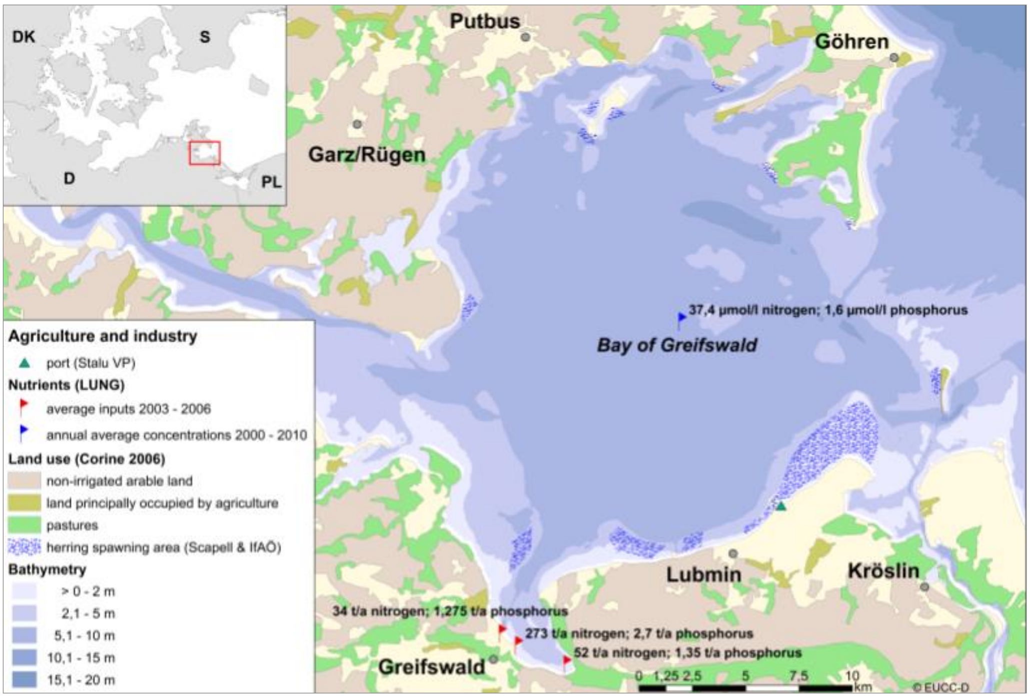
Shipping lanes in the Bay of Greifswald, industrial harbours, marinas, berth of ships and jetties (EUCC-D, Anne Hiller)



Landing of the Nordstream gas pipeline in Lubmin, spoil fields, dumping sites and gravel mining (EUCC-D, Anne Hiller)

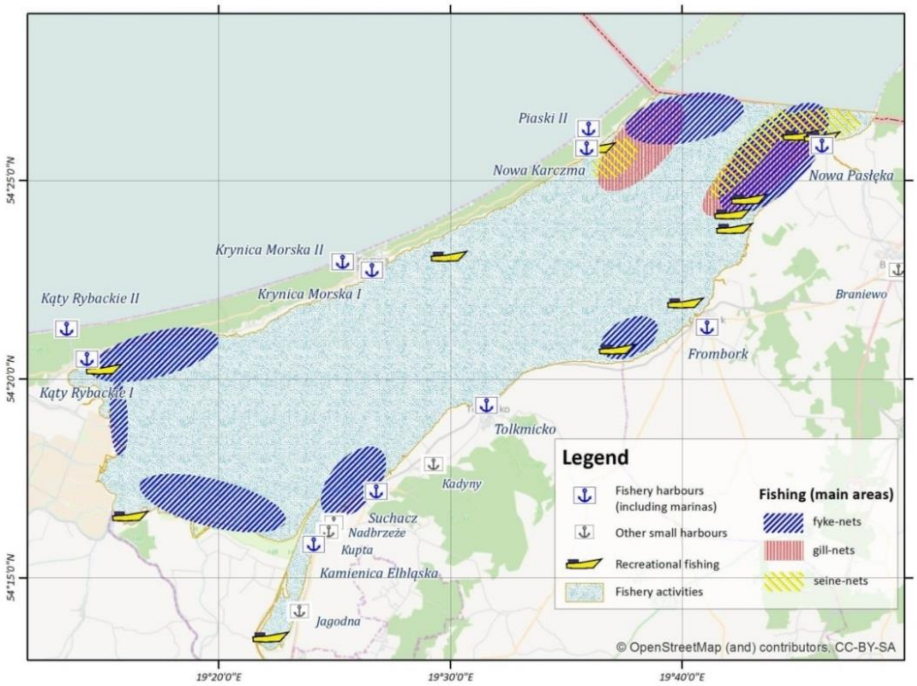


Nature conservation in the Bay of Greifswald (EUCC-D, Anne Hiller)

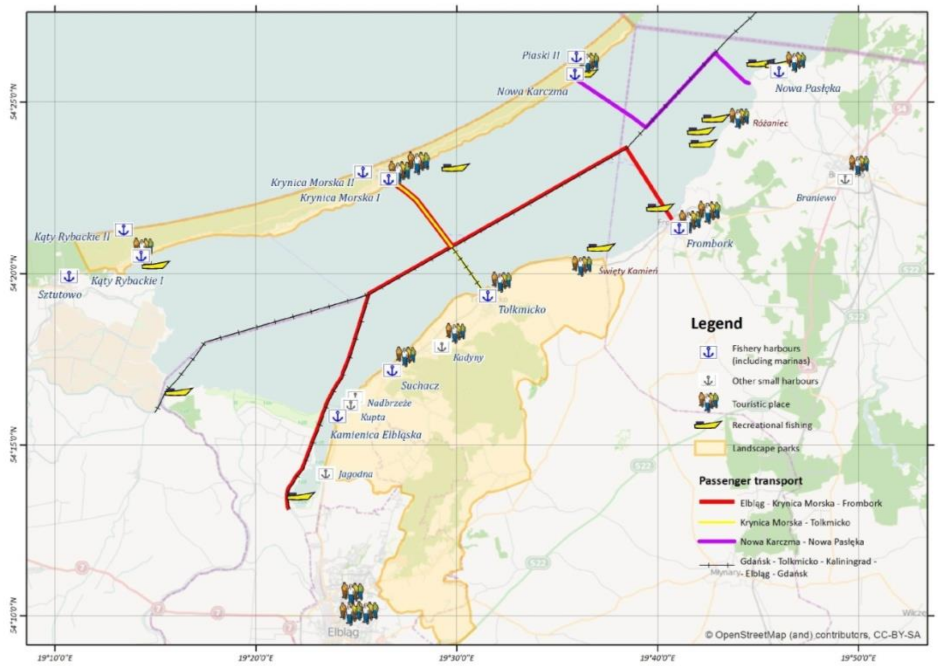


Areas used for agriculture in the Bay of Greifswald (arable land and grassland), as well as phosphorus and nitrogen discharge (EUCC-D, Anne Hiller)

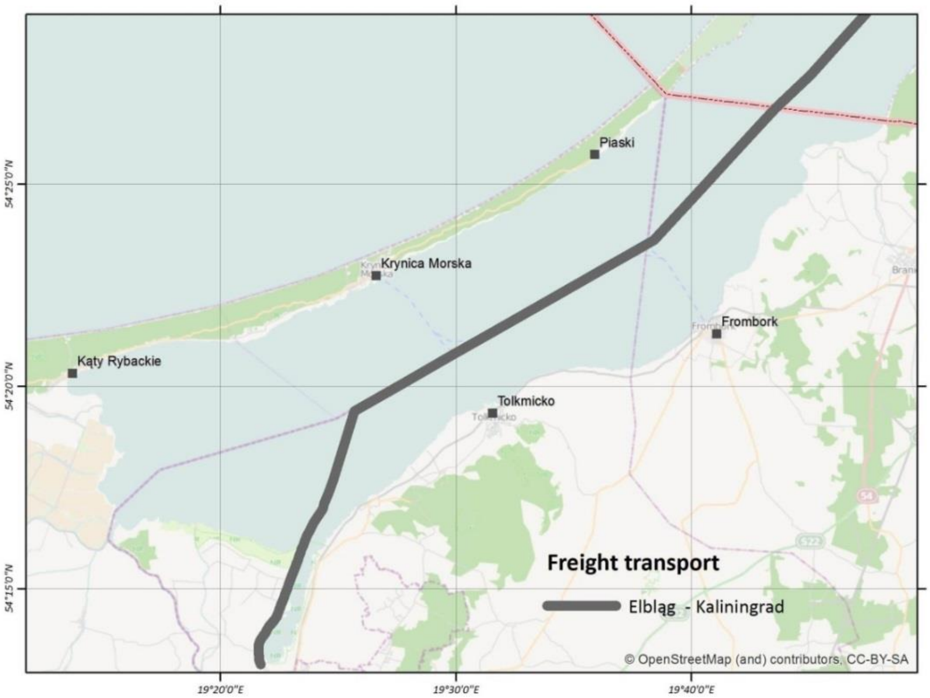
5.2 Poland – Vistula Lagoon



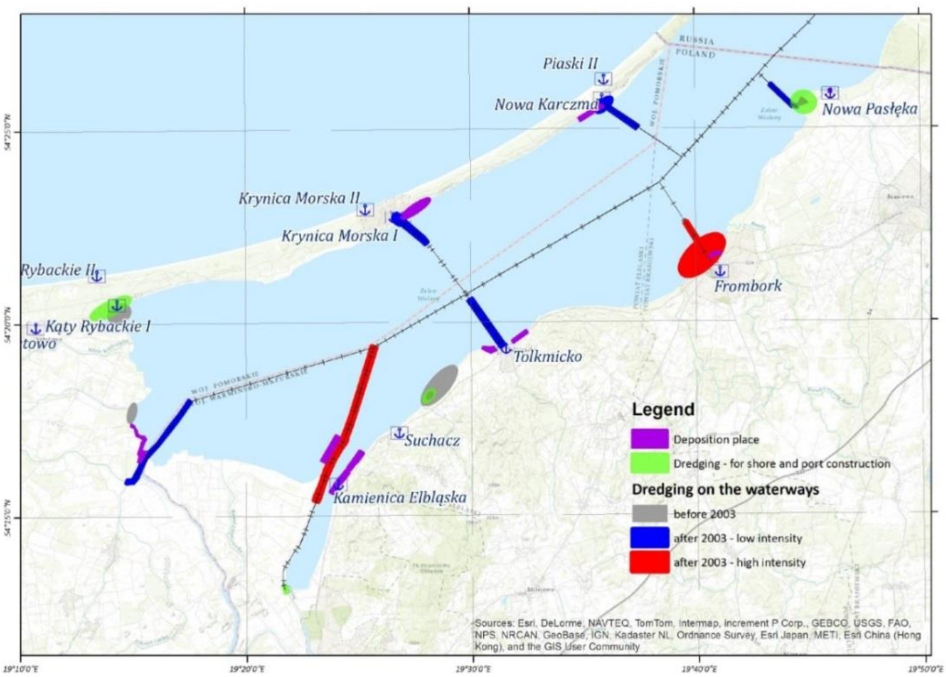
Commercial and recreational fishing, including marinas and harbours (Map: Lena Szymanek)



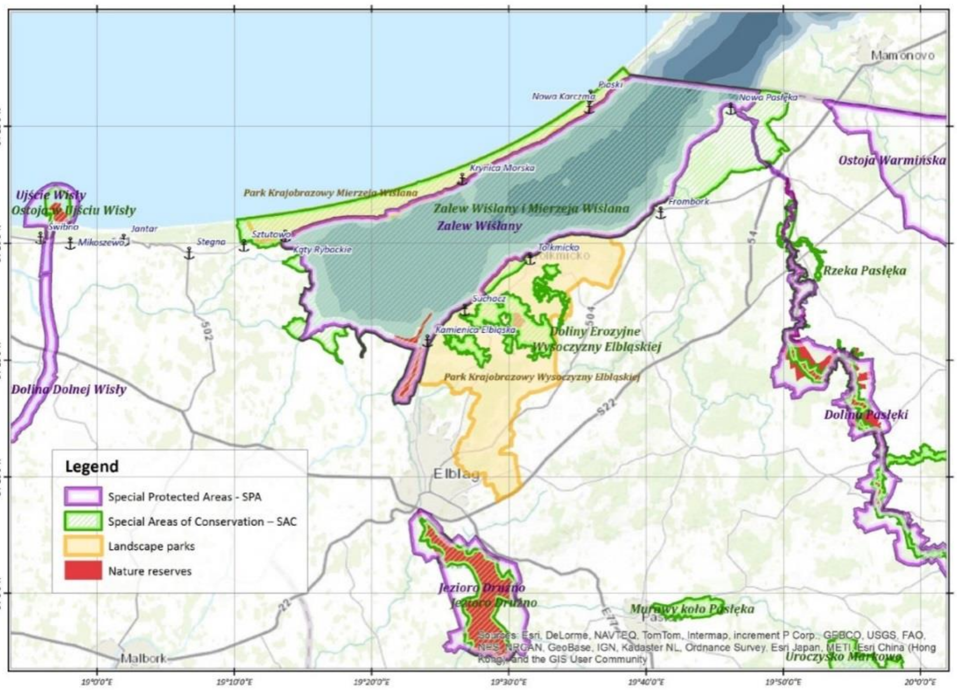
Touristic uses (Map: Lena Szymanek)



Marine transport (Map: Lena Szymanek)

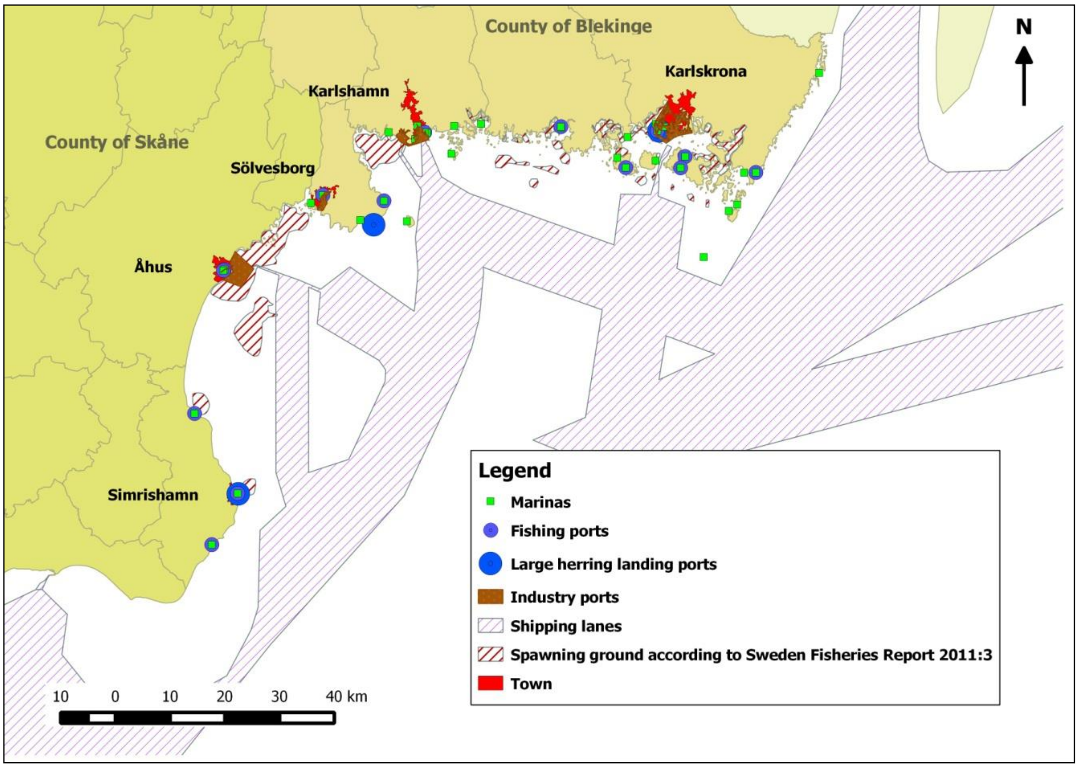


Dredging, channelling, and sand extraction (Map: Lena Szymanek)

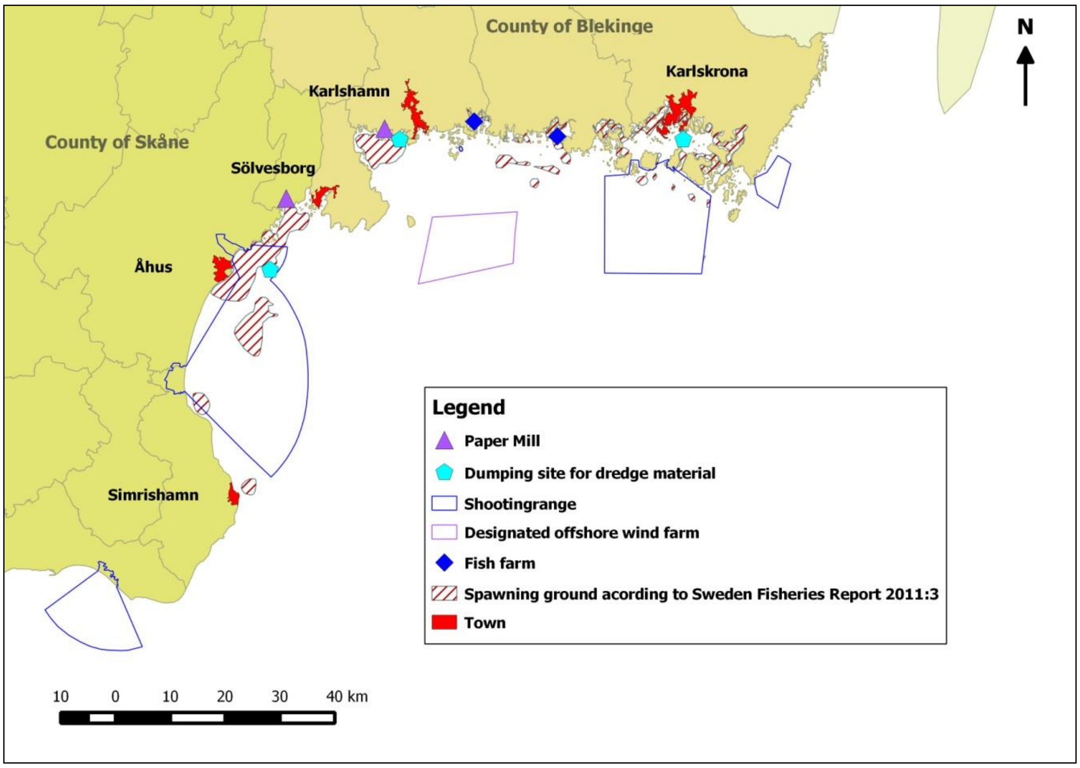


Special areas of conservation (Map: Lena Szymanek)

5.3 Sweden - the Hanö Bight and Blekinge Archipelago



Source: http://projektwebbar.lansstyrelsen.se/gis/Sv/Pages/karttjanster.aspx; Composed by Lilitha Pongolini



Source: http://projektwebbar.lansstyrelsen.se/gis/Sv/Pages/karttjanster.aspx; Composed by Lilitha Pongolini

6. Climate change

Climate change is an anthropogenic factor that has a high impact on the natural ecosystem through higher water temperatures, changes in salinity, sea level rise, and more frequent storm events, to name but a few examples. Small pelagic fishes such as herring react quickly and strongly to climate change due to their tight links to environmental forcing, which affects key processes such as distribution, growth, spawning and feeding (Rose 2005).

According to 2013 report from the Intergovernmental Panel on Climate Change (IPCC) the global average temperature will continue to increase between 0.5 °C to 5 °C until 2100. On regional levels the temperature may be even more substantial. Long time-series of hydrographic measurements in the Baltic Sea show a trend of increasing temperatures and decreasing salinity (Swedish Meteorological and Hydrological Institute). The average temperature during summer indicates an increasing trend over the time period 1975 to 2010 in the surface waters of both central Baltic and northern Baltic (Andersson M et al. 2012). Looking only at the last 2 decades the temperature has been on a relatively even level (Fig. 10).

A rising sea level causes problems not only for open coastal areas but also for coastal lagoons, because the naturally sheltered character of these ecosystems could be endangered. Increased storm events cause sediment mobilization, which due to increased turbidity and multiple storm events can uproot submerged aquatic vegetation. Furthermore, storm events lead to resuspension of accumulated harmful substances and nutrients in the water column. Even a slight increase in temperature may significantly influence the period of the ice-cover in the lagoons leading to increased riverine loads during winters. Another possible consequences of climate change are changes in community structure of phytoplankton and zooplankton (zooplankton is an important food source for herring larvae and juveniles) as well as shifts in their taxonomic dominance, increased primary production including the algal blooms intensity and even changes in fish communities. Intensified algal blooms and increased supply of particles from run off areas, are factors that increase the turbidity in the coastal waters. This leads to less sunlight reaching down to the vegetation on the seabed and the inhibition of macrophytic growth. Changing water temperatures may result in a shift of spawning periods and spring plankton blooms, and this might affect fish recruitment by predator-prey mismatch. Because warmer water sustains less oxygen, the consequence of a rising temperature may lead to general lower oxygen content in the water.

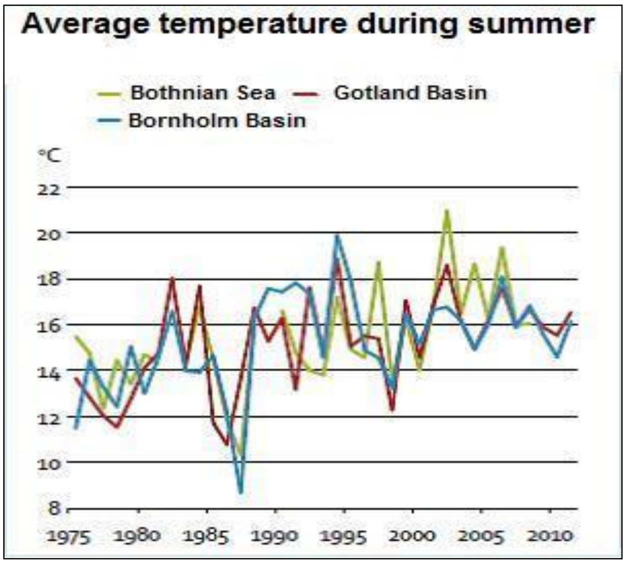


Fig. 10. Average temperature during the summer over the period 1975 to 2010 (Source: Andersson et al. 2012. (Swedish Agency for Marin and Water Management))

On the other hand, some of the climate change consequences may have positive effects. For example, the increased frequency of milder winters with shorter ice-cover period or even entirely without ice-cover will extend the herring reproductive period. The longer herring spawning period will increase the probability of matching the best first feeding conditions for herring larvae. This, on average, should result in higher survival of the herring year-classes.

Considering the complexity of all the described above interactions and their ecosystem effects, it is difficult to foresee the consequences of climate change in the specific case study areas. Therefore, it is important to conserve the present environmental status before investing in expensive restoration efforts. Some examples of important first steps include minimizing nutrient discharge or implementing sustainable management of urban coastal development. Furthermore, it is important to promote research on multiple impact factors in order to understand ecological cascades and to evaluate the ecological response to an increasingly large suite of anthropogenic stressors.

7. Conclusions

The existence of good quality spawning areas for herring is not only important for the vitality of the herring stocks, but also for the marine ecosystem as the species is an important part between lower and higher trophic levels. It is therefore important to identify the human activities that have a negative impact on herring spawning grounds and herring stocks as well as having a purpose to through best practice management and measures reduce these negative factors.

7.1 Germany - Greifswald Bay

The ecological status quo of the GWB is well assessed; however ongoing monitoring of important parameters is patchy. In particular, research on the potential effects of anthropogenic impacts on herring spawning success is scarce.

In general, water temperature, salinity, and oxygen supply are the main physical drivers for the successful development of herring eggs. However, these variables are highly influenced by human impacts. Although success has been made reducing nutrient inflows in the previous decades due to the reduction of point source discharges, e.g. installation of sewage systems with nitrogen elimination systems, there are still issues concerning nutrient inflows from diffuse sources.

Climate-change related risks from increasing water temperatures and salinity changing due to sea level rise and the inflow of Baltic Sea water have the potential to jeopardize the WBSS herring stock by further reducing macrophyte coverage in GWB.

The State Agency of Environment, Nature Conservation and Geology of Mecklenburg-Western Pomerania has implemented a water quality assessment policy for coastal waters and controlled annual water quality since 1979. In this water quality report, abiotic parameters and the state of eutrophication and pollution are analyzed and assessed, as well as coastal monitoring of fauna and flora (for more information: www.lung.mv-regierung.de). According to this source, eutrophication is one of the major remaining challenges of GWB.

An ecosystem is influenced by a multitude of factors and interactions. Caution is required to ensure that the right measures are taken. A holistic approach helps to understand the possible consequences of treating one symptom and thereby triggering other issues due to unknown ecological linkages.

An extensive ecological monitoring is necessary to describe the condition of these highly productive inner coastal ecosystems. However, currently extensive monitoring programs are limited to the outer coastal zone of the Baltic Sea. Monitoring the status of the Natura 2000 area GWB exists, but it is necessary to get more information concerning anthropogenic factors and their impact on spawning habitat of herring. A baseline should be established, including year-round monitoring of nutrient and pollutant concentrations in water and sediments on a suitable spatial scale. Additionally, detailed mapping of submerged aquatic vegetation should be initiated.

As a sound baseline for competent management, more research on herring spawning ecology is needed to further develop scientific insight into the interactions between abiotic parameters, anthropogenic factors, and their impact on the natural spawning habitat of herring and herrings' reproductive success.

It can be expected that the effects of anthropogenic stressors and the process of climate change will accumulate in the future and will negatively affect the spawning habitat of the WBSS herring stock and the success of reproduction.

7.2 Poland – Vistula Lagoon

Because it is a widely-held opinion that herring spawning grounds in the Vistula Lagoon do not require any special protection, it is very important to take some steps to significantly increase the awareness in regard to possible risks for successful spawning of herring in the Vistula Lagoon. For sure one of the main factors affecting the level of interest in protection of a given species is its economic importance. This is why we consider it as an important issue to increase the profitability of herring fisheries and to promote herring products at the same time.

Most of the human activities that could be responsible for unfavorable changes in the environment and herring spawning grounds in the Vistula Lagoon area are currently practiced at either low levels of intensity (e.g., fisheries, tourism, passenger and cargo transport, dredging, industry, urbanization) or are non-existent in this region (e.g., mining, energy extraction). The possibility of the increased intensity of such activities in the near future is the highest for tourism, especially if the plan for building a channel through the Vistula Spit is executed.

Currently, agriculture is probably the most significant sector impacting the Vistula Lagoon. Although nutrient concentrations have decreased in the lagoon considerably in recent years (especially with regard to phosphorus), the risk posed by increased intensity in agriculture on the drainage area cannot be ignored. This is especially true if the high internal potential for eutrophication and contamination of the lagoon is considered; the shallow depth of the lagoon facilitates bottom sediment resuspension, and restricted water exchange with the Gulf of Gdansk severely limits the ability of lagoon waters to self-purify. Another main current danger for herring spawning grounds is related to dredging and sand extraction - appropriate dredging methods and extracted material handling, with consideration of the herring spawning sites distribution, should be employed.

The effects of climate change are very difficult to foresee. The expected increase in temperature may drastically change the functioning of the whole ecosystem but the direct impact on herring spawning success in the Vistula Lagoon is expected to be positive as the extended reproductive period will increase the probability of matching the best first feeding conditions for herring larvae.

The current information on herring spawning sites distribution is very weak. Therefore, implementation of three years research project providing accurate data for mapping of herring spawning grounds is strongly advised. It should be in fact treated as a priority if herring spawning grounds safety is to be considered during preparation of the development plans in the Vistula Lagoon area.

7.3 Sweden - the Hanö Bight and Blekinge Archipelago

It is of importance to conduct annual studies with the aim of mapping geographically the most important spawning grounds for herring. As there is a lack of knowledge about the location, quality and importance of the spawning grounds in Hanö Bight, it complicates the ability to identify and evaluate the negative human impact and to have an efficient management approach.

It is of importance to regulate the fisheries with an ecosystem approach to be able to fish sustainably. There is a need to take into account and adapt to, not only the effect of the direct fishing targeting herring but also the indirect effects, as well as other human induced factors that can have a negative impact on fish stocks.

To avoid physical disturbance and destruction of herring spawning grounds, such as dredging and dumping, it is of importance to have the knowledge about the geographical area where the spawning grounds are situated. Establishing nature reserve and Natura 2000 areas would be a good approach to implement protection of the most important spawning grounds.

Many toxic substances are known to have a major negative impact on marine organisms. As the different life stages of herring occupy both benthic coastal seas as pelagic open seas it is a species that is especially exposed to various kinds of toxic emissions. The research and knowledge about the toxicity of different substances have a hard time to keep up since many new chemical substances emerge and are emitted to the environment without adequate tests. It is of importance to have knowledge about which different substances are emitted and their toxicity as well as what effect combinations and accumulation of these toxics have. Determining the legal limits of each chemical substance must take this in to consideration. It is essential to follow up known toxic emissions and monitor the environmental impact.

There are several rivers and streams having their outlet in Hanö Bight, and as these pass large agricultural and forestry areas there is a substantial transport of nutrients and suspended particles to the sea, with the consequence of eutrophication and lower visibility and water quality. Preventive work that have been performed is improvement of sewage and treatment plants as well as establishment of wetlands and ponds that serve as barriers of excessive nutrients and suspended particles before they reach the sea. Due to preventive efforts the emission of nutrient from the industry and other anthropogenic activity had shown a significant decrease. Since the nutrient load of to the Baltic Sea is high, the effects of preventive measures may linger and it is essential to develop and continue these measures.

The various effects of climate change with increasing temperatures, decreasing salinity, acidification, sea level rise and changes in weather conditions may impact the whole ecosystem in the Baltic Sea by altering the marine physical and chemical environment as well as species abundance and composition. How these changes will affect the population and spawning grounds of herring is hard to predict. An assumption is that climate change in combination with other anthropogenic stressors may decrease the resilience of herring populations and enhance the negative impact of the stressors induced to the marine environment. It is important that measures are taken at regional, national and global level to reduce greenhouse gas emissions.

8. SWOT analysis

SWOT analysis for the three Coastal Case Studies - Greifswalder Bodden (DE), Vistula Lagoon (PL), and Hanö Bight (SW) - as important spawning areas of the South Baltic Sea showing parameter for a sustainable development of the coastal area/ and sustainable management of herring spawning areas.

8.1 Germany - Greifswald Bay

STRENGTHS	WEAKNESSES
Factor ENVIRONMENT	
Good knowledge of the area based on long-term monitoring data (water quality, fisheries, feasibility study of hard-coal fired power plant Lubmin)	Nutrient contents still too high following WFD targets; eutrophication as main reason for decrease of macrophytes
Whole lagoon is designated as NATURA 2000 area	Underwater structures (e.g. macrophytes) are mentioned in NATURA 2000 plan but no active protection
Most important spawning area of the Western Baltic Spring spawning herring	Less knowledge about local spawning areas and necessary environmental conditions for spawning success
Factor SOCIO-ECONOMIC	
Yearly spawning event of high interest for fishermen and anglers/ tourists	Multiple uses within the Bay of Greifswald with possible negative affects for spawning areas of the herring (agriculture, shipping, energy sector, dredging)
Herring traditionally caught with passive methods	No temporal regulation, just a quota for fishermen/ not for recreational anglers
S6 highly attractive to tourists because of nice angling territory/ landscape	W6 numbers of fishermen and herring quotas decreasing
	W7 less knowledge about catch by tourists
Factor GOVERNANCE	
Comprehensive management of land and sea aspects (water quality, NATURA 2000, spatial planning, fisheries)	Different management bodies with less knowledge exchange and harmonization of management levels
Regional spatial plan currently under revision (with reserved areas for fishery (Vorbehaltsgebiet))	No (active) protection of spawning areas of the herring
KÜFVO regulates temporal and spatial limitations for fishermen/ anglers (for various economic important fish species)	Relevant management tools/ documents are currently under revision (KÜFVO, regional spatial plan) and updating/implementation of protection for herring spawning into these documents would take 5-10 years
S10 fishing license for tourists	
OPPORTUNITIES	**THREATS**
Factor ENVIRONMENT	
Internal measures for water quality improvement (mussel cultivation, reed, artificial settlement of macrophytes) as basis for expansion of macrophytes	No water quality improvement, due to high nutrient loads and internal eutrophication – no improvement on macrophyte coverage
Further work of HERRING research (e.g. master and Phd students)	Introduction of invasive species due to increasing shipping
	Further decrease of herring population

Factor SOCIO-ECONOMIC	
Implementation of environmental impact assessments incl. impacts on herring spawning areas	Increase of uses and spatial demands affecting spawning areas (increase of marinas, traffic, expansion of water ways)
	Fishermen fear "non-use areas" and are not motivated to discuss spawning area management
Factor GOVERNANCE	
Regular information for all stakeholders and round tables for sustainable management	
Adding of herring spawning areas and their protection into relevant planning documents (KÜFVO, NATURA 2000 management plan, regional spatial plan)	
Implementation of a voluntary agreement for protection of herring spawning areas	

8.2 Poland - Vistula Lagoon

STRENGTHS	WEAKNESSES
Factor ENVIRONMENT	
Vistula Lagoon is one of the most important herring spawning grounds in this part of the Baltic Sea.	High internal potential for eutrophication and contamination - large drainage area and limited exchange with the Gulf of Gdansk.
Lagoon provides sheltered spawning areas with high productivity and high water temperature supporting growth rate of herring larvae.	Limited areas with a proper spawning substrate - the area covered by plants with submersible leaves is limited. Most of the lagoon area is a sandy or muddy bottom.
	High potential for density dependant processes - significant top-down predatory pressure of herring larvae on zooplankton.
Factor SOCIO-ECONOMIC	
Herring is an important target fish for local fisherman community.	Low priority for herring spawning grounds protection - a common opinion within the local community is that herring spawning grounds do not require any special protecting activities.
Low economic activity in the lagoon, which prevents spawning areas degradation.	Low or even extremely low price for herring, which creates a low resource protection awareness.
	Increasing tourism - potential conflict for space and natural resources.
Factor GOVERNANCE	
Polish–Russian Commission for the Management of Fish Resources in Vistula Lagoon - well established and regularly-meeting international body setting quotas and discussing the fish management issues.	Fishing quotas - existing herring quotas are not adjusted to the high variability in spawning migration intensity conditions.
	Lack of herring spawning grounds protection - difficult in practise as herring is using large areas for spawning but it is also a result of an opinion that herring spawning grounds do not require any special protection.
OPPORTUNITIES	**THREATS**
Factor ENVIRONMENT	
Climate change - on average the winter severity will be lower including a shorter ice coverage period (which influences the beginning of spawning migration).	Climate change threat of increased intensity of more extreme weather-conditions. Higher temperature during summer-time may increase the blue-green blooms intensity and oxygen deficits.

Factor SOCIO-ECONOMIC	
EC funding - EC is actively supporting the development of the scientific basis for the policy implementation through various financial mechanisms (e.g. 7FP).	Unemployment - in general a negative consequences on local economy and social conditions.
EC funding - Fishery pressure is much lower recently due EC compensation for fishing boats dismantling.	Outflow of young people and aging of population - lack of sufficient governmental strategy to change/improve situation. In general a negative consequences on local economy and social conditions.
Factor GOVERNANCE	
The existing international environmental regulations - Helsinki Convention strong and proactive, Baltic Sea Action Plan, Natura 2000 area, Water Framework Directive (WFD).	EU/Non-EU states border - transboundary issues between EU and Non-EU countries are always demanding due to e.g. different legal systems and priorities.
	Natura 2000 area - Designation as a N2K area in additional to Opportunities creates various limitations to human activities (that could help in herring fishery support).
	Large catchment area - the most important stakeholders might be from the agriculture sector. Emphasis will be on the importance of linking CAP and CFP and WFD.

8.3 Sweden - Hanö Bight and Blekinge Archipelago

STRENGTHS	WEAKNESSES
Factor ENVIRONMENT	
Monitoring programmes are established since 1990 - It gives the capacity to analyse changes in the ecosystem of Hanö Bight according to hydrographic and biological aspects.	Eutrophication - high amount of streams and rivers having their outlet in Hanö Bight transporting nutrients from agriculture and other anthropogenic source.
A variable environment along the coast of Hanö Bight - The variability of the marine environment may increase the resilience of the living organisms living in that environment.	Signs indicating an ecosystem in bad condition - Fish disappearing from the coast and showing signs of malnutrition and wounds.
Large protected areas in the northern part of Skåne and in Blekinge archipelago - Nature reserves, Natura 2000 and Biosphere reserve are available tools for protecting and manage the area sustainably.	Monitoring program -The existing monitoring program has not been able to discover the reasons for the poor state of Hanö Bight.
	Monitoring program - There are lack of evaluation and quality check in the aspect of ecosystem analysis from the results of the monitoring programme
Factor SOCIO-ECONOMIC	
Touristic potential- Many opportunities for tourism development	Decrease in commercial fisheries - Poor water quality, poor condition of fish and overfishing.
Business potential-Good opportunities for establishing and developing business	Algal blooms negative effect on tourism - The accumulations of algal blooms close to the shore and beaches has a negative effect on tourist and summer visitors.

Factor GOVERNANCE	
Infrastructure projects - Expanding roads between the west coast to the east coast	Limited access of monitoring data - Difficulties in retrieving the marine biological data from the national data host.
OPPORTUNITIES	**THREATS**
Factor ENVIRONMENT	
Environmental projects - Creation of wetlands and ponds to prevent nutrients to reach the sea	Climate change - Large scale ecosystem changes that may have cascade effects at many trophic levels and changes in species composition
Phase out of private sewers - Planning on connecting all private sewers to the municipal sewer system	Emissions of various pollutants may together create an harmful cocktail effect that have a negative effect on specific marine organisms or the marine ecosystem
Protect herring spawning areas - Protect important spawning areas for herring with nature reserves and Natura 2000.	Physical disturbance and destruction of herring spawning ground
Develop monitoring programme - Evaluation and improvement of existing monitoring programme. Follow up monitoring of fish health and fish stock	Fisheries may have negative impact on spawning stock biomass
Develop monitoring programme - Monitor and increase knowledge about spawning areas and the spawning success of herring.	The knowledge is low regarding quality and the geographic distribution of spawning grounds for herring
Factor SOCIO-ECONOMIC	
Good communication possibilities - Good infrastructure makes the area accessible to locals working at other location then the study area, making the area more accessible	Unemployment- Lack of sufficient governmental strategy to change/improve situation
	Outflow of young people and aging of population - Lack of sufficient governmental strategy to change/improve situation
Factor GOVERNANCE	
Education and information centers - Develop centers for marine education and information to raise the public awareness.	Monitoring and protection of spawning areas for herring have a low priority
Improve infrastructure - Improving railroad and roads for better connections with the more populated west coast.	
Fiber network projects - Extend the fiber network making the area more accessible	

9. Best-practice approaches

Bearing in mind all the information presented in this report and especially the summary of human activities effect on environment and spawning success of herring in the three case studies, a set of best-practices approaches have been developed for each of them.

Germany - Greifswald Bay

- Preserve the status quo.
- Implement a precautionary approach and avoid or reduce all direct and indirect stressors which negatively affect spawning grounds.
- Identify individual spawning grounds along the Mecklenburg-Western Pomerania coast.

- Establish an extensive monitoring program for the major spawning area of WBSSH, including abiotic parameters, nutrient and pollution concentrations, and extensive mapping of macrophyte coverage in GWB.
- Include spawning grounds and macrophyte habitats in existing protection concepts.

Poland - Vistula Lagoon

- Increase the awareness of the possible effects of human activities on herring spawning grounds in local society and among relevant stakeholders.
- Increase the importance of herring fishery for local community (price of herring, fishing quotas, infrastructure development).
- Establish research program to describe (to map) the distribution of herring spawning grounds in the Vistula Lagoon and along the Polish coast.
- Implement precautionary approach to reduce the effects of human activities on herring spawning grounds.
- Increase the cooperation with Russia in activities related to research and management in the Vistula Lagoon area.

Sweden - Hanö Bight and Blekinge Archipelago

- Improve knowledge about the location of important herring spawning grounds by establishing a monitoring program that extend over a long period of time, in order to distinguish patterns and changes in the environment of the locations and of the herring spawning behavior.
- Evaluate continuously the existing environmental monitoring program for its ability of determining the status and detecting changes in the marine environment.
- Identify the human activities that may have a direct or indirect negative impact on herring spawning grounds.
- Raise awareness of the importance of protecting spawning grounds for herring and include these areas in marine spatial planning to minimize negative human impact.
- Include fisheries, political authorities and relevant stakeholders to determine the best course of action to protect herring spawning areas and how to improve the opportunities for successful spawning in order to increase recruitment to the herring stock.

There are some differences in the best-practice approaches developed for each of the case studies but one issue is common. It is the need for knowledge improvement about the location of herring spawning grounds. Without as precise as possible description of the herring spawning grounds distribution, effective protection of those areas from harmful human impacts is not possible. Depending on financing possibilities, a short-time research projects or long-term monitoring programs should be established not only in this project case study areas but also in the other potentially important herring spawning areas.

References

Aho T, Ask I, Axenrot T, Bergström L, Bergquist B, Bogelius A, Dahlberg M, Dahlström M, Degerman E, Funegård P, Florin A-B, Gustavsson T, Johannesson J, Jonsson A, Lundström K, Lunneryd S-G, Mattson Y, Mo K, Modin j, Nordwall F, Nyberg P, Plsson J, Petterson E, Sandström A, Sjöstrand B, Sköld M, Svedäng H, Ulmestrand M, Valentinsson D, Westerberg H, Åsgård B, Öresland V. 2009. Fiskebestånd och miljö I hav och sötvatten – Resurs- och miljööversikt 2009. Fiskeriverket

Allen JRM, Wootton RJ. 1982. The effect of ration and temperature on the growth of the three-spined stickleback, Gasterosteus aculeatus L. Journal of Fish Biology 20: 409-422, doi:10.1111/j.1095-8649.1982.tb03934.x

Andersson M, Appelberg M, Axenrot T, Bartolino V, Beier U, Bergenius M, Bergström L, Bergström U, Boström M, Massimiliano C, Casini M, Degerman E, Dannewitz J, Edsman L, Florin A-B, Gebel Frida, Gårdsmark A, Hammar J, Karlsson M, KönIgson S, Lingman A, Lundström K, Lunneryd S-G, Mo K, Ovegård M, Palm S, Petersson E, Ragnarsson S, Sandström A, Sjöstrand B, Sköld M, Svedäng H, Werner M, Westerberg H and Wickström H. 2012. Fiskebestånd och miljö I hav och sötvatten, Resurs- och miljööversikt 2012. Rapporten har skrivits av SLU, institutionen för akvatiska resurser på uppdrag av Havs- och vattenmyndigheten

Aneer G. 1989. Herring (*Clupea harengus* L.) spawning and spawning ground characteristics in the Baltic Sea, Fisheries Research 8(2): 169-195

Aneer G, Florell G, Kautsky U, Nellbring S, Sjöstedt L. 1983. In-situ observations of Baltic herring (*Clupea harengus membras*) spawning behaviour in the Askö-Landsort area, northern Baltic proper, Marine Biology 74: 105-110

Anonymous. 2005. Raport o stanie środowiska województwa pomorskiego według badań monitoringowych przeprowadzonych w 2004 roku, Inspekcja Ochrony środowiska, Wojewódzki Inspektorat Ochrony Środowiska, Biblioteka Monitoringu Środowiska, Gdańsk, 2005, 1-149

Arrhenius F. 1995. Bioenergetics of young-of-the year herring (Clupea harengus) and a revision of bioenergetics model, [in:] Feeding ecology of Baltic Sea herring (Clupea harengus L.) – field and model studies of a dominant zooplanktivor, ed. F. Arrhenius, Stockholm, Sweden, 1-16

Barko JW, Adams MS, Clesceri NL. 1986. Environmental Factors and their Consideration in the Management of Submersed Aquatic Vegetation: A Review. J. Aquat. Plant Manage. 24: 1-10

Barko JW, Smart RM. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67: 1328-1340

Bogdanowicz R. 1998. Hydrologiczne i antropogeniczne uwarunkowania zmienności zanieczyszczeń wód powierzchniowych zlewni Zalewu Wiślanego, [w:] Hydrologia u progu XXI wieku, wyd. Retro-Art., Warszawa, 51-60

Casini M, Cardinale M, Arrhenius F. 2004. Feeding preferences of herring (Clupea harengus) and sprat (Sprattus sprattus) in the southern Baltic Sea. – ICES Journal of Marine Science 61: 1267 – 1277

Cardinale M, Arrhenius F. 2000. Decreasing weight-at-age of Atlantic herring (Clupea harengus) from the Baltic Sea between 1986 and 1996: a statistical analysis. ICES J. Mar. Sci. 57: 882-893

Chubarenko B. 2008. Shared watersheds in the South-East Baltic, [in:] Transboundary waters and basins in the South-East Baltic, ed. B. Chubarenko, Kaliningrad, Terra Baltica, 7-21

Chubarenko I, Tchepikova I. 2001. Modelling of man-made contribution to salinity increase into the Vistula Lagoon (Baltic Sea), Ecological Modelling 138: 87-100

Dziaduch D. 2011. Diet composition of herring (*Clupea harengus* L.) and cod (*Gadus morhua* L.) in the southern Baltic Sea in 2007 and 2008, Oceanological and Hydrobiological Studies 40(4): 96-109

Elmer S. 1983. Undersökning av sillens reproduktionsområde I Blekinge skärgård 1980 -1982. Meddelande från havsfiskelaboratoriet, Lysekil.

Geffen AJ. 2009. Advances in herring biology: from simple to complex, coping with plasticity and adaptability, ICES Journal of Marine Science 66: 1688-1695

Haegele CW, Schweigert JF. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1): 39-55

HELCOM 2005.

Holliday FGT, Blaxter JHS. 1960. The effects of salinity on the developing eggs and larvae of the herring. Journal of the Marine Biological Association of the United Kingdom 39: 591-603, doi:10.1017/S0025315400013564

Holliday FGT, Blaxter JHS, Lasker R. 1964. Oxygen Uptake of Developing Eggs and Larvae of the Herring (Clupea Harengus). Journal of the Marine Biological Association of the United Kingdom 44: 711-723, doi:10.1017/S0025315400027880

ICES WGBFAS 2012. Report of the Baltic Fisheries Assessment Working Group 2012 (WGBFAS) 12-19 April 2012, ICES Headquarters, Copenhagen, ICES CM 2012/ACOM:12

Kiørboe T, Frantsen E, Jensen C, Sørensen G. 1981. Effects of suspended sediment on development and hatching of herring (Clupea harengus) eggs. Estuarine, Coastal and Shelf Science 13: 107-111, doi:http://dx.doi.org/10.1016/S0302-3524(81)80109-0

Klinkhardt M. 1996. Der Hering: Clupea harengus. Spektrum Akademischer Verlag 1996

Krasovskaya N. 2002. Spawning grounds and empronial development of Baltic herring in the Gulf of Riga. Thesis of Dr. diss. Latv. Univ. Riga, 1-40.

Kwiecień K. 1975. Klimat i warunki synoptyczne, Wiatr, [w:] Hydrometeorologiczny ustrój Zalewu Wiślanego, red. N.N. Łazarienko, A. Majewski, Wydawnictwa Komunikacji i Łączności, Warszawa, 92-99.

Linkowski TB, Fey DP, Wyszyński M. 2001. Spring vs. autumn spawners of the Baltic herring on the basis of otolith microstructure and morphology, Working Document submitted to the ICES SG on Herring Asseeement Units in the Baltic Sea, Meeting in Copenhagen, January, 2001, 21-24

Łomniewski K. 1958. Zalew Wiślany, Prace Geograficzne 5: 1-106

Möllmann C, Kornilovs G, Fetter M, Köster FW. 2004. Feeding ecology of central Baltic Sea herring and sprat, Journal of Fish Biology 65: 1563-1581

Munkes B. 2005. Eutrophication, phase shift, the delay and the potential return in the Greifswalder Bodden, Baltic Sea. Aquat. Sci. 67: 372-381, doi:10.1007/s00027-005-0761-x

Ojaveer E. 1981. Influence of temperature, salinity, and reproductive mixing of Baltic herring groups on its embryonal development, [in:] The Early Life History of Fish: Recent Studies, Rapports et Proces-Verbaux des Reunions du Conseil International pour L'Exploration de la Mer, eds. R. Lasker, K. Sherman, Northwest Atlantic Fisheries Organization, Dartmouth, Nova Scotia, Canada, 178: 409-415

Ojaveer E, Arula T, Lankov A, Shpilev H. 2011. Imapact of environmental deviations on the larval and year-class abundances in the spring spawning herring (*Clupea harengus membras* L.) of the Gulf of Riga (Baltic Sea) in 1947-2004, Fisheries Research 107: 159-168.

Parmanne R, Rechlin O, Sjöstrand B. 1994. Status and future of herring and sprat stocks in the Baltic Sea. Dana 10: 29-59.

Podolska M, Horbowy J, Wyszyński M. 2006. Discrimination of Baltic herring populations with respect to *Anisakis simplex* larvae infection, Journal of Fish Biology 68: 1241-1256

Rajasilta M, Eklund J, Hänninen J, Kurkilahti M, Kääriä J, Rannikko P, Soikkeli M. 1993. Spawning of herring (*Clupea harengus membras* L.) in the Archipelago Sea, ICES Journal of Marine Science 50: 233-246

Rajasilta M, Laine P, Eklund J. 2006. Mortality of herring eggs on different algal substrates (Furcellaria spp. And Cladophora spp.) in the Baltic Sea – an experimental study. Hydrobiologia 554: 127-130

Rajasilta M, Laine P, Hänninen J. 2001. Ovarian weight of the Baltic herring (Clupea harengus membras) in relation to spawning time in the Archipelago Sea, northern Baltic. ICES Journal of Marine Science 58: 106-113.

Rannak LA. 1958. Quantitative study of the Baltic herring eggs and larvae in the northern part of the Gulf of Riga and principle factors determing their survival. Trudy VN1RO (In Russian translation by Fish. Res. Bd. Can., No. 238) 34: 7-18

Renk H, Ochocki S, Zalewski M, Chmielowski H. 2001. Environmental factors controlling primary production in the Polish part of the Vistula Lagoon. Bull Sea Fisheries Inst 1:77–95

Rose GA. 2005. On distributional responses of North Atlantic fish to climate change. ICES J Mar Sci 62: 1360-1374

Różanska Z, Więcławski. F. 1978. Warunki środowiskowe Zalewu Wiślanego, Studia i Materiały Oceanologiczne 21, Biologia Morza 4: 9-36.

Rönkkönen S, Ojaveer E, Raid T, Viitasalo M. 2004. Long-term changes in Baltic herring (Clupea harengus membras) growth in the Gulf of Finland, Canadian Journal of Fisheries and Aquatic Sciences 61: 219-229

Sætre R, Toresen R, Søiland H, Fossum P. 2002b. The Norwegian spring-spawning herring – spawning, larval drift and larval retention. Sarsia 87: 167-178.

SMHI 2009. http://www.smhi.se/kunskapsbanken/oceanografi/uppvallning-1.6002

SMHI 2011. SMHI Faktablad nr 52-2011, Strömmar i Svenska hav.

Tomczak MT. 2006. Ocena gospodarowania zasobami śledzi (*Clupea harengus membras* L.) centralnego Bałtyku, Praca doktorska, Uniwersytet Gdański, Gdynia, 1-126.

Urho L. 1992, Morphological and ecological differences in the development of smelt and herring larvae in the northern Baltic Sea, Sarsia 77: 1-10.

Urho L, Hildén M. 1990. Distribution patterns of Baltic herring larvae, *Clupea harengus* L., in the coastal waters off Helsinki, Finland, Journal of Plankton Research 12: 41-54

Zagarese HE, Williamson CE. 2001. The implications of solar UV radiation exposure for fish and fisheries. Fish and Fisheries 2: 250-260, doi:10.1046/j.1467-2960.2001.00048.x

Żmudziński L, Szarejko D. 1955. Badania hydrograficzno-biologiczne Zalewu Wiślanego, Prace Morskiego Instytutu Rybackiego w Gdyni 8: 283-312

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