2008-03-31

FISKERIVERKET

Consultancy Reports

1.

Risk analysis: ecological consequences of sprat reduction in the Baltic Sea.

2.

Evaluation and assessment of the risk that no effects will be detected.

Report 1. Risk analysis: ecological consequences of sprat reduction in the Baltic Sea.

Patrik Börjesson/PB MiljöData

Introduction

The rationale behind the zooplanktivore reduction project is to aid rebuilding populations of predatory fish. This will be achieved through experimentally reduced predation on zooplankton, which in turn regulates the phytoplankton community, and reduced competition between sprat and juveniles of other fish species. However, removal of a dominating zooplanktivore could also; *i*) result in changed interactions in the zooplankton community, *ii*) lead to competitive release for other zooplanktivores, and *iii*) force higher trophic level consumers to change foraging behaviour and/or foraging areas. In addition, the fishing effort needed to significantly reduce sprat biomass may result in more incidental catches of other fish, seabirds and mammals, as well as in physical disturbance in costal habitats.

The present report includes a qualitative assessment of ecological risks that can be associated with an increased catch of sprat to promote populations of predatory fish in coastal areas of the Baltic Sea. Subjects that will be treated are how this could affect other zooplanktivores, specifically the newly invaded species *Mnemiopsis leidyi*, how populations of herring and other fish species could be affected and potential consequences for seabirds and marine mammals. The report also briefly discusses the fishing effort needed to obtain measurable results and criteria for identifying suitable areas for the experiment.

Jellyfish and comb jellies

Mass occurrence of gelatinous species is known to cause significant negative impact on human activities. Predatory species feed on zooplankton, effectively reducing the food available for other zooplanktivores and changing the zooplankton community. They also eat fish eggs and larvae thereby reducing fish populations directly. Local mass occurrences can impact coastal industries and power plants by clogging water intakes needed for cooling systems. Large catches of jellyfish can damage fishing gear and ruin the catch (reviewed by Purcell et al. 2007).

Until recently, only two gelatinous species were widespread in the Baltic Sea; the scyphomedusae *Aurelia aurita* (Moon jellyfish) and the ctenophore *Pleurobrachia pileus* (Sea Gooseberry). Mass occurrence of *A. aurita* is known from the Baltic and negative impact of local blooms on survival of larval herring and clogging of water intakes have been reported (Möller 1984). A few additional marine species frequently occur in the south-western Baltic (Scyphozoa: *Cyanea capillata*; Ctenophora: *Bolinopsis infundibulum*, *Beroe cucumis* and *B. gracilis*) but further expansion are restricted by low salinities. In 2006, a new species, the ctenophore *Mnemiopsis leidyi* (American comb jelly) was reported in the Baltic Sea.

Mnemiopsis leidyi is a euryhaline, eurythermal species with high reproductive and growth potential. Populations are regulated by temperature, food availability and predation (Kremer 1994). The most critical time for *Mnemiopsis* survival is winter since it cannot survive in low salinity water when temperatures are low (Shiganova 1998). Biomass normally peaks in August – September, depending on temperature and food availability. The main food items are copepods, copepod nauplii, cladocerans and bivalve veligers (Purcell et al. 2001). In the Caspian Sea *Mnemiopsis* was estimated to consume 30-40% per day of the mesozooplankton and 20-25% per day of the microzooplankton (Finenko et al. 2006). *Mnemiopsis* also prey on fish eggs and larvae. In Chesapeake Bay it has been estimated that the *Mnemiopsis* populations are capable of clearing 30-100% per day of anchovy eggs and 5% per day of the larvae. However, in mesocosm experiments, predation on eggs and larvae was reduced by 36% and 91% respectively, in the presence of zooplankton (Purcell et al. 2001). The most important predators on *Mnemiopsis* are the scyphomedusae *Crysaora quinquecirra* and ctenophores of the genus *Beroe*, foremost *B. ovata*. Harvest fish and butterfish are known predators on *Mnemiopsis*, but several other fish species, among them mackerel, saithe and spiny dogfish, are known to consume gelatinous prey (Arai 2005).

In the Baltic Sea, *Mnemiopsis leidyi* was first observed in the Kiel Bight in autumn 2006 (Javidpour et al. 2006). Following successful overwintering and rapid spread the species has now been documented from the south-western parts of the Baltic to the Bothnian Sea and in the Gulf of Finland (Kube et al. 2007; Haslob et al. 2007; Janas and Zgrundo 2007; Lehtiniemi et al. 2007). It is possible that the rapid expansion was possible because of the exceptional mild winter 2006/2007 and that the population will be kept under control during average climate conditions (Javidpour et al. 2006). However, *Mnemiopsis* in the Baltic appear to be most abundant below the halocline where temperature and salinity is relatively stable (Haslob et al. 2007; Lehtiniemi et al. 2007). Observations of eggs, newly hatched larvae and juvenile stages indicate that reproduction occur at lower temperatures than previously reported (Lehtiniemi et al. 2007)

The combination of an available overwintering refuge and successful reproduction clearly indicate that *Mnemiopsis* is established in the Baltic Sea. If a species will become invasive, i.e., if it will cause ecological, environmental or economical harm, is difficult to predict. The best predictor probably is whether it is invasive in other similar systems where it has been introduced. The situation in the Baltic Sea is many ways similar to that in the Black Sea where *Mnemiopsis* was accidentally introduced in the early 1980s. Both systems have experienced radically reduced populations of piscivores (e.g. seals, cetaceans and fish), extensive eutrophication and intensive fishing on zooplanktivorous fish (Daskalov et al 2007; Österblom et al 2007).

Mnemiopsis leidyi was first observed in the Black Sea in 1982. By 1988 it had spread throughout the Black Sea and in 1989 the highest abundance and biomass was recorded (Purcell et al. 2001). Since then recurring blooms has taken place, and the species has invaded the Sea of Azov, Sea of Marmara and the Caspian Sea (Shiganova et al 2001.) Major changes in the Black Sea ecosystem have been attributed to the outbreaks of *Mnemiopsis* including reduced zooplankton abundance, low survival of fish eggs and larvae, and collapse of other zooplanktivore populations (Purcell et al. 2001 and references therein). It should be kept in mind that *Mnemiopsis* was present in the system for a number of years before the first mass occurrences took place, probably triggered by overfishing and collapse of planktivorous fish stocks (Bilio and Nierma 2004; Daskalov et al. 2007). Purcell et al. (2001) concluded that the impact of *Mnemiopsis* on the Black Sea ecosystem probably occurred because of the shortage of competition and predation. Supportive evidence for this comes from the observation that following reduced fishing pressure on planktivorous fish and accidental introduction of the predator *Beroe ovata*, the *Mnemiopsis* population decreased and the zooplankton community began to recover (Shiganova et al. 2001; Daskalov et al. 2007). Based on the experience from the Black Sea and adjacent seas it seems possible that *Mnemiopsis* will have adverse affects on zooplankton and planktivore abundance in the Baltic Sea. It would therefore be rash to perform a large-scale reduction of sprat until sufficient data on population dynamics of *Mnemiopsis* in the Baltic have been acquired.

Experiments involving small-scale biomass reduction of coastal sprat will not likely result in major outbreaks, although local blooms of *Mnemiopsis* or *Aurelia* could occur. Local blooms would probably have negative consequences for the project, i.e. the experiment may not generate measurable results, but are not likely to spread to other areas. The abundance of sprat and herring will still be high in neighbouring areas, thus termination of the reduction fishery can be expected to restore competitive interactions in a similar way to what have been observed when the fishing pressure on planktivorous fish in the Black Sea was reduced.

Crustacean

More than 20 species of mysid shrimps occur in the Baltic Sea, but only seven are common past the Arkona basin. *Mysis mixta* and two sibling species of *M. relicta* are pelagic, whereas the remaining four are distributed mainly within the littoral zone (Viherluoto 2001). Together with sprat and herring, mysids are the dominating pelagic zooplanktivores in the Baltic Sea and therefore potential competitors for food (Hansson et al 1990; Rudstam et al. 1992). Field measurements and experiments on *M. mixta* show that the species is food limited (Hansson et al. 1990; Mohammadian et al. 1997). There is therefore a risk that effects of the experimental reduction in sprat biomass on zooplankton abundance will be masked by rapid population growth and increased predation on zooplankton by mysids. Mysids in the Baltic Sea are eaten, for example, by adult herring and perch so an increase in mysid abundance could lead to improved population growth and condition status in these commercially important species.

Fish

Sprat and small herring in the Baltic are strictly zooplanktivores feeding on mesozooplankton. The diet is dominated by the calanoid copepods *Temora longicornis*, *Pseudocalanus elongatus* and the cladoceran *Bosmina maritima* (Casini et al. 2004; Möllmann et al. 2004). Sprat is a size-selective feeder, feeding almost exclusively on the oldest copepodite stages (Möllmann et al. 2004). Reduction in sprat abundance would therefore result in lower predation on the larger size classes of mesozooplankton. Some mesozooplankton may prey on ciliates and other microplankton rather than feeding on phytoplankton (Granéli and Turner 2002) therefore increased abundance of mesozooplankton could result in smaller increases in grazing intensity than anticipated.

There is a significant overlap in diet among sprat and small herring, whereas older herring feed more on nektobenthos such as mysids, amphipods and polychaetes (Rudstam et al. 1992; Casini et al. 2004, Möllmann et al. 2004). A reduction in sprat biomass would therefore initially affect growth and condition of sprat and small herring but older herring could also be expected to respond positively on reduced abundance of sprat. Similarly, other planktivorous species such as cyprinids could be expected to experience increased food availability and improved growth conditions. In lake systems it has been shown that cyprinids are capable to depress perch through competitive interactions. However, an analysis of late summer abundance of juvenile fish 1989-2003 in inlets along the Swedish Baltic coast revealed no patterns indicating that high abundance of cyprinids would have negative effects on the abundance of either perch or pike (Ljunggren pers com).

Seabirds

A variety of marine birds feed on clupeids and can thus be expected to respond to changes in sprat abundance. For example, population dynamics of lesser black-backed gull appears to be correlated with clupeid abundance (Lyngs 1992; Lif et al. 2005) and fledging body mass in common guillemots responds rapidly to changes in sprat abundance and condition (Österblom et al. 2002; 2006). Common guillemots in the Baltic feed their chicks almost exclusively on sprat, however, energy content per item appears to be more important than the number of food items per se (Lyngs and Durinck 1998; Österblom et al. 2006). Thus, although local removal of sprat within reasonable distance of breeding colonies could result in lower feeding rates and higher mortality it could also be beneficial for some species, if biomass reduction result in improved condition of remaining sprat.

Great cormorants in the Baltic have undergone a spectacular population development since the early 1980s (Engström and Pettersson 2003). Cormorants are capable of feeding on a variety of fish, but abundant species usually contributes most to the diet (Engström and Pettersson 2003; Andersen et al 2007). According to available data, sprat does not seem to constitute an important part of the cormorant diet in the Baltic (Engström and Pettersson 2003; Boström 2006), however, most of this data was collected in the mid-1990s and the situation may have changed. It is therefore possible that local removal of sprat could result in increased predation by cormorants on other fish species, but lack of data (recent diet analyses) makes it difficult to evaluate this risk.

Marine mammals

Marine mammals in the Baltic mainly feed on fish. Analyses of stomach contents indicate that herring is the principal prey for both grey seals (Söderberg 1972; Lundström et al. 2007) and harbour porpoises (Lindroth 1962; Aarefjord et al. 1995, Börjesson unpublished data). Other important prey for grey seals are common whitefish, cyprinids, flounder, sprat and cod (only the latter two occurred frequently in porpoise stomachs). Ringed seals feed on herring, sculpin and benthic prey but also on the isopod Saduria *entomon*. Harbour seals are described as opportunistic foragers, feeding on locally and seasonally abundant species. Data from the Baltic is not available but studies of nearby populations indicate that the diet largely consists of clupeids, cod and flatfish (Härkönen 1987; Härkönen and Heide-Jörgensen 1991; Andersen et al. 2007).

Based on available information on abundance, distribution and feeding ecology of marine mammals in the Baltic Sea it can be concluded that there is low risk that a reduction in sprat biomass will have negative effect on the populations. If biomass reduction results in increased growth and condition of sprat and herring it may even lead to improved feeding conditions. However, care should be taken that an increased effort in fishing does not lead to higher bycatch, disturbance at haulout sites or on feeding grounds. Special consideration is needed for the harbour seal in Kalmar sound since this is the only locality for this species.

Fishing effort needed to obtain measurable results

Analyses of simulated data was performed in order to evaluate the risk of no or masked effects of an experimental reduction in sprat biomass in ICES subdivision 27 (Börjesson unpubl). To date, three response variables have been examined; condition in sprat (age 1-5), condition in herring (age 1), and condition in herring (age 2-5). Only condition in sprat (age 1-5) turned out to be of practical use for the experiment. Back-calculation of target sprat biomass in subdivision 27 gave a point estimate of 58 000 tonnes (one-sided PI = -154 000 tonnes). Based on the estimated sprat biomass in subdivision 27 during 2002-2006 the annual removal need to be in the range 35%-82% (mean 62%), which is comparable to the 70-80% recommended in bio-manipulation of freshwater lakes (Hansson 2008). A biomass reduction of this magnitude is probably not practicable for logistic reasons and not recommended for ecological reasons since it could trigger an outburst of *Mnemiopsis*. However, assuming that sprat is relatively non-migratory (Hansson et al. 1997) sufficient biomass reduction may be feasible on a local scale in coastal areas.

Criteria for identifying suitable areas for the experiment

Based on the main objectives and the identified risks associated with an increased take of sprat, a list of criteria to be used when selecting experimental areas has been put together. The criteria are not conclusive but ought to be considered when selecting areas for the experiment.

Criteria in support for use as experimental areas:

- *Available time series for relevant organisms and environmental data* – This is probably the most important criterion since it is needed for evaluation of treatment effects. This is central both for experimental design and for designs including before – after treatment effects.
- *Recent history as nursery area for perch and pike* – Presences of juvenile stages of predatory fish (target organisms in the project) that can benefit from the experimentally reduced competition with zooplanktivores are mandatory for selection of experimental areas. Areas with recent history as nursery areas for perch and pike are considered primary candidates.
- *High densities of sprat and/or sticklebacks* – Zooplankton predation and competition between zooplanktivores and juvenile stages of predatory fish have likely been most intense in areas with high densities of sprat and/or sticklebacks. In such areas it will be possible to vary effect size (i.e. reduction of zooplanktivores) to a larger extent and to obtain sufficient power for the experimental design.
- *Suitable geography for the experimental design* – Given the experimental design the choice of experimental area will depend on the local geography, e.g. is it possible to exclude fish using fine-meshed nets, and availability of representative control areas.

Criteria against use as experimental areas:

- *High bycatch risk for cod, seabirds and mammals* – Local increase in fishing effort can result in higher incidental catches of cod, seabirds and mammals. For cod and harbour seals in ICES subdivision 27, the risk of bycatch is highest in the southern part, whereas for grey seals the risk is highest in the northern parts. Incidental catches should be monitored so that they do not reach unacceptable levels.
- *Power plants, industries and aquacultures dependent on reliable supply of seawater* – Local mass occurrence of gelatinous species can clog water intakes and ruin fish in aquaculture pens. Efforts should be made to minimize the consequences of jellyfish blooms that can be triggered by the reduction fishery.
- *Seabird and seal colonies* – Sufficient reduction of sprat biomass will need a significant increase in fishing effort. To minimize disturbances on seabirds and seals, adequate distance should be maintained to protected colonies and haulout sites. For harbour seals the recommended distance is 30 km.
- *Migratory routes for diadromous fish* – Efforts should be made to avoid net enclosures and intensive trawling along important migratory routes for diadromous fish.

Acknowledgement

This report was funded by The Björn Carlson Foundation Baltic Sea 2020.

References

Aarefjord H, Bjørge AJ, Kinze CC, Lindstedt I (1995) Diet of the harbour porpoise (*Phocoena phocoena*) in Scandinavian waters. Rep Int Whal Commn (special issue) 16: 211-222

Andersen SM, Teilmann J, Harders PB, Hansen EH, Hjollund D (2007) Diet of harbour seals and great cormorants in Limfjord, Denmark: interspecific competition and interaction with fishery. ICES J Mar Sci 64: 1235-1245

Arai MN (2005) Predation on pelagic coelenterates: a review. J Mar Biol Ass UK 85: 523-536

Bilio M, Niermann U (2004) Is the comb jelly really to blame for it all? *Mnemiopsis leidyi* and the ecological concerns about the Caspian Sea. Mar Ecol Prog Ser 269:173-183

Boström M (2006) Cormorant diet assessment; impact on commercially important fish. Honours thesis Lund University, Lund, Sweden

Casini M, Cardinale M, Arrhenius F (2004) Feeding preferences of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in the southern Baltic Sea. ICES J Mar Sci 61: 1267-1277

Daskalov GM, Grishin AN, Rodionov S, Mihneva V (2007) Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem shift. PNAS 104: 10518-10523

Engström H, Pettersson C (2003) Förvaltningsplan för mellanskarv och storskarv. Naturvårdsverket. Rapport 5261, 48 pp. In Swedish with English summary

Finenko GA, Kideys AE, Anninsky BE, Shiganova TA, Roohi A, Tabari MR, Rostami H, Bagheri S (2006) Invasive ctenophore *Mnemiopsis leidyi* in the Caspian Sea:

feeding, respiration, reproduction, and predatory impact on the zooplankton community. Mar Ecol Prog Ser 314: 171-185

Granéli E, Turner JT (2002) Top-down regulation in ctenophore-copepod-ciliate-diatom-phytoflagellate communities in coastal waters: a mesocosm study. Mar Ecol Prog Ser 239: 57-68

Hansson LA (2008) Biomanipulering som restaureringsverktyg: kunskapssammanställning för limniska och marina system. Report to the Swedish Environmental Protection Agency. In Swedish.

Hansson S, Hobbie JE, Elmgren R, Larsson U, Fry B, Johansson S (1997) The stable nitrogen isotope ration as a marker of food-web interactions and fish migration. Ecology 78: 2249-2257

Hansson S, Rudstam LG, Johansson S (1990) Are marine planktonic invertebrates food limited? The case of *Mysis mixta* (Crustacea, Mysidacea) in the Baltic Sea. Oecologia 84: 430-432

Härkönen T (1987) Seasonal and regional variations in the feeding habits of the harbour seal, *Phoca vitulina*, in the Skagerrak and the Kattegat. J Zool 213: 535-543

Härkönen T, Heide-Jörgensen MO (1991) The harbor seal *Phoca vitulina* as a predator in the Skagerrak. Ophelia 34: 191-207

Haslob H, Clemmesen C, Schaber M, Hinrichsen HH, Schmidt JO, Voss R, Kraus G, Köster FW (2007) Invading *Mnemiopsis leidyi* as a potential threat to Baltic fish. Mar Ecol Prog Ser 349: 303-306

Ivanov VP, Kamakin AM, Ushivtzev VB, Shiganova T, Zhukova O, Aladin N, Wilson SI, Harbison GR Dumont HJ (2000) Invasion of the Caspian Sea by the comb jellyfish *Mnemiopsis leidyi* (Ctenophora). Biological Invasions 2: 255-258

Janas U, Zgrundo A (2007) First record of *Mnemiopsis leidyi* A. Agassiz, 1865 in the Gulf of Gdansk (southern Baltic Sea. Aquatic Invasions 2: 450-454

Javidpour J, Sommer U, Shiganova T (2006) First record of *Mnemiopsis leidyi* A. Agassiz 1865 in the Baltic Sea. Aquatic Invasions 1:299-302

Kremer P (1994) Patterns of abundance for *Mnemiopsis* in US coastal waters – a comparative overview. ICES J Mar Sci 51:347-354

Kube S, Postel L, Honnef C, Augustin CB (2007) *Mnemiopsis leidyi* in the Baltic Sea – distribution and overwintering between autumn 2006 and spring 2007. Aquatic Invasions 2: 137 – 145

Lehtiniemi M, Pääkkönen, J-P, Flinkman J, Katajisto T, Gorokhova E, Karjalainen M, Viitasalo S, Björk H. (2007) Distribution and abundance of the American comb jelly (*Mnemiopsis leidyi*) – A rapid invasion to the northern Baltic Sea during 2007.

Lif M, Hjernquist M, Olsson O, Österblom H (2005) Long-term population trends in the Lesser Black-backed Gull *Laurus f.* f*uscus* at Stora Karlsö and Lilla Karlsö, and initial results on breeding success. Ornis Svecica 15: 105-112

Lindroth A (1962) Baltic salmon fluctuations 2: porpoise and salmon. Rep Inst Freshwater Res Drottningholm 44:105-112

Lundström K, Hjerne O, Alexandersson K, Karlsson O (2007) Estimation of grey seal (*Halichoerus grypus*) diet composition in the Baltic Sea. Namco Sci Publ 6: 177-196

Lyngs P (1992) Ynglefuglene på Græsholmen 1925– 90. Dan Orn Foren Tidsskr 86: 1–93

Lyngs P, Durinck J (1998) Diet of Guillemots *Uria aalge* in the central Baltic Sea. Dan Orn Foren Tidsskr 92): 197-200

Mohammadian MA, Hansson S, Stasio BT (1997) Are marine planktonic invertebrates food limited? The functional response of *Mysis mixta* (Crustacea, Mysidacea) in the Baltic Sea. Mar Ecol Prog Ser 150: 113-119

Möller H (1984) Reduction of a larval herring population by jellyfish predator. Science 224: 621-622

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

Österblom H, Bignert A, Fransson T, Olsson O (2001) A decrease in fledging body mass in common guillemot *Uria aalge* chicks in the Baltic Sea. Mar Ecol Prog Ser 224: 305-309

Österblom H, Casini M, Olsson O, Bignert A (2006) Fish, seabirds and trophic cascades in the Baltic Sea. Mar Ecol Prog Ser 323: 233-238

Österblom H, Hansson S, Larsson U, Hjerne O, Wulff F, Elmgren R, Folke C (2007) Human-induced trophic cascades and ecological regime shift in the Baltic Sea. Ecosystems 10: 877-889

Purcell JE, Shiganova TA, Decker MB, Houde ED (2001) The ctenophore *Mnemiopsis* in native and exotic habitats: U.S. estuaries versus the Black Sea basin. Hydrobiologia 451: 145–176

Purcell JE, Uye S, Lo WT (2007) Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Mar Ecol Prog Ser 350: 153-174

Rudstam LG, Hansson S, Johansson S, Larsson U (1992) Dynamics of planktivory in a coastal area of the northern Baltic Sea. Mar Ecol Prog Ser 80: 159-173

Shiganova TA (1998) Invasion of the Black Sea by the ctenophore *Mnemiopsis leidyi* and a recent change in pelagic community structure. Fish Oceanogr 7: 305-310

Shiganova TA, Bulgakova YV, Volovik SP et al (2001) The new invader *Beroe ovata* Mayer 1912 and its effect on the ecosystem in the north-eastern Black Sea. Hydrobiologia 451: 187-197

Söderberg S (1972) Sälens födoval och skadegörelse på laxfisket i Östersjön. Undersökning på uppdrag av Svenska Ostkustfiskares Centralförbund.60 pp. In Swedish

Viherluoto M (2001) Food selection and feeding behaviour of Baltic Sea mysid shrimps. PhD thesis, University of Helsinki, Helsinki, Finland

Report 2. Evaluation and assessment of the risk that no effects will be detected.

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Summary

Analyses of simulated data was performed in order to evaluate the risk of no or masked effects of experimental reduction in sprat biomass in ICES subdivision 27. Only condition in sprat (age 1-5) turned out to be of practical use for the experiment. Back-calculation based on the minimum effect size that would be detectable at $\alpha = 0.05$ with a power of 0.80 gave a point estimate of 58 000 tonnes (one-sided PI = -154 000 tonnes) for the target sprat biomass in subdivision 27. Based on the estimated biomass during the last 5 years the reduction in sprat biomass need to be on average 62% (range 35%-82%) to reach the point estimate. Other response variables, for example zooplankton abundance, can and should be simulated in a similar fashion. It would probably also be worthwhile to redo the power analyses on estimates of potential sprat removal reduction based on available resources.

Introduction

Analyses of simulated data was performed in order to evaluate the risk of no or masked effects of experimental reduction in sprat biomass in ICES subdivision 27. To date 3 response variables have been examined; condition in sprat (age 1-5), condition in herring (age 1), and condition in herring (age 2-5). Other response variables can and should be simulated in a similar fashion, for example zooplankton abundance, but data for this is not yet available.

The available data comes from acoustic surveys undertaken in the Baltic Sea. These surveys have been carried out for the last 30 years but only data from 1991 and forward were available at this point. The main survey takes place in autumn (October) but some spring data have also been collected (not used here). Data are presented as abundance or biomass by ICES rectangle and by subdivision. Estimated biomass is calculated from the abundance estimate and the biological samples taken during the survey (two trawl hauls per rectangle). The biological samples are also used to estimate condition for sprat and herring. Two sets of condition index data was available for analyses; weight-at-length and Fulton's condition factor (*K*). Weight-at-length is estimated as the weight at, for sprat 120 mm length and for herring 200 mm length, based on the regression of weight on length for all individuals caught per ICES subdivision and year. Weight-at length was not used in the simulations due to the lack of replication within areas, i.e. only one data point was available for each subdivision and year. Fulton's condition factor is calculated as; $K = \text{body mass} / \text{total length}^3$. Usually two trawl samples per rectangle are collected, and ideally, these should be used as replicates in the analysis. However, at the present time only mean condition per ICES rectangle and year was available for analyses.

Methods

The aim with the simulations was to evaluate the risk of no effect in the experiment, i.e., that no significant impact of a reduction in sprat biomass will be detected. Two sources of uncertainty has been evaluated; *i*) that an actual effect is masked by normal variation (caused by for example hydrographical conditions), and *ii*) the impact size, i.e., how large reduction in sprat biomass is called for? With this in mind I designed the experiment as a Beyond BACI design (Underwood 1992). Basically, the design is a tree-way asymmetrical ANOVA, where each location (L) are sampled several times (T) before and after (B) an impact, in this case sprat reduction. Locations are further classified as either impact (I) or controls (C). The asymmetric design comes from the fact that there is only one impact location but several control locations. Times are nested in B and both times and locations are random factors (with the obvious exception that the impact location need to be included). Since many of the assumptions of analysis of variance and power calculations can be relieved given a balanced design the same number of times before and after was used (t=5). Five replicates (rectangle) per location (subdivision) were sampled. The analysis of sprat condition is used to explain the different steps in the simulation. Analysis of variance and simulations were done following the outline in Underwood (1993) and regressions were done following the outline in Sokal and Rolf (1995). Calculations were performed in Microsoft Excel, Statistica, and R.

Response variable 1: Sprat condition (age 1-5)

Fulton's condition factor (*K*) for sprat was available as mean condition per ICES rectangle from 1986 – 2006 (Fig1). Only some subdivisions were sampled sufficiently during the last five years (Table 1). Data from 1986-1990 for the dedicated impact area (SD 27) was used to estimate maximum realistic difference (d_{max} = mean $X_{86\text{-}90}$ – mean $X_{02\text{-}06}$), which was used as the upper limit in the simulations (see below).

Table 1. Number of ICES rectangles by subdivision and year for which sprat (age 1-5) condition data was available. Shading indicates data that were included in the analysis.

SD	86	87	88	89	90	92	94	96	98	99	00	01	02	03	04	05	06
23												2					
24					1							3	2	1	1	1	1
25	4	6	1	8	7	8	7	9	6	8	8	7	5	7	7	6	7
26	5	6	6	2	1	4	1	2	1		1	1					
27	3	5	6	5	6	3	6	6	6	6	5	7	6	7	7	5	7
28	4	8	6	4	5	1	3	3	5	3	3	4	2	5	5	6	6
29S	4	3	1	1	4	2	6	5	4	6	2	5	6	5	6	4	4
29N		2														1	1

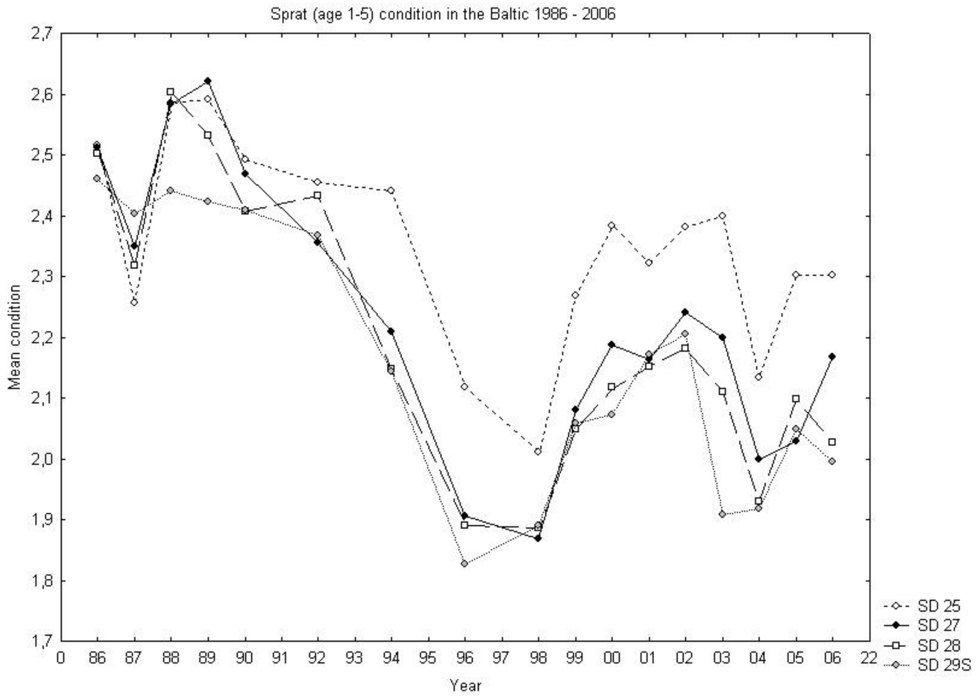

Figure 1. Mean condition of sprat (age 1-5) in the Baltic by year and subdivision

Visual comparison of sprat condition vs. biomass (Fig 2) suggested that changes in condition of sprat in subdivision 25 (SD 25) do not follow the same pattern as in other areas. The cause for this is unclear but could depend on a number of factors (e.g., different levels of predation, migration etc). Whatever the reason may be, I decided to exclude SD 25 from the simulations.

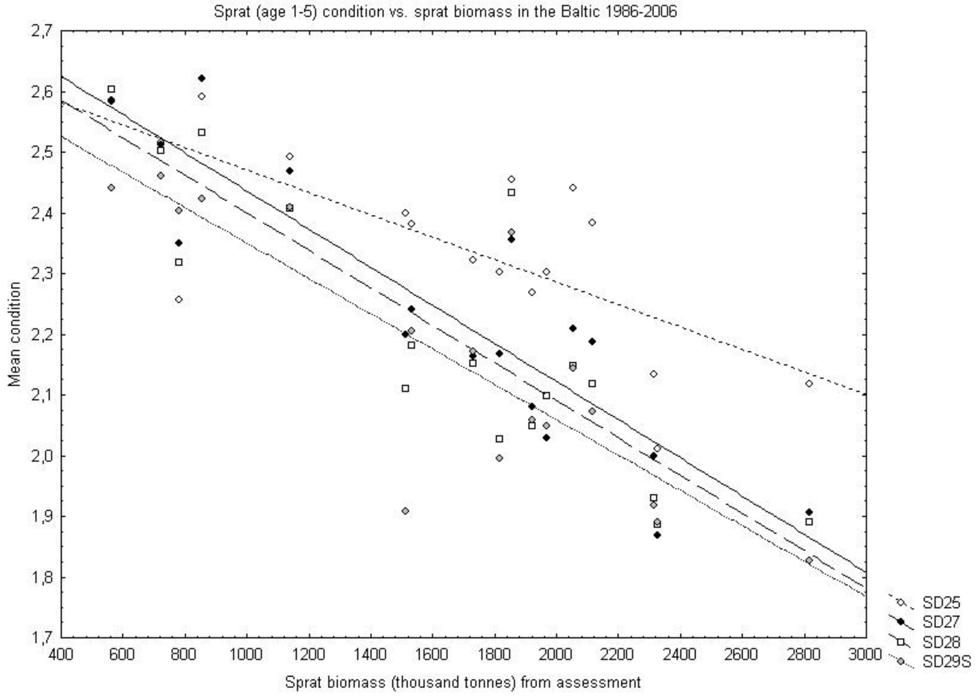

Figure 2. Sprat (age 1-5) condition versus sprat biomass (in thousand tonnes) in the whole Baltic 1986-2006. The figure on biomass used in this graph originates from stock assessment, not from surveys.

Data simulation

1. Data from the 2002-2006 was used as before impact data. To obtain a balanced dataset, missing replicates (less than 5 rectangles were sampled in SD28 in 2002 and in SD 29S in 2005 and 2006, see Table 1) was generated by random sampling from a normal distribution with the mean and standard deviations for respective subdivision and year. A second time series (‘after impact’) was generated in a similar way, drawn from normal distributions based on the means and pooled standard deviations (among years) within each subdivision (including the previously simulated replicates). Before and (simulated) after data is presented in Figure 3. At this point there is no effect (by design) on sprat condition (Table 2).

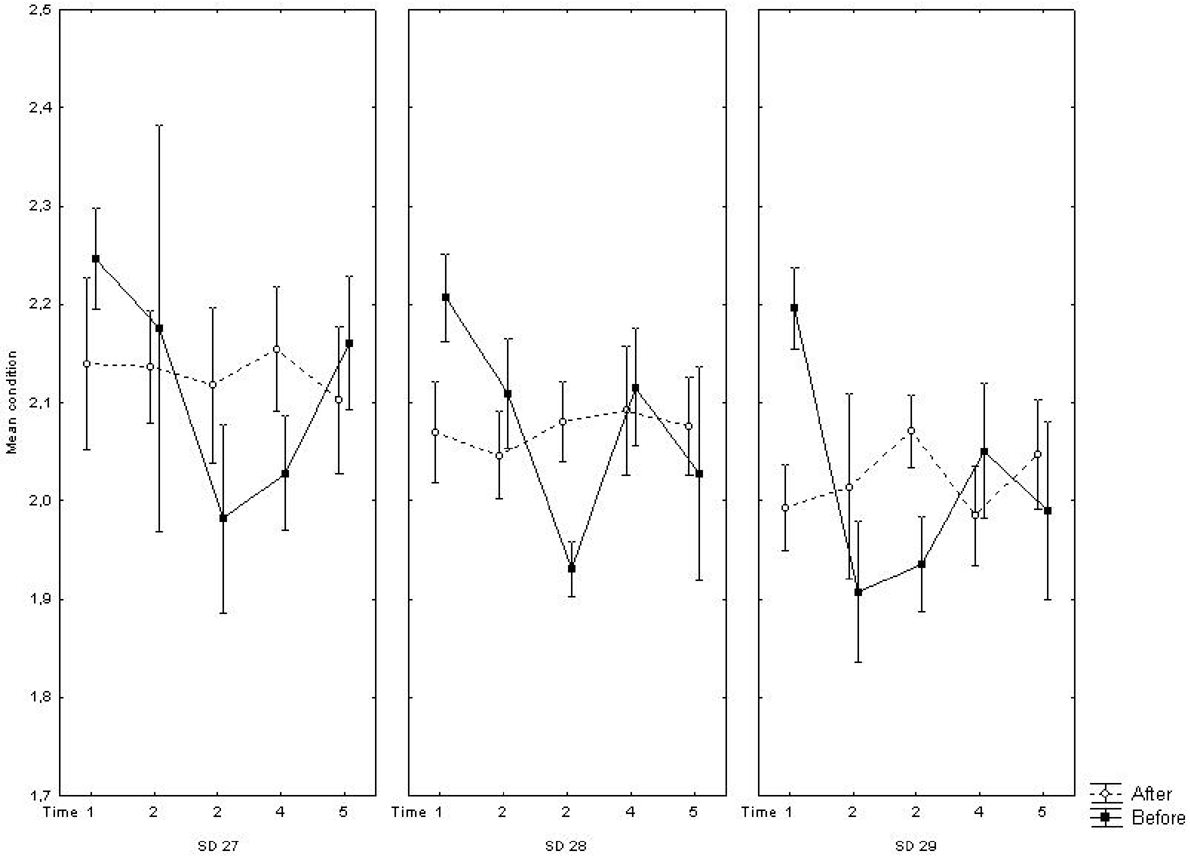

Figure 3. Mean sprat (age 1-5) condition by subdivision (SD) and time of sampling. Before data represents actual mean conditions 2002-2006 (including simulated missing replicates) whereas after data were simulated.

Table 2. Analysis of an impacted (SD 27) and two control locations (SD 28 & SD 29) sampled five times before and five times after a disturbance (with no impact).

Source of variation		d.f.	Mean squares	Test 1 F-ratio vs. Residual	Test 2 F-ratio vs. MS B*I
Before vs. After	= B	1	0.0006		
Among Times (Before or After)	= T(B)	8	0.0685		
Among Locations	= L	2	0.1389		
Impact vs. Controls[a]	= I	1	0.1983		
Among Controls[a]	= C	1	0.0795		
B×L		2	0.0009		
B×I[a]		1	0.0011	0.30 ns	1.37 ns
B×C[a]		1	0.0008	0.22 ns	
T(B)×L		16	0.0133		
T(Bef)×L[a]		8	0.0223		
T(Bef)×I[a]		4	0.0274		
T(Bef)×C[a]		4	0.0171		
T(Aft)×L[a]		8	0.0043		
T(Aft)×I[a]		4	0.0047	1.34 ns	
T(Aft)×C[a]		4	0.0040	1.12 ns	
Residual		120	0.0035		
Total		149			

[a] Repartioned sum of squares.

i) What is the minimum detectable effect given available information on variability?

Given the observed variation in Table 2, the minimum mean square needed to detect a sustained impact by the sprat reduction program (B×I would be significant at $\alpha = 0.05$ in table 2 and no short-term temporal interaction, i.e., neither T(Aft)×C or T(Aft)×I would be significant) was calculated. σ^2_e was estimated as the mean square residual and mean square B×C, for test 1 and 2 respectively and power was fixed to 0.80 or 0.95 (Table 3).

Table 3. Values for calculation of minimum detectable mean square

Power	Impact test	n	d.f.	α	σ^2_e	F'	F_{crit}	Minimum MS B×I	Increase
0.80	B×I vs. Residuals	5	1, 120	0.05	0.0035	0.06	3.92	0.215	0.15
0.80	B×I vs. B×C	5	1, 1	0.05	0.0008	0.11	161.45	1.182	0.37
0.95	B×I vs. Residuals	5	1, 120	0.05	0.0035	0.00	3.92	3.514	-
0.95	B×I vs. B×C	5	1, 1	0.05	0.0008	0.01	161.45	20.149	-

The actual response was modelled by a stepwise increase (+0.01) in condition in all of the replicates in the impact area (SD 27) ‘after sprat removal began’ until MS B×I in Table 2 exceeded Minimum MS B×I in Table 3, or until the increase exceeded $d_{\max}$ (for sprat age 1-5, $d_{\max} = 0.379$). As Underwood (1993) points out, this is an overly simplified simulation since no other mean squares of importance are modified. However, the approach provides an estimate of the minimum increase in mean condition that is needed to be detectable with a sufficient power. Minimum detectable increase with a power = 0.80 was estimated to 0.15 and 0.37, for test 1 and test 2 respectively. With power set to 0.95 the minimum detectable increase exceeded $d_{\max}$ for both test (Table 3).

ii) How large reduction in sprat biomass is needed?

Sprat and herring condition is known to correlate with sprat biomass and one fundamental idea behind BFB is that removal of sprat in one area will lead to increased availability of zooplankton, either more zooplankton in absolute terms or more zooplankton prey per individual consumer. Either way it is expected that this will lead to an increase in condition of consumers in that area (e.g., sprat, herring and cod). Given the estimate on minimum detectable effect (with a given power) it is possible to do some back-calculations to get a rough idea on how much sprat must be removed, or actually, what the target sprat biomass should be to obtain this effect. This back-calculation involves a number of more or less drastic violations on statistic logic (i.e., treating a correlation as a regression, and estimating X from Y), thus the interpretation and use of these estimates should be prudent.

Target sprat biomass in subdivision 27 was estimated for the minimum detectable effect (with a power of 0.8) for test 1 and 2 respectively. The correlation between sprat condition and biomass in subdivision 27 is presented in figure 4. Mean condition for the simulated after data (with no impact) was 2.13 so given the minimum detectable effect mean condition should be 2.28 (2.13 + 0.15) and 2.50 (2.13 + 0.37) for test 1 and test 2, respectively. The higher mean condition 2.50 lies outside the scale and it clearly makes no sense to estimate target sprat biomass for this scenario. For the lower mean condition the point estimate for target sprat biomass is 58 432 tonnes with a one-sided lower 95% prediction interval ranging to –154 211 tonnes.

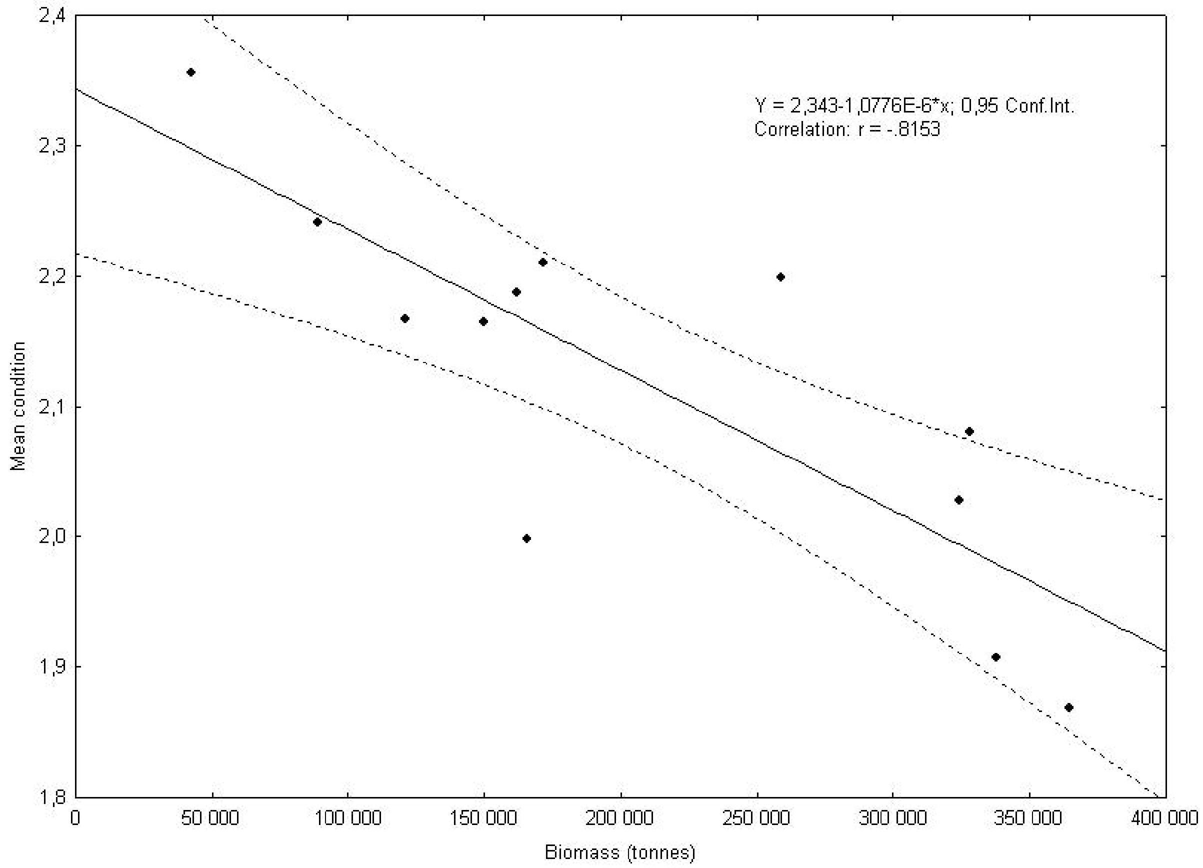

Figure 4. Sprat condition vs. biomass in subdivision 27 1992-2006. Condition is measured as average condition per year and estimated biomass comes from acoustic surveys.

Response variable 2 & 3: Herring condition (age 1 and age 2-5)

The evaluation of response variable 2 & 3 followed the same procedure. Minimum detectable increase exceeded d_{max} for both tests for both response variables; herring (age 1) $d_{max} = 0.027$, herring (age 2-5) $d_{max} = 0.057$. Consequently no target sprat biomass was calculated based on these response variables. Figures and tables for the response variable herring condition are presented in appendix 1 (age 1) and appendix 2 (age 2-5).

Discussion

Given the present design the optimal way to increase power, and thus to decrease the minimum detectable increase, would probably be to add more control stations. In appendix 3 the sprat example was repeated, but now including subdivision 25 (an addition of one control area). As a result the minimum detectable increase for test 2 decreased from 0.37 to 0.26 (appendix 3, table 2). Adding more replicates (for example by using the individual hauls as replicates) would also increase the power to detect differences. However, the effect of this would be small since the residual d.f. is already quite large. Adding more data or pooling data from several subdivisions could potentially reduce the prediction interval around the estimated target biomass. This work is under way but no dramatic changes in point estimates are expected from this work. Basically, the large temporal variation in all areas makes it difficult to detect significant changes caused by a reduction in the impact area.

Several of the available data sets/times series show drastic changes around times of known major inflows (1986, 1992/1993, 2002/2003). Supposedly, increased salinity benefits growth of important prey species for sprat, herring and cod (in some early life stages). If a strong link to such infrequent (random) events exists, and such events take place during the experiment, there is an obvious risk that effects of sprat reduction in subdivision 27 will not be detectable.

Another important issue concerns sprat migration. Although the sampling design used in the simulations accounts for, at least some of the environmental variability by including real observations, it is based on the assumption that sprat abundance are reduced to a new stable level. Significant migration between subdivisions or redistribution of the whole sprat population according to some ideal-free distribution will also tend to mask experimental effects.

Acknowledgement

This report was funded by The Björn Carlson Foundation Baltic Sea 2020.

References

Sokal RR, Rolf FJ (1995) Biometry. 3nd ed. WH Freeman and Company NY. 887p

Underwood AJ (1992) Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J Exp Mar Biol Ecol 161: 145-178

Underwood AJ (1993) The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. Aust J Ecol 18:99-116

Appendix 1

Response variable 1: Herring condition (age 1)

Table 1. Number of ICES rectangles by subdivision and year for which sprat (age 1-5) condition data was available. Shading indicates data that were included in the analysis.

SD	86	87	88	89	90	92	94	96	98	99	00	01	02	03	04	05	06
23												2					
24						1						3	2	1	1	1	1
25	10	6	10	10	7	8	7	9	6	5	6	7	5	7	7	6	7
26	8	7	6	6	2	4	1	2	1		1	1					
27	6	7	5	6	6	5	5	6	6	6	5	6	6	7	7	6	7
28	8	8	7	5	7	1	2	2	5	2	3	4	2	5	5	4	6
29S	7	3	1	3	4	2	6	5	4	6	2	5	4	5	5	4	4
29N																1	1

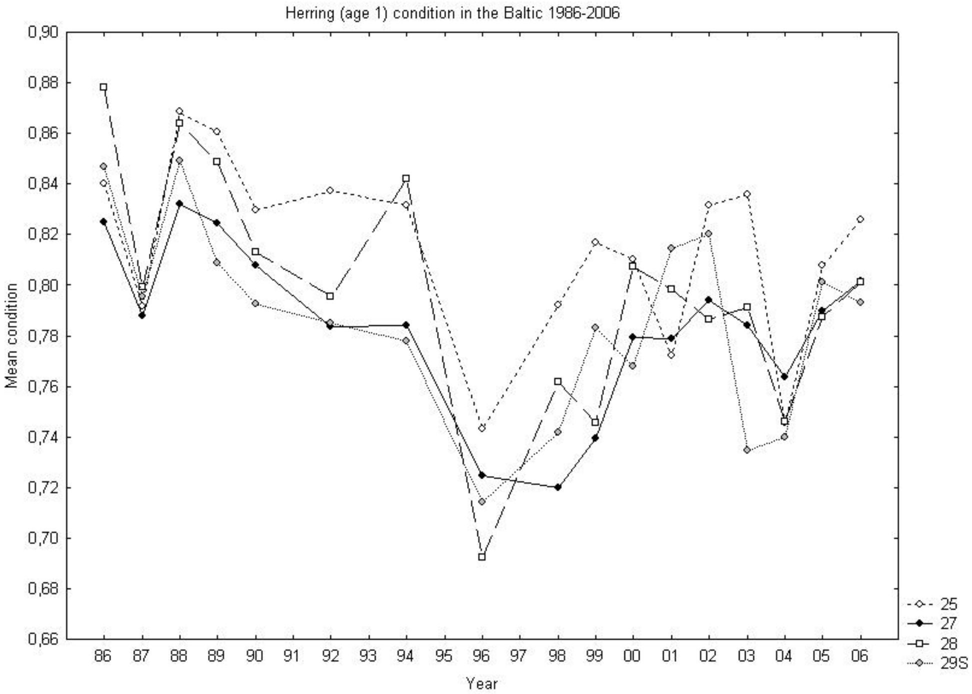

Figure 1. Mean condition of herring (age 1) in the Baltic by year and subdivision

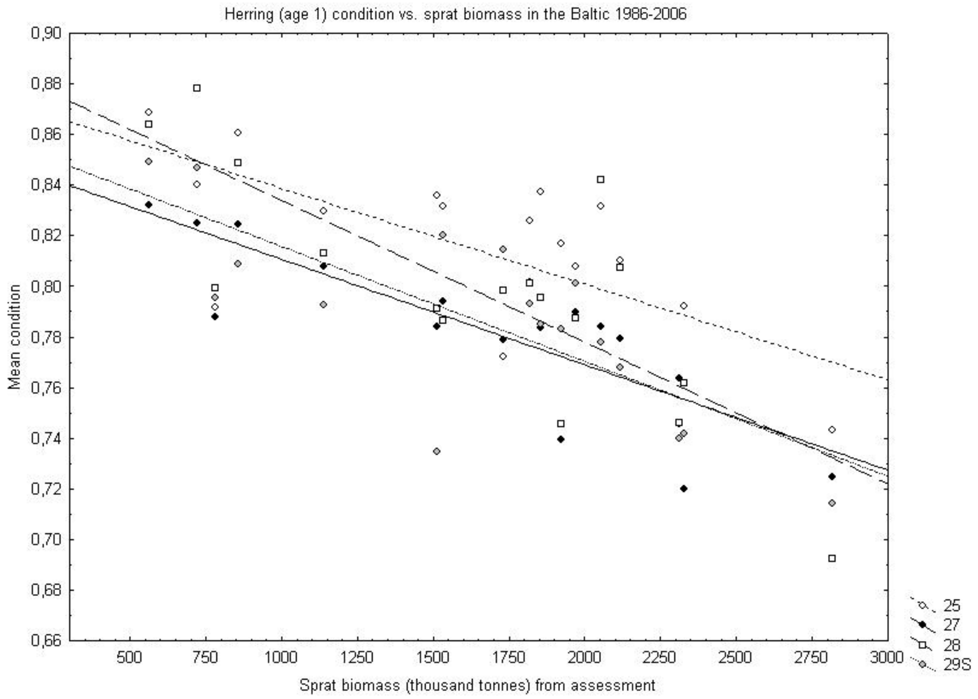

Figure 2. Herring (age 1) condition versus sprat biomass (in thousand tonnes) in the whole Baltic 1986-2006. The figure on biomass used in this graph originates from stock assessment, not from surveys.

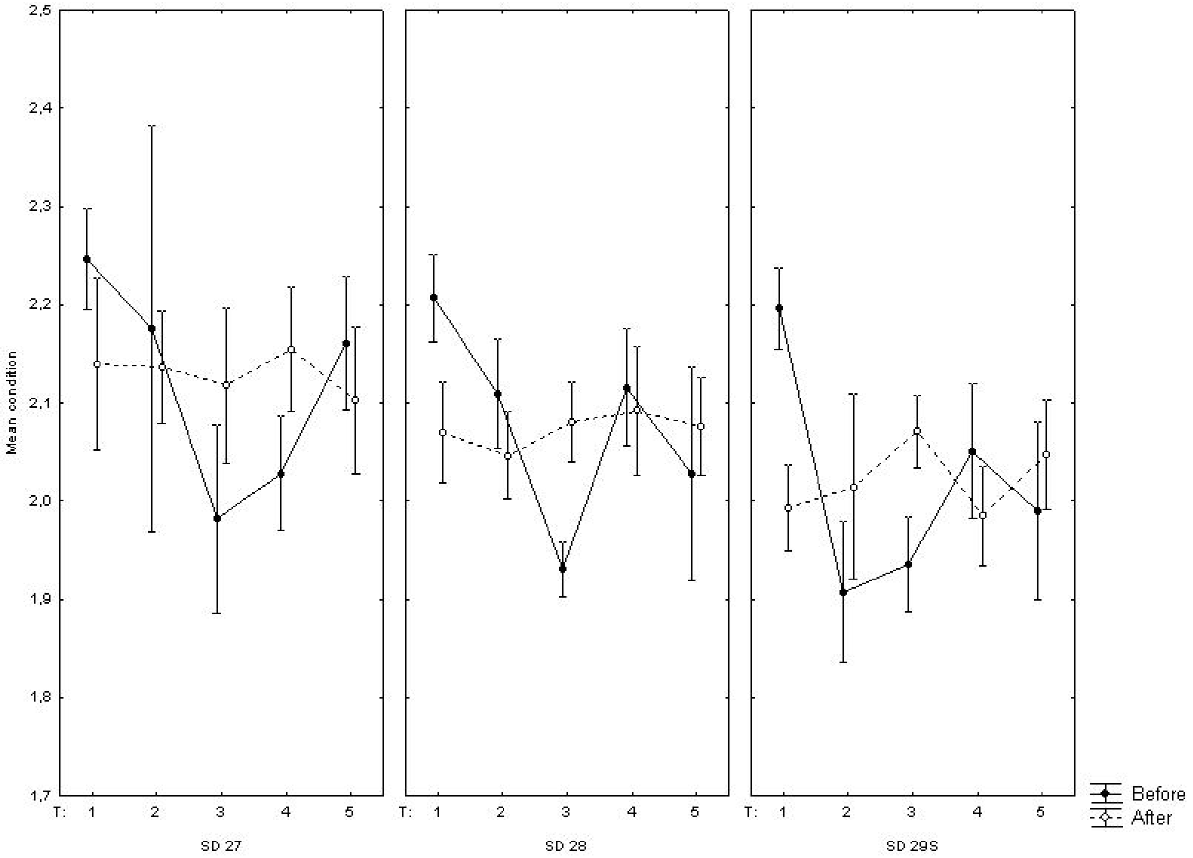

Figure 3. Mean herring (age 1) condition by subdivision (SD) and time of sampling. Before data represents actual mean conditions 2002-2006 (including simulated missing replicates) whereas after data were simulated.

Table 2. Analysis of an impacted (SD 27) and two control locations (SD 28 & SD 29) sampled five times before and five times after a disturbance (with no impact).

Source of variation		d.f.	Mean squares	F-ratio vs. Residual	F-ratio vs. MS B*I
Before vs. After	= B	1	0.0013		
Among Times (Before or After)	= T(B)	8	0.0041		
Among Locations	= L	2	0.0010		
Impact vs. Controls[a]	= I	1	0.0002		
Among Controls[a]	= C	1	0.0017		
B×L		2	0.0004		
B×I[a]		1	0.0007	0.64 ns	4.00 ns
B×C[a]		1	0.0002	0.16 ns	
T(B)×L		16	0.0024		
T(Bef)×L[a]		8	0.0021		
T(Bef)×I[a]		4	0.0008		
T(Bef)×C[a]		4	0.0035		
T(Aft)×L[a]		8	0.0026		
T(Aft)×I[a]		4	0.0019	1.72 ns	
T(Aft)×C[a]		4	0.0034	3.07 *	
Residual		120	0.0011		
Total		149			

[a] Repartioned sum of squares.

Table 3. Values for calculation of minimum detectable mean square

Power	Impact test	n	d.f.	α	σ^2_e	F'	F_{crit}	Minimum MS B×I	Increase
0.80	B×I vs. Residuals	5	1, 120	0.05	0.0011	0.064	3.92	0.067	-
0.80	B×I vs. B×C	5	1, 1	0.05	0.0002	0.106	161.45	0.270	-
0.95	B×I vs. Residuals	5	1, 120	0.05	0.0011	0.004	3.92	1.092	-
0.95	B×I vs. B×C	5	1, 1	0.05	0.0002	0.006	161.45	4.599	-

Appendix 2

Response variable 1: Herring condition (age 2-5)

Table 1. Number of ICES rectangles by subdivision and year for which herring (age 2-5) condition data was available. Shading indicates data that were included in the analysis.

SD	86	87	88	89	90	92	94	96	98	99	00	01	02	03	04	05	06
23												2					
24						1						3	2	1	1	1	1
25	10	4	10	10	7	8	7	9	6	6	6	7	5	7	7	6	7
26	8	7	6	6	2	4	1	2	1		1	1					
27	7	7	5	6	6	5	6	6	6	6	5	6	5	7	7	6	7
28	9	8	7	5	7	1	3	2	5	3	3	4	2	5	5	6	6
29S	7	3	1	3	4	2	6	5	4	6	2	5	4	5	5	4	4
29N																1	1

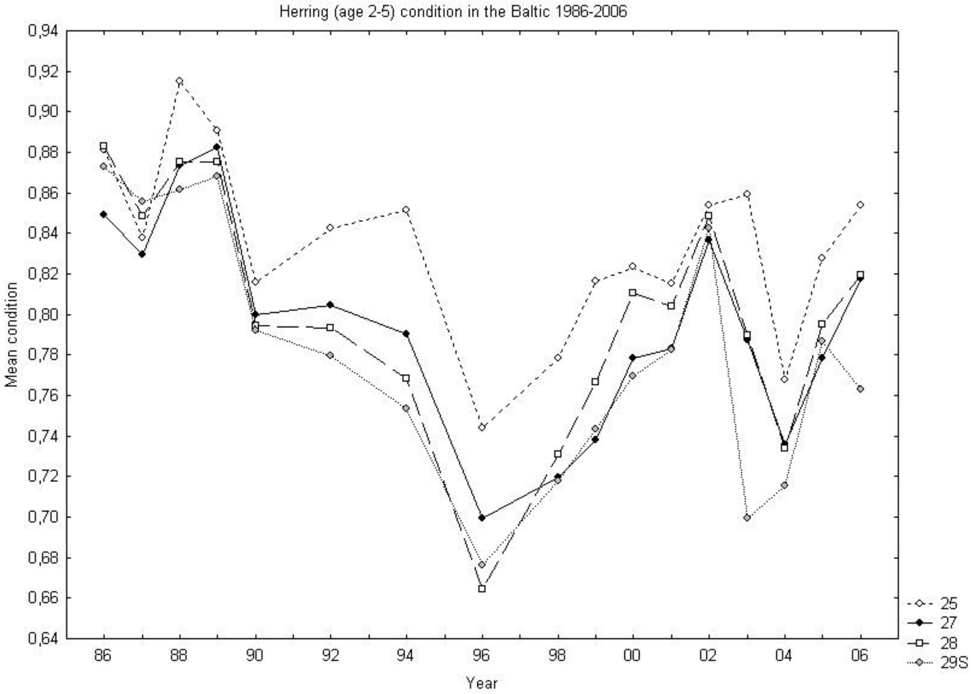

Figure 1. Mean condition of herring (age 2-5) in the Baltic by year and subdivision

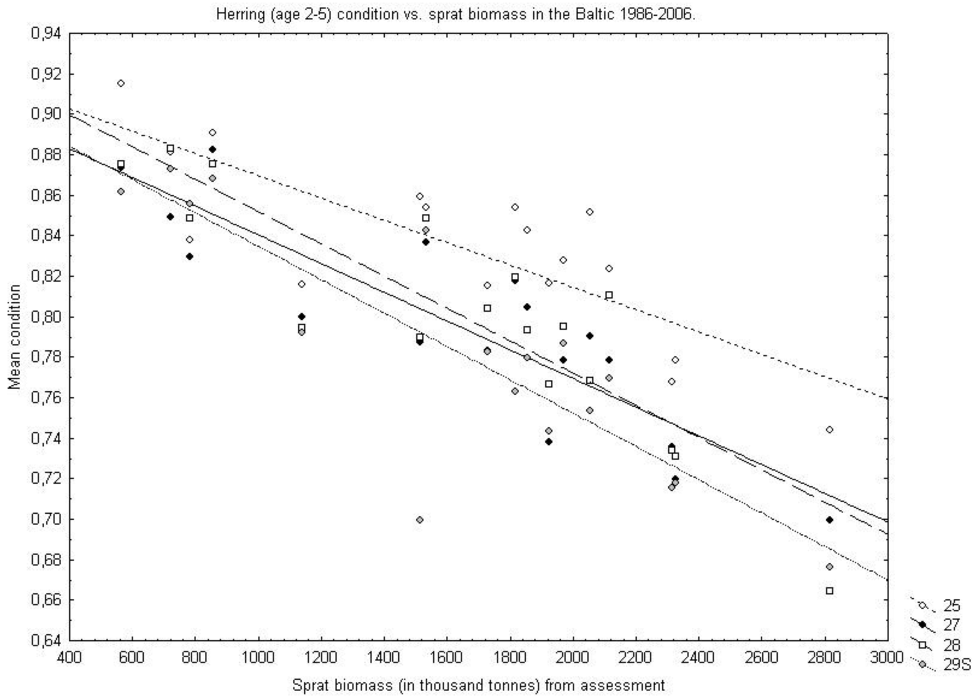

Figure 2. Herring (age 2-5) condition versus sprat biomass (in thousand tonnes) in the whole Baltic 1986-2006. The figure on biomass used in this graph originates from stock assessment, not from surveys.

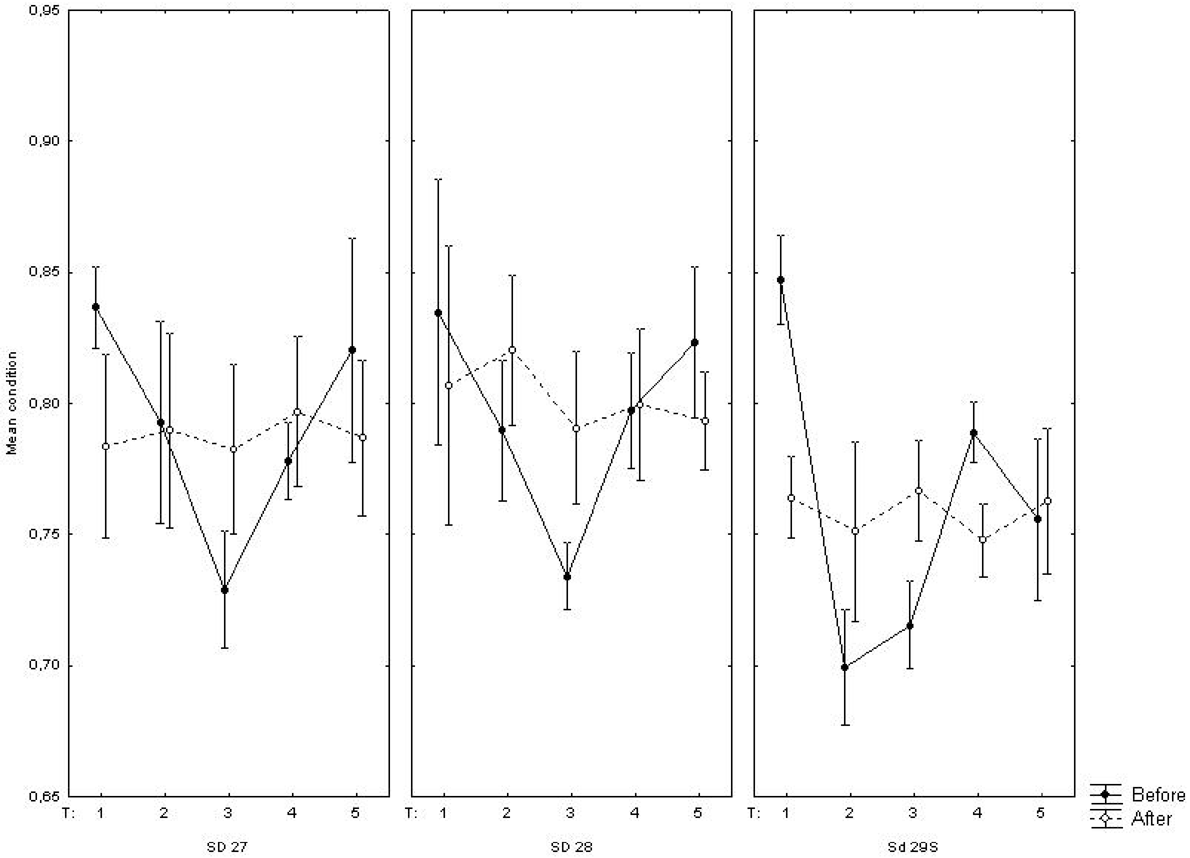

Figure 3. Mean herring (age 2-5) condition by subdivision (SD) and time of sampling. Before data represents actual mean conditions 2002-2006 (including simulated missing replicates) whereas after data were simulated.

Table 2. Analysis of an impacted (SD 27) and two control locations (SD 28 & SD 29) sampled five times before and five times after a disturbance (with no impact).

Source of variation		d.f.	Mean squares	F-ratio vs. Residual	F-ratio vs. MS B*I
Before vs. After	= B	1	0.0000		
Among Times (Before or After)	= T(B)	8	0.0137		
Among Locations	= L	2	0.0208		
Impact vs. Controls[a]	= I	1	0.0034		
Among Controls[a]	= C	1	0.0382		
B×L		2	0.0004		
B×I[a]		1	0.0002	0.40 ns	0.42 ns
B×C[a]		1	0.0005	0.94 ns	
T(B)×L		16	0.0020		
T(Bef)×L[a]		8	0.0034		
T(Bef)×I[a]		4	0.0023		
T(Bef)×C[a]		4	0.0046		
T(Aft)×L[a]		8	0.0006		
T(Aft)×I[a]		4	0.0003	0.56 ns	
T(Aft)×C[a]		4	0.0008	1.48 ns	
Residual		120	0.0005		
Total		149			

[a] Repartioned sum of squares.

Table 3. Values for calculation of minimum detectable mean square

Power	Impact test	n	d.f.	α	σ^2_e	F'	F_{crit}	Minimum MS B×I	Increase
0.80	B×I vs. Residuals	5	1, 120	0.05	0.0005	0.064	3.92	0.033	-
0.80	B×I vs. B×C	5	1, 1	0.05	0.0005	0.106	161.45	0.777	-
0.95	B×I vs. Residuals	5	1, 120	0.05	0.0005	0.004	3.92	0.534	-
0.95	B×I vs. B×C	5	1, 1	0.05	0.0005	0.006	161.45	13.248	-

Appendix 3

Table 1. Analysis of an impacted (SD 27) and two control locations (SD 28 & SD 29) sampled five times before and five times after a disturbance (with no impact).

Source of variation		d.f.	Mean squares	F-ratio vs. Residual	F-ratio vs. MS B*I
Before vs. After	= B	1	0,0003		
Among Times (Before or After)	= T(B)	8	0,0957		
Among Locations	= L	3	0,7151		
Impact vs. Controls[a]	= I	1	0,0043		
Among Controls[a]	= C	2	1,0705		
B×L		3	0,0022		
B×I[a]		1	0,0004	0.08 ns	0.13 ns
B×C[a]		2	0,0030	0.64 ns	
T(B)×L		24	0,0135		
T(Bef)×L[a]		12	0,0210		
T(Bef)×I[a]		4	0,0176		
T(Bef)×C[a]		8	0,0226		
T(Aft)×L[a]		12	0,0061		
T(Aft)×I[a]		4	0,0059	1.24 ns	
T(Aft)×C[a]		8	0,0062	1.31 ns	
Residual		160	0,0048		
Total		199			

[a] Repartioned sum of squares.

Table 2. Values for calculation of minimum detectable mean square

Power	Impact test	n	d.f.	α	σ^2_e	F'	F_{crit}	Minimum MS B×I	Increase
0.80	B×I vs. Residuals	5	1, 160	0.05	0.0048	0.06	3.90	0.288	0.17
0.80	B×I vs. B×C	5	1, 2	0.05	0.0030	0.08	18.51	0.676	0.26
0.95	B×I vs. Residuals	5	1, 160	0.05	0.0048	0.00	3.90	4.706	-
0.95	B×I vs. B×C	5	1, 2	0.05	0.0030	0.01	18.51	11.231	-