Integrating spatial processes into ecosystem models for sustainable utilization of fish resources
INSPIRE

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INSPIRE Overview

Process-based understanding of changes in commercial fish spatial distributions, and to disentangle the role of natural drivers and various anthropogenic impacts, is a challenging research topic with high relevance to resource management. The very recently started four-years BONUS INSPIRE project will fill in the most persistent gaps in knowledge of the spatial ecology of the major commercial fish and thereby support the effectiveness of the relevant policies and ecosystem-based management of the Baltic Sea. The project would serve as a „*framework axis project*“ which other Baltic Sea research could be related to.

INSPIRE is designed to substantially advance our knowledge on the major commercial fish species – cod, herring, sprat and flounder, which represent key elements of the Baltic Sea ecosystems. The specific objectives of INSPIRE are to:

i. Quantify processes generating heterogeneity in spatial distributions of fish;
ii. Quantify and map potential hazards to the connectivity between identified key habitats, and assess the impact of anthropogenic and climatic environmental changes on habitat connectivity;
iii. Quantify the population dynamics and interactions of the fish species in a spatially explicit context;
iv. Develop spatially explicit advice for ecosystem-based fisheries management.

INSPIRE proposes pilot ecosystem integrated surveys to resolve the habitat requirements of different life-stages of fish species by combined use of traditional methods and application of modern advanced analysis techniques. The surveys are conducted in close collaboration with local fishermen.

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Executive Summary

The current report provides information on the discussions held and decisions made at the fourth integrating workshop of INSPIRE. The overall aim of integrating workshops is to ensure timely discussions of important issues of the project to secure timely submission of project deliverables. The first workshop has focused on the integration between static distributions (WP1) and dynamics in the spatial distributions (WP2), the second workshop focused on the integration between dynamics in the spatial distributions and their scaling towards Baltic-wide population dynamics of the target species cod, herring, sprat and flounder (WP3), and the third workshop focused to facilitate the input from the first three work-packages into stock assessments (WP4), and agreeing upon partners responsibilities for performing concrete stock assessments.

The overall objective of the fourth integrative workshop was to facilitate the flow between the first work-packages and WP5, the implementation of the findings in the ecosystem based management perspective and agreeing upon responsibilities for timely achieving WP5 deliverables. In addition, several yet unresolved issues related to flounder stock assessments were discussed.

The report below outlines the discussion points and gives an overview on the state-of-the-art of the situation.

Introduction

Integrating workshops are seen in INSPIRE as venues to ensure effective and efficient linkage not only across the various work packages, but also to secure timely discussions on operational issues to achieve the project deliverables and aims, and balanced incorporation of all four fish taxa considered in the project (i.e. cod, flatfish, herring and sprat) into research activities. In total, there are four integrating workshops planned in the project.

The fourth integrating workshop of INSPIRE was held in Hamburg, Germany, during 31. January – 2. February 2017. The meeting was hosted by the University of Hamburg and co-convened by Christian Möllmann (UH) and Stefan Neuenfeldt (DTU-Aqua). The meeting was attended by 16 participants.

Core activity

The workshop report is arranged by workpackages and provides overview on the discussions held and content agreed of the upcoming deliverables until the end of the project (M48).

Workpackage 1 Spatial distributions

(Lead: Michele Casini, P5, SLU)

D1.5 Manuscript on habitat preferences of different life-stages of fish (M38)

Habitat preferences of large flounder during spawning time.

The abundance of flounder collected during the INSPIRE survey will be analysed together with information on hydrological variables, habitat characteristics (vegetation and substrate) and other biological information (abundance of prey and competitors). This will be done for the flounder spawning time and separated for the demersal and pelagic ecotypes. This analyses will investigate what is the habitat selected by flounder during the spawning period.

D1.6 Manuscript on spatially explicit population and foodweb modeling (M40)

Spatially explicit population and foodweb modelling – state of the art and where to go from here in INSPIRE.

Management of fisheries for cod can have an impact on fishing opportunities for sprat and herring, and vice versa. Cod are predatory, and their main prey is sprat and, to a lesser extent, herring and also juvenile cod (cannibalism). Growth of herring and sprat has been density-dependent. The relative distributions of predator (cod) and prey (herring and sprat, juvenile cod) have changed substantially during the last years, and for the time being much herring and sprat are outside the predatory reach of cod.

Preliminary model runs have indicated that the present distribution patterns of cod, herring and sprat imply that an increase in fishing mortality (F) on cod not necessarily will result in increasing Baltic wide clupeid stock sizes. Conversely a decrease in F on cod will not necessarily result in a decrease of the Baltic

clupeid stock size if it will not be accompanied by a cod expansion to northern areas. Higher sustainable fishing mortalities for herring and sprat are also obtained when density dependent growth is assumed for the two species, as the stocks compensate by a higher growth at lower stock densities due to either higher fishing mortalities or predation.
A basic model has been developed that is purely length based and couples population dynamcis, foraging behavior and predator (cod) growth. The model will be expanded to account for different spatial units and apply the knowledge gathered in INSPIRE.

Updates on spatial food web modelling for the Baltic.

Understanding the dynamics across the established regime shift observed in the late 1980s requires novel research into the spatial heterogeneity of the key processes. In this project with INSPIRE, the emphasis will be to develop more sophisticated models, based on enhanced field data, that help explore the spatial and temporal relationships. Using a similar set of collected and modelled environmental and ecological data (describing the trophic structure and environmental status) we will develop 2 model approaches in synchrony. The first model described as the size structured mechanistic model is based on mathematically describing the relationships (often based on metabolic theory) across the trophic web. The second model is the development of a spatially explicit Bayesian Belief Network. The first step currently underway is the collection of data spanning many years and relevant to a suite of factors deemed most influential in the dynamics. The next step will be the use of the data to generate conditional probabilities such that a fully working model is constructed. This model will encompass spatial structure, not through isolated instances of the model but through a process of identifying the key spatial drivers of the population interaction. At the moment, the model is ready for testing both spatially and temporally. A manuscript will be prepared collectively with the experts in spring 2017 and the results will be presented at the international Baltic Sea Science Conference in June 2017.

D1.7 Design protocol for future surveys for flatfish and juvenile cod (M44)

Based on lessons learnt from INSPIRE sampling of flounder and cod, combined with previous knowledge and earlier praxis of sampling from ICES (WGBIFS) and HELCOM (HELCOM FISH) a survey design for the future will be created. The survey design will have a protocol including both field sampling and biological analyses (genetics, otoliths etc).

Workpackage 2 Passive movements, active migrations, and habitat connectivity

(Lead: Christian Möllmann, P8, UHAM)

Five deliverables (D2.1-2.5) have been submitted and accepted by BONUS Secretariat. D2.6 is almost ready and will be submitted according to BONUS INSPIRE SoD.

Workpackage 3 Scaling from individuals to populations

(Lead: Patrick Polte, P7, TI-OF)

D3.1 Manuscript on distribution probability maps for juvenile cod and flounder (M36)

The following manuscript was submitted/delivered as scheduled in the DoW - M36 (January 2017):

Hinrichsen, H.-H., von Dewitz, B., Lehmann, A., Bergström, U. and Hüssy, K. Spatio-temporal dynamics of cod nursery areas in the Baltic Sea. Fisheries Oceanography (submitted)

For the first time, a drift study has been performed in which fertilized cod eggs have been released in historically important Baltic cod spawning grounds. These eggs drifted at levels of neutral buoyancy until they entered the first feeding state. The end positions of this drift study were the starting positions for the subsequent drift study, where first feeding stage larvae drifted until they reached the age of settlement (90 days). Then after checking for suitable habitats, either the drift ended successfully or the particles were not counted as settled juveniles.

The study has shown that also particles representing eastern Baltic cod juveniles settled to a relatively large extent in the western Baltic cod management area, and may significantly contribute to western Baltic cod recruitment. Therefore, it could be suggested that not only immigration but also larval and juvenile transport could contribute to recruitment in the western Baltic Sea. However, it is also evident that the stock component in the Gotland Basin only to a minor degree contributed particles to nursery grounds in other ICES subdivisons.

D3.2 Manuscript on the impact of active migrations in the observed distributional changes of cod, herring and sprat (M40)

The deliverable will consist of three items:

1. Moll et al. Estimating the contribution of single nursery areas to the overall herring (*Clupea harengus*) population in the western Baltic Sea by otolith chemistry (manuscript, under prep.)

For many fish species, coastal areas are ecologically important by providing essential spawning and nursery habitats. However these habitats are often highly impacted by multiple anthropogenic threats. Western Baltic populations of Atlantic herring (*Clupea harengus*) are an economically and ecologically important component of the Baltic Sea ecosystem. Herring shows a distinct homing behavior returning to particular spawning grounds every year during spring. Attributed to early life stage mortality, herring recruitment decreased in the western Baltic Sea during the past two decades. Since major drivers and stressors for herring reproduction are potentially introduced on the local scale of spawning and nursery grounds, the knowledge of the contribution of different nurseries to population dynamics is essential but challenging to investigate.

We used elemental fingerprinting in herring otoliths to detect differences in the chemical composition based on varying water chemistry in particular spawning areas. Cluster analysis revealed a distinct chemical separation between juvenile herring caught in the vicinity of the Island of Ruegen (south-western Baltic Sea) and other potential nursery areas further west in the Baltic Sea. Element concentrations differed significantly among areas, indicating that otolith chemistry is a suitable means to identify the origin of herring offspring and therefore the contribution of particular nursery areas.

Further analyses of trace elements in otoliths from a random sample of adult herring will prove the ratio of individuals that originated in a certain nursery area. Otolith chemistry is considered a valuable tool for evaluating the contribution of different spawning areas to the adult population which could lead towards a more directed management of important spawning grounds and nursery areas.

2. Polte et al. Ontogenetic loops in habitat use highlight the importance of littoral habitats for early-life stages of oceanic fishes in temperate waters. *Scientific Reports* (in press)

General concepts of larval fish ecology in temperate oceans predominantly associate dispersal and survival to exogenous mechanisms such as passive drift along ocean currents. However, for tropical reef fish larvae and species in inland freshwater systems behavioural aspects of habitat selection are evidently important components of dispersal. This study is focused on larval Atlantic herring (*Clupea harengus*) distribution in a Baltic Sea retention area, free of lunar tides and directed current regimes, considered as a natural mesocosm. A Lorenz curve originally applied in socio-economics to describe demographic income distribution was adapted to a 20 year time-series of weekly larval herring distribution, revealing size-dependent spatial homogeneity. Additional quantitative sampling of distinct larval development stages across pelagic and littoral areas uncovered a loop in habitat use during larval ontogeny, revealing a key role of shallow littoral waters. With increasing rates of coastal change, our findings emphasize the importance of the littoral zone when considering reproduction of pelagic, ocean-going fish species; highlighting a need for more sensitive management of regional coastal zones.

3. Summary of work done during the ICES WKSPATIAL (Riga, 2016)

D3.3 Manuscript on the role of small- and meso-scale drivers and stressors for overall Baltic herring recruitment (M40)

The deliverable will synthesize findings of the following four publications/manuscripts, dealing with Baltic spring herring recruitment dynamics at different spatial and temporal scales:

- ✓ Arula, T., Laur, K., Simm, M., Ojaveer, H. 2015. Dual impact of temperature on growth and mortality of marine fish larvae in a shallow estuarine habitat. Estuarine, Coastal and Shelf Science 167: 326-336.

High individual growth and mortality rates of herring Clupea harengus membras and goby Pomatoschistus spp. larvae were observed in the estuarine habitat of the Gulf of Riga, Baltic Sea. Both instantaneous mortality (0.76-1.05) as well as growth rate (0.41-0.82 mm day^{-1}) of larval herring were amongst highest observed elsewhere previously. Mortality rates of goby larvae were also high (0.57-1.05), while first ever data on growth rates were provided in this study (0.23-0.35 mm day^{-1}). Our study also evidenced that higher growth rate of marine fish larvae did not result in lower mortalities. We suggest that high growth and mortality rates primarily resulted from a rapidly increasing and high (>18 °C) water temperature that masked potential food-web effects. The explanation for observed patterns lies in the interactive manner temperature contributed: i) facilitating prey production, which supported high growth rate and decreased mortalities; ii) exceeding physiological thermal optimum of larvae, which resulted in decreased growth rate and generally high mortalities. Our investigation suggests that the projected climate warming may have significant effect on early life history stages of the dominating marine fish species inhabiting shallow estuaries.

- ✓ Arula, T., Raid, T., Simm, M., Ojaveer, H. 2016. Temperature-driven changes in early life-history stages influence the Gulf of Riga spring spawning herring (*Clupea harengus m*.) recruitment abundance. Hydrobiologia 767: 125-135.

Processes occurring during early life-history stages influence the year-class abundance of marine fish. We found that the abundance of 1-year old spring spawning herring is statistically significantly determined by the number of post-flexion herring larvae in the Gulf of Riga (Baltic Sea). The abundance of consecutive developmental stages of larvae: yolk-sac, pre-flexion, flexion and post-flexion strongly correlated with each other, indicating that factors which already influence the yolk-sac stage are important in determining the abundance of postflexion herring larvae. Winter air temperature before spawning determined the timing of maximum abundance of pre-flexion herring larvae, but not their main prey: copepod nauplii, implying that different mechanisms governing major preconditions for the formation of year-class strength. The abundance of postflexion larvae displayed a potential dome-shaped relationship with sea surface temperature experienced after hatching. We suggest that increased summer temperatures, which exceed the physiological optimum negatively, affect the survival of post-flexion herring larvae. Overall, future climate warming poses an additional risk to larval herring survival and this may lead to a reduction in those herring stock which rely on recruitment from shallow coastal areas.

- ✓ Moll, D., Kotterba, P., v. Nordheim, L., Polte, P. Storm-induced Atlantic herring (*Clupea harengus*) egg mortality in Baltic Sea inshore spawning areas Estuaries & Coasts (submitted).

During their spring migration Atlantic herring (*Clupea harengus*) populations in the Baltic Sea rely on shallow transitional waters, such as estuaries, bays and lagoons for spawning. Those inshore spawning grounds are ecologically important by providing suitable substrates for demersal egg deposition. However, these habitats are often highly impacted by multiple anthropogenic threats. Decades of eutrophication caused a decline in depth distribution of submerged aquatic vegetation, the main herring spawning substrate of *C. harengus* in the Baltic Sea. Nowadays spawning beds are limited to the shallow littoral zone (≤ 3 m depth). Accordingly, macrophytes are increasingly exposed to mechanic forcing due to storm induced wave action.

Generally, reproductive success and year class strength of the Western Baltic herring population is strongly determined by the survival of early life stages such as eggs and larvae in local nursery areas. However, the explicit mechanisms by which local stressors might affect overall recruitment are currently not well understood.

Hypothesizing that a water depth limit of vegetation causes increased herring egg mortality due to high exposure to storm induced hydrodynamics, we performed a combination of field studies investigating the impact of storm events on herring egg loss. Results of egg loss experiments and -quantification of eggs attached to wrack on the shoreline revealed a total egg loss of 29% in one single spawning bed during a storm event within the spawning season. Our results emphasize the potential of regional weather extremes such as storm events to act as influential stressors for herring reproduction (Fig. 1).

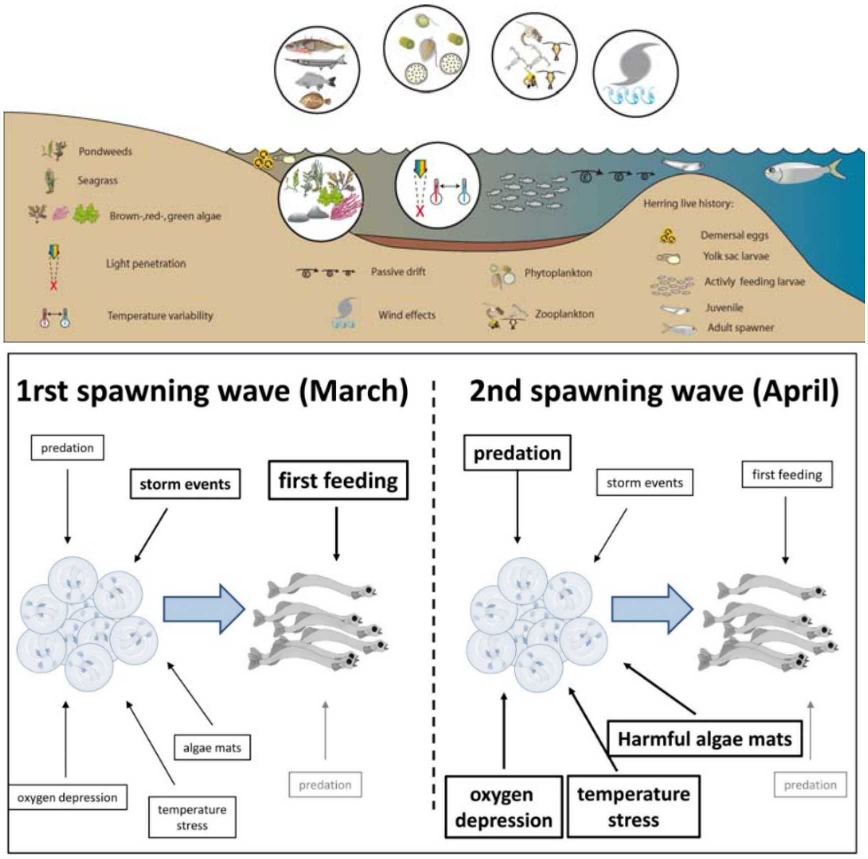

Fig1. In the inner coastal waters of the Western Baltic Sea a differing suite of environmental stressors affect herring early life stages along the season

✓ Ojaveer, H., MacKenzie, B.R., Raid, T., B., Kornilovs, G., Klais, R. Key recruitment drivers of a small landlocked herring population in the priphery of the species distribution area. ICES Journal of Marine Science (submitted).

Scientific interest in the dynamics of fish recruitment dates back to the beginning of the 20th century, when it was first understood that variations in catch could be related to variations in year-class strength. Since then, several studies have shown that the recruitment (R) is affected more by the environment than by the spawning biomass (SSB), and that models with environmental variables significantly improved the predictions of recruitment. This study investigates the individual and combined effects of several abiotic and biotic variables on the inter-annual variability of the Gulf of Riga (Baltic Sea) spring herring R during 1957-2012. The linearly combined effects of annual sum of sunshine hours (SH_A) and water temperature in January-March (T_{JFM}) resulted in highest explanatory power of R over the entire time series (Fig. 2), while T_{JFM} and the Baltic Sea Index in December-March were the best predictors of R during the periods of low and high SSB. Although significant, the SSB as predictor was inferior compared to abiotic drivers. Non-stationary and nonlinear functional relationships between R and its controlling factors were detected in more detailed modelling, with the effects of abiotic drivers depending on the mean level of SSB. In the same analyses, SSB was shown to have a notable effect on R during periods of relatively low water temperature, suggesting a threshold-like transient links between R, SSB, and environmental forcing. Resolving the non-linear and non-stationary effects of abiotic drivers will improve both, our understanding of recruitment dynamics, as well as skills of predictive models that determine how different environmental and fishing scenarios might affect future recruitment and stock dynamics.

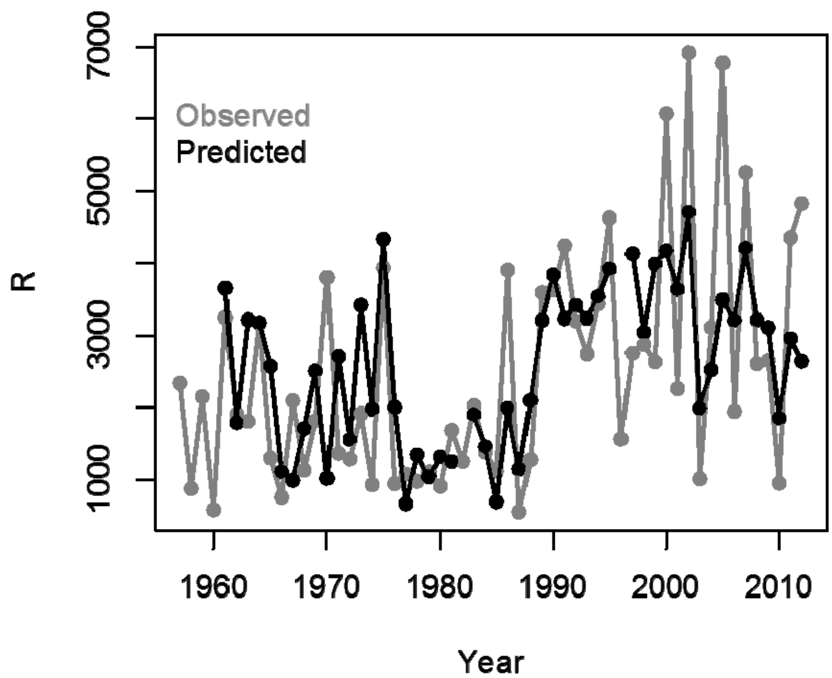

Fig. 2. Observed vs. predicted Gulf of Riga spring herring recruitment abundance dynamics. R = -6400 + 4.55*sun hours + 648* winter water temperature ($R^2 = 0.45$, $p < 0.0001$). 'Observed' data from Ojaveer et al. 2004 and ICES 2015.

References:
Ojaveer, E., Raid, T., Suursaar, Ü. 2004. On the assessment and management of local herring stocks in the Baltic Sea. *In* Management of shared fish stocks, pp. 240–250. Ed. by A. Payne, C. O'Brien, and S. Rogers. Blackwell Publishing, Oxford.

ICES. 2015. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 14- 21 April 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/ACOM:10. 806 pp.

Workpackage 4

(Lead: Jan Horbowy, MIR-PIB)

D4.1 Report on assessment of herring, sprat and cod, including spatial effects (biomass distribution, natural populations) (M36)

The activities concerning WP4 since the second annual meeting (held in Riga, September 2016) mainly concentrated on assessment work to achieve Deliverable 4.1. The assessments of sprat and herring stocks by former assessment units (up to beginning of 1990s, sub-stocks) were performed. Basic assessments methods used were XSA and SAM. In addition, cohort analysis which may use assumed survey catchability (e.g. average estimated for sub-stocks) was developed. Development and use of such additional assessment tool was necessary due to differences in estimated by XSA and SAM survey catchability within sprat or herring sub-stocks. As there was not clear reason for these differences (surveys use the same methodology and are internationally coordinated by ICES) additional assessment tool allowing to assume the same catchability for sub-stocks within given species was developed. The assessments by sub-stocks showed similar trends and generally summed up to the present ICES assessment of the stocks. Major contributors to the assessments of sub-stocks were MIR-PIB, UT-EMI, LUKE, BIOR.

Content of D4.1 was briefly discussed during the workshop and submitted according to SoD (i.e., January 2016). The deliverable consists of the main body of the report (according to BONUS INSPIRE reporting format) and the following five annexes:

1. Raid, T., Järv, L., Pönni, J., Raitaniemi, J., Kornilovs, G. 2016. Central Baltic Herring stock: what does the combined assessment say about its status? Guedes Soares & Santos (Eds) © 2016 Taylor & Francis Group, London, ISBN 978-1-138-03000-8
2. Horbowy, J. 2016. Effects of varying natural mortality and selectivity on the assessment of eastern Baltic cod (Gadus morhua Linnaeus, 1758) stock. Journal of Applied Ichthyology, 32: 1032-1040. doi:10.1111/jai.13202
3. Herring assessments in ICES SD 25-27 vs 28-29+32
4. Herring assessments in ICES SD 28-29+32)
5. Sprat assessments in ICES SD 22-25, 26+28, 27,29-32)

As stressed already in a few previous INSPIRE deliverables, there are major problems with cod assessment in the Baltic Sea. ICES was unable to provide analytical assessment and advice for 2015 & 2016, due to the following main problems:

- ✓ Strongly declining growth and condition of cod
- ✓ Very bad retrospective pattern of assessments
- ✓ Serious problems with age reading – no consistency even within the country
- ✓ Inconsistencies between fisheries and survey information – unstable catchability

Therefore, **more than previously assumed work on cod was undertaken** and the results are shown in the Annex 2 (publication). These results advance our understanding of recent changes in cod dynamics. However, it is only one of the steps to solve problems with cod analytical assessment and it was decided and agreed, that it is beyond the scope of INSPIRE to solve all cod assessment issues.

Some of the future direction of work might include resolving issues related to:

- ✓ cod distribution – enlarging hypoxic/anoxic areas

- ✓ decreasing overlap with clupeids
- ✓ strongly declining condition, probably leading to increasing natural mortality?
- ✓ increasing infestation with parasites – negative impact on condition and mortality
- ✓ Effects of seals

D4.2 Database for flounder assessment or stock evaluation by stock (M38)
D4.3 manuscript on model and methods of assessment or evaluation of flounder stocks status (M46)

Sub-group was formed to discuss tasks related to flatfish assessments and providing Deliverables 4.2 and 4.3. WP lead chaired the sub-group. It was agreed to start analyses with three stocks presently considered by ICES, i.e. flounder in sub-divisions 24-25, flounder in sub-divisions 26+28, and flounder in sub-divisions 27,29-32.

Separation into bottom and pelagic components were discussed. So far results indicated that flounder in sub-divisions 24-25 is in over 90% pelagic, and flounder in sub-divisions 27,29-32 is mostly demersal (over 90%), while flounder in sub-divisions 26+28 is partly pelagic - partly demersal (about 50% for each eco-type). The eco-type analyses (DNA, otolith microchemistry) were not finished yet, so the decision on the approach to the eco-types in flounder assessment units will be undertaken when final evaluation of stock structure is obtained.

The biggest problem in flounder assessment is the estimation of discards which in some fisheries may be very large, while in some are low (even negligible). To include discards in stock assessment the discard series has to be estimated backwards for several years. Meanwhile, discard estimates from only two latest years are considered of good quality; estimates from preceding years are rather poor with many gaps and uncertainties. Methods to extend discard series backwards were discussed. It was proposed to inspect possibility to apply Cook’s model (Cook, 1995, CM 1995/D:12) used years ago to estimate unreported catches or SURBA for estimation of discards. However, first impression was that these methods may allow for such estimates only when for most years discards data are reliable and their estimates are needed only for some years. The use of GLMs to estimate discards as dependent variable with explanatory variables like country, years, season, gear could be also considered. In any case the sensitivity of assessment models to discard data should be tested; different assumptions on discards levels could be made and their effects on stocks estimates and management inspected.

For several years, the age determination was considered a problem with flounder assessment. However, presently a few countries are using recommended age determination methods, and Poland (one of the biggest flounder fishery) estimated flounder age using recommended thin section method till 2000 backwards. It was concluded that at least for some stocks (e.g. flounder in sub-divisions 24-25) the age data are extensive and of acceptable quality and could be used in the age-structured assessments.

Concerning assessment methods several approaches were discussed. For stocks for which quality of input age-structured data is acceptable the XSA and SAM models could be applied. Flounder in sub-divisions 24-25 is a candidate for such assessments. For stocks where age data will be unsatisfactory the stock-production models may be tried. Some of them are easily implemented in spreadshit. However, the work on more advanced approaches including random effects in the stock-production models was undertaken in DTU-Aqua/ICES (Casper Berg) and the status of that work and possibility to apply such models in flounder assessment could be considered. There is also possibility to apply length structured models (in essence most of them need some age information, to allow transformation of length classes into age group) for assessments. It was noted that ICES WKLIFE worked on assessments and evaluation of data-limited stocks and exploration of the methods described in WKLIFE reports could be helpful in flounder assessments.

The responsibility on the flounder assessments was agreed as follows:

1. flounder in sub-divisions 24-25 - MIR-PIB (contact person J. Horbowy)
2. flounder in sub-divisions 26+28 - BIOR (contact person D. Ustups) with help of Poland and Estonia
3. flounder in sub-divisions - 27,29-32 – SLU (TBC) with help of Finland and Estonia

MIR-PIB offered help in some methodological issues within its expertise. To facilitate assessments which are considered quite heavy task it was decided to conduct flounder workshop in Gdynia, a few days in 12-16 June, 2017.

Workpackage 5 Ecosystem-based management
(Lead: Jari Raitaniemi, P9, LUKE)

D 5.1 Report on the early warning indicators of cod stock development (M40)

Potential early warning indicators of the eastern Baltic cod stock, needed tasks, and responsible persons are shown in Table 1.

Environment of recruitment: In the Baltic Sea, the environmental conditions of cod recruitment are crucial with limiting factors like e.g. salinity, which needs to be at least 11‰ for the eggs to float and develop to larvae. In the Baltic brackish water conditions, this salinity is found in the deep waters of a few basins in the southern Baltic Sea. However, low oxygen content reduces the suitable volume for cod reproduction. Condition and Consumption/feeding level: Decreasing condition was observed before the existence of more problems, e.g. the symptoms of starving, were understood. Stock abundance and recruitment data can be used from those years, when the assessments have been considered reliable, i.e. 1966–2012. Size distribution, L(max), and .95 length percentile describe the changes in length distribution that have appeared when the cod sizes in the stock have decreased. The decreasing status of the eastern cod is also seen in the percentage of the stock total area that is occupied. During the time series of 1965–2015, an increasing trend has been found in the coverage of hypoxic benthic areas. Sufficient oxygen content is not only important to cod reproduction in the deep basins, but also to benthic areas that are important to cod as food resource and habitat.

Table 1. Early warning indicators of the Baltic eastern cod stock development.

Indicator (time-period)	Notes / reference levels	Responsibility	Comments
Recruitment environment	Thresholds for envir. variables	C. Möllmann	Analysis done
Condition (1976-2014)	< 0.8 is critical, what proportion of the stock to choose?	M. Casini/S. Neuenfeldt	Early warning analysis
Stock Abundance (1966-2012)	Last accepted assessment	A. Orio	Early warning analysis
Consumption/feeding level (1965-2014)	<0.4 is critical, what prop?	S. Neuenfeldt	Early warning analysis
Recruitment (1966-2012)	Last accepted assessment time series	S. Neuenfeldt	Early warning analysis
Size distribution (1991-2015)	Reference level?	A. Luzenczyk	Early warning analysis
L(max) (1978-2014)	Reference level?	Alessandro	Early warning analysis
.95 length percentile (1991-2015)	Reference level?	A. Luzenczyk	
90% of the stock total area occupied (1982-2011)	Reference level – proportion of the max	M. Casini/ S. Neuenfeldt (WKSPATIAL)	Early warning analysis
Hypoxic benthic areas – trend (1965-2015)		S. Neuenfeldt /M. Casini (WKSPATIAL)	Early warning analysis

D 5.2 Report on spatially explicit MSFD indicators (M40)

Potential spatially explicit MSFD indicators for cod, herring, sprat and flounder, together with responsibilities are given in Table 2.

The agreed spatial resolution for indicators will be ICES SD's (25, 26, 28). Relevant published papers and submitted manuscripts, dealing with application of different scales of spatial aggregation, will be included into D5.2. Several results will be incorporated from ICES WKSPATIAL, which has during the past two years been advanced ICES science in this field through participation of INSPIRE scientists.,

Table 2. Proposed spatially explicit MSFD indicators

Indicator	Notes	Responsibility
Cod SSB Herring SSB Sprat SSB	Use assessment by assessment units, distribute over SD using survey data	S. Neuenfeldt (WGBFAS)
Cod TSB Herring TSB Sprat TSB		
Cod survey Herring survey Sprat survey		
Flounder survey		A. Orio
Cod maximum length		A. Orio
Flounder maximum length		A. Orio
Proportion flounder ecotypes		A-B. Florin / D. Ustups
Prop. of fish > x cm		S. Neuenfeldt / M. Casini / C. Möllmann
Cod % in SD		M. Casini

D 5.3 Manuscript on the role of spatial heterogeneity in Baltic ecosystem-based management (M48)

D5.3 was discussed, and the INSPIRE consortium agreed upon following potential issues to be treated in the manuscript.

- Sub-systems with different carrying capacities (SSB-R relationships, growth)
- Cod migration between western and eastern Baltic (SDs 24&25)
- GES in meaningful spatial units
- Regional trophic cascades

- Spill-over effects
- Density dependent habitat selection only inside basins?
- Redistribution at ‘recovery’ not sufficient to avoid food-dependent growth limitation
- Protecting ‘sources’?
- Regional thinning out? – change in commercial trawl selectivity

All the above mentioned bulleting point are results from other INSPIRE deliverables, and will be addressed in separated review-like sections of the manuscript. The synthesis will then make the point that for the Baltic Sea, spatially explicit multi-species assessment and management are crucially necessary for a successful ecosystem-based fisheries management.

D5.4 Manuscript on regionalization of Baltic Sea ecosystem-based management (M48)

The INSPIRE consortium wishes to highlight the major thought behind the INSPIRE project in a high-level paper, basically a comment to a globally respected journal.
The major thought is that changes in spatial heterogeneity are not to be neglected in understanding ecosystem changes and how to fit management to these changes.
The manuscript on the need of considering spatial heterogeneity in ecosystem-based management [with the Baltic as the case study]. It could be a policy forum in SCIENCE or comment in NATURE.
The structure that was discussed builds upon the novel ecosystems (NE) theory which is, yet, spatially implicit:

1. Link of novel ecosystem (NE) theory to fish stocks and fisheries management
2. Baltic herring and cod examples on the state of <u>NE development</u> (cod) or future risk of <u>NE establishment</u> (herring)
3. Implications for future EB(F)M.

Management implications will include:

- Link of coastal zone management to fisheries management (herring)
- Consider multiple pressures (from FM to EBFM to EBM); i.e. fisheries, eutrophication, coastal infrastructure
- More flexibility in spatial management units (what does this mean for data collection and assessment routines)
- Preparing for lower carrying capacities – planning for adaptation of management goals and fisheries capacity (cod)
- Climate change adaptation – better anticipation & preparation for future climate change
- What does this mean for present EU management which is ignoring all of this?

Annex I. List of participants

No.	Name	Institute
1	Bergström Ulf	SLU
2	Blenckner Thorsten	SU
3	Casini Michele	SLU
4	Horbowy Jan	MIR-PIB
5	Kornilovs Georgs	BIOR
6	Lehmann Andreas	GEOMAR
7	Luzenczyk Anna	MIR-PIB
8	Moll Dorothee	TI-OF
9	Möllmann Christian	UHAM
10	Neuenfeldt Stefan	DTU-Aqua
11	Ojaveer Henn	UT-EMI
12	Orio Alessandro	SLU
13	Polte Patrick	TI-OF
14	Raid Tiit	UT-EMI
15	Raitaniemi Jari	LUKE
16	Ustups Didzis	BIOR

Annex II. Meeting agenda

Tuesday, 31.1.2017

9:00-9:15	Welcome and house keeping
9:15-10:15	Where are we? -Get a condensed update on the project status by WP -15 minutes presentations for WPs 1-4: WP1 Distributions (SLU; M. Casini), WP2 Passive movements (UHAM, C. Möllmann), WP3 Scaling (TI-OF, P. Polte), WP4 Stock Assessments (J. Horbovy, MIR-PIB)
10:15-11:00	Del 5.1 Report on the early warning indicators of cod stock development (M40, MIR-PIB) -Gain an overview over indicators and distribute responsibilities -Discussion round the table -prepare table of indicators, responsible scientists and time of delivery
11:15-11:30	Coffee break
11:30-12:30	Del. 5.2 Report on spatially explicit MSFD indicators (M40, MIR-PIB) -Gain an overview over indicators (focus on fish?) and distribute responsibilities -Discussion round the table -Prepare table of indicators, responsible scientists and time of delivery
12:30-13:15	Lunch break
13:15-14:15	Intro discussion on Del. 5.3 Manuscript on the role of spatial heterogeneity in Baltic ecosystem-based management -Identify structure of the manuscript and journal. Idea: by species and areas, submit to symposium -Discussion round the table -Agree on idea, structure and issues to be dealt with in breakout groups
14:15-14:30	Coffee break
14:30-16:30	Del 5.3 breakout groups -Prepare an abstract for each identified issue (cod, herring, sprat, flatfish, plankton, hydrography – something like that) – what are the most important points? -Small writing groups -1 Abstract per group
16:30-17:00	Del 5.3 synthesis -Put issues in perspective to each other, discuss flow of the paper -Groups present their abstracts -First tentative structure and focus of the paper, distribution of responsibilities, time plan.

Wednesday, 1.2 2017

9:30-10:30	Wrap-up Del. 5.3 – fresh views, leftovers from the day before -Agree on next steps
10:30-11:00	Intro to Del 5.4 Manuscript on regionalization of Baltic Sea ecosystem-based management (S. Neuenfeldt, C. Möllmann) -Re-iterate the starting ideas for a high profile paper -Decide how to go ahead for the rest of the workshop
11:00-11:15	Coffee break
11:15-12:30	Work in groups
12:30-13:15	Lunch break
13:15-14:15	Work in groups
14:15-14:30	Coffee break
14:30-16:30	Work in groups
16:30-17:00	Wrap up for the day

Thursday, 2.2.2017

9:00-10:00	Any other business
10:00-11:00	Continue work on Del. 5.4
11:00-11:15	Coffee break
11:15-12:30	Work in groups
12:30-13:15	Lunch break
13:15-14:15	Work in groups
14:15-14:30	Coffee break
14:30-15:00	Wrap up and concluding the meeting