Herring: Linking biology, ecology and population status in the context of changing environments

Conference Report

National University of Ireland, Galway, 26th to 29th August 2008

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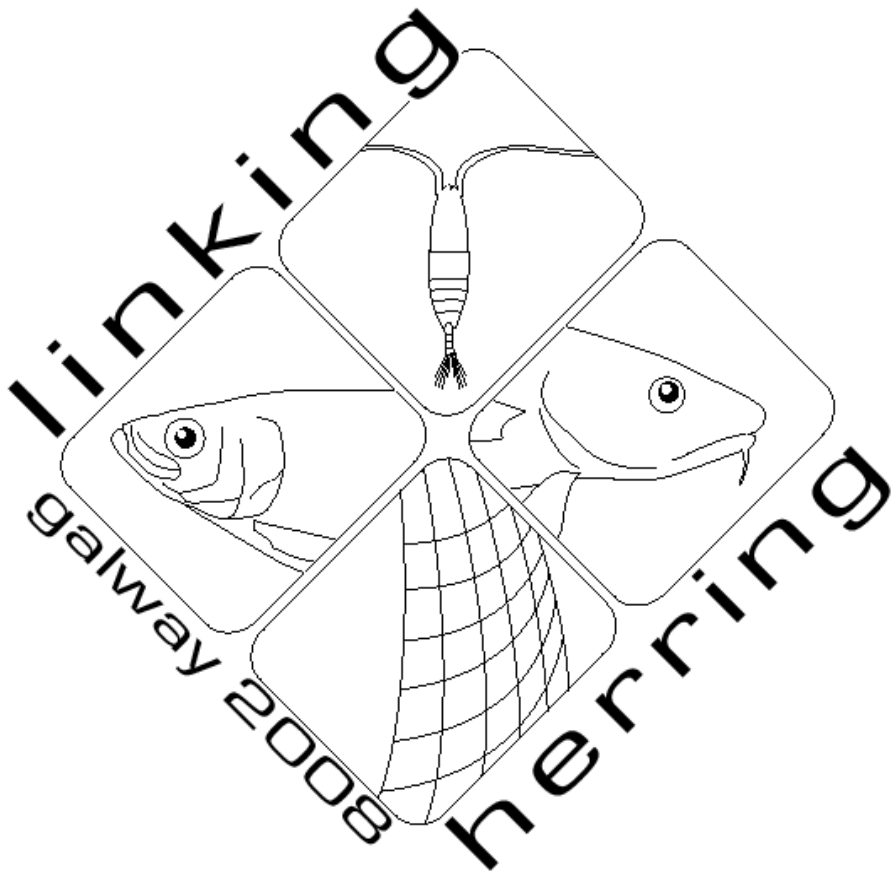
Conference Report



Foreword

This symposium took place from the 26th to the 29th August 2008, at the National University of Ireland, Galway. The symposium was organized to link our understanding of herring biology, population dynamics and exploitation in the context of ecosystem complexity. It is beyond argument that herring play a pivotal role in shaping the structure and dynamics of many boreal continental-shelf ecosystems. As fisheries management moves towards an ecosystem approach, the time seemed right for ICES to hold another herring symposium. Since the last ICES symposia on herring were in the 1960s (ICES Herring Symposium, 1961; Biology of Early Stages and Recruitment Mechanisms of Herring, 1968) many of the former paradigms have been rejected and substantial progress has been made by striking out on new avenues of thought. In addressing this particular topic, we can also follow on from the decadal herring symposia series held in North America and thus cover new research from both the ICES and PICES community. It was fitting that this conference enjoyed the support of ICES, PICES and GLOBEC.

A science committee was drawn from the international community, spanning a range of specialisations in both the Atlantic and Pacific. It comprised of Doug Hay (Canada), Brenda Norcross (USA), Yoshiro Watanabe (Japan), Deirdre Brophy (Ireland), Richard Nash (Norway), Emma Hatfield (UK) and Øyvind Fiksen (Norway). The committee and conveners selected papers and posters for the three and a half days of the conference. A total of 95 delegates attended, representing 15 countries. There were 65 oral presentations and 19 posters spanning the six thematic areas. These covered the Atlantic (NE and NW), Pacific (NE and NW) and Baltic herrings. Regrettably, no papers on Arctic stocks were finally presented. Delegates attended from Ireland, UK, Norway, Denmark, Italy, France, the Netherlands, the Faroe Islands, Germany, Canada, USA, Russia, Latvia, Iceland and Poland. The proceedings are being published in a special issue of the ICES Journal of Marine Science, Volume 66, under the Guest Editorship of Niels Daan (the Netherlands).

Much has changed in the world of herring, since the last ICES symposium. Stocks have collapsed, recovered, and in some cases, have collapsed again. Work in recent years has focused on the development and evaluation of management strategies for herring stocks, and this work continues. The importance of herring in the food chain is an ever present consideration. Despite the many advances, in our knowledge of stock structure and biology, herring populations still present a challenge in terms of managing highly variable populations. We hope that this summary report, prepared by the science committee and the conveners, accurately represents the variety of presentations and discussions on this most variable of fishes.

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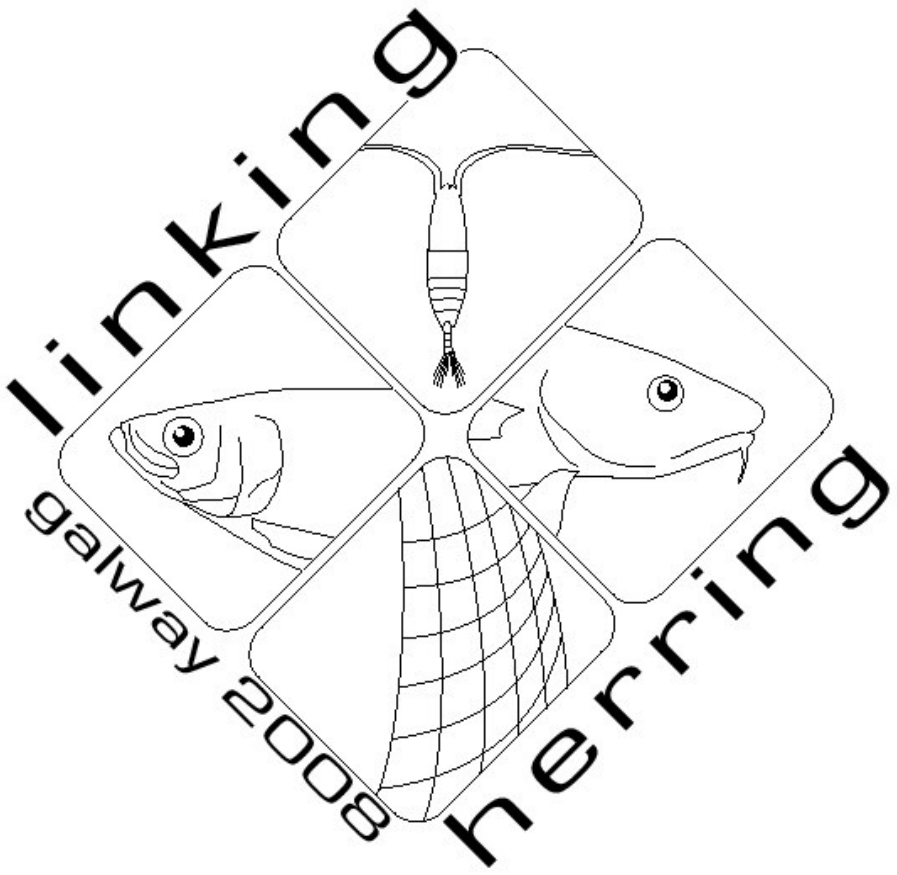
April 2009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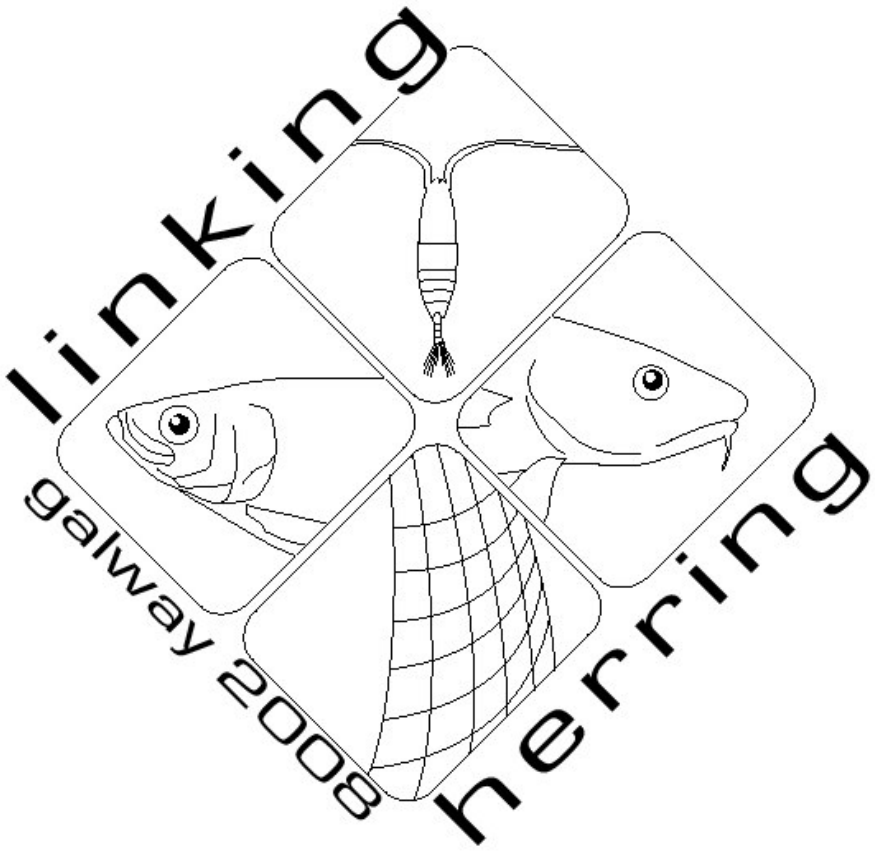


Conference Schedule

Opening of Symposium

Mike Sinclair	**Conference keynote address: Herring, ICES and ideas**
Session 1: Counting herring	Oral presentations
John Simmonds	**Counting herring - qualitative and quantitative estimation of herring and its application**
Doug Hay	Spatial and temporal variation in herring spawn and herring fisheries in British Columbia: biological and management implications
Daniel Howell	Age-length structured modelling of Norwegian spring spawning herring in the Barents sea ecosystem
Stefano Mariani	Estimating the number of breeding North Sea herring using genetic data
Claude Le Blanc	Using acoustics on fishing vessels to monitor herring spawning dynamics in the southern Gulf of St. Lawrence
Rainer Oeberst	When is year class strength determined in western Baltic herring?
Mark Payne	Finding the signal in the noise: judicious data selection improves the assessment of western Baltic spring spawning herring
Emma Hatfield	A study of variability in the biomass and distribution of clupeid populations in selected Scottish west coast sea lochs
Tommaso Russo	Progress in modelling herring populations: individual-based models of growth
Richard Thorne	Acoustic surveys of herring in Prince William Sound, Alaska: a long and successful series
Corinne Martin	Schooling behaviour and distribution of herring: application of acoustic methodology in the English Channel
Sherri Dressel	Stock assessment of Pacific herring in Sitka Sound, Alaska

Session 1: Counting herring	Poster presentations
Emma Hatfield et al.	Exploratory Methot net sampling of herring larvae during the 2008 west coast q1 IBTS
Jake Schweigert et al.	Using indices of juvenile (0+) herring for predicting recruitment in Georgia Strait, British Columbia.
Lindsay McPherson and Tara Marshall	Inaccuracies in proportion of Atlantic herring (*Clupea harengus* L.) mature during the North Sea herring acoustic survey
Beatriz Roel and Jose de Oliveira	A Two-Stage Biomass model given additional variance in the recruitment index
John Simmonds	North Sea herring: Probably the best assessment .....
Session 2: Advances in herring biology	Oral presentations
Audrey Geffen	**Advances in herring biology - from simple understanding to complex knowledge**
Loïc Baulier	Is maximum body size in herring constrained by prey size?
Sandrine Vaz	Mapping herring distribution and habitat preferences in the eastern English Channel
Paul Hershberger	Recurring viral erythrocytic necrosis (VEN) epizootics in juvenile Pacific herring from Puget Sound, WA, USA
Rainer Oeberst	Mean daily growth of herring larvae based on weekly repeated cruises in the Greifswalder Bodden
Deirdre Lynch	Long term trends in biological parameters of Celtic Sea herring
Mark Dickey-Collas	Variability in Herring growth: Comparison among North Atlantic stocks
Stephanie Kramer-Schadt	Investigating the factors contributing to the *Ichthyophonus hoferi* outbreak in NSSH *Clupea harengus* 1992-2007
Session 2: Advances in herring biology	Poster presentations

Azza El Ganainy and M. Sabra.	Preliminary assessment of the round herring, *Etrumeus teres*, stock in the Gulf of Suez, Red Sea, Egypt
Paul Hershberger et al.	Larval Pacific herring are Highly Susceptible to Viral Hemorrhagic Septicemia and Survivors are Partially Protected after their Metamorphosis to Juveniles
Tatyana Prokhorova et al.	Differences in calculation of growth rate by scales from various body parts of the Norwegian spring spawning herring
Papa Rey Donne	Updates on the feeding ecology of the endemic freshwater sardine of Taal Lake, Phillipines, *Sardinella tawilis* (Herre 1927).

Session 3: Variable production Oral presentations

Peter Munk	Oceanographic influence on the early life of herring at North Sea spawning grounds
Cindy van Damme	Fecundity regulation in North Sea autumn and winter spawning herring
Arild Folkvord	Environmental and genetic influence on growth strategies in herring larvae
Deborah Davidson	Linking environmental factors to spatial and temporal variation in fat content of North Sea herring
Katja Enberg	Fisheries-induced life history changes in North Sea herring (*Clupea harengus*)
James Kennedy	Induction and occurrence of skipped spawning in Norwegian spring-spawning herring
Susan Lusseau	Recruitment failure in North Sea herring: a gut feeling?
Aril Slotte	Effects of hatching time on year-class strength in Norwegian spring spawning herring
Hilkka Ndjaula	Reproduction and recovery rate of Norwegian spring-spawning herring
Christine Röckmann	Herring: change in climate, change in habitats?

Session 3: Variable production Poster presentations

Geir Huse et al.	Peaks in recruits to spawner ratio correlates with abrupt changes in herring wintering areas

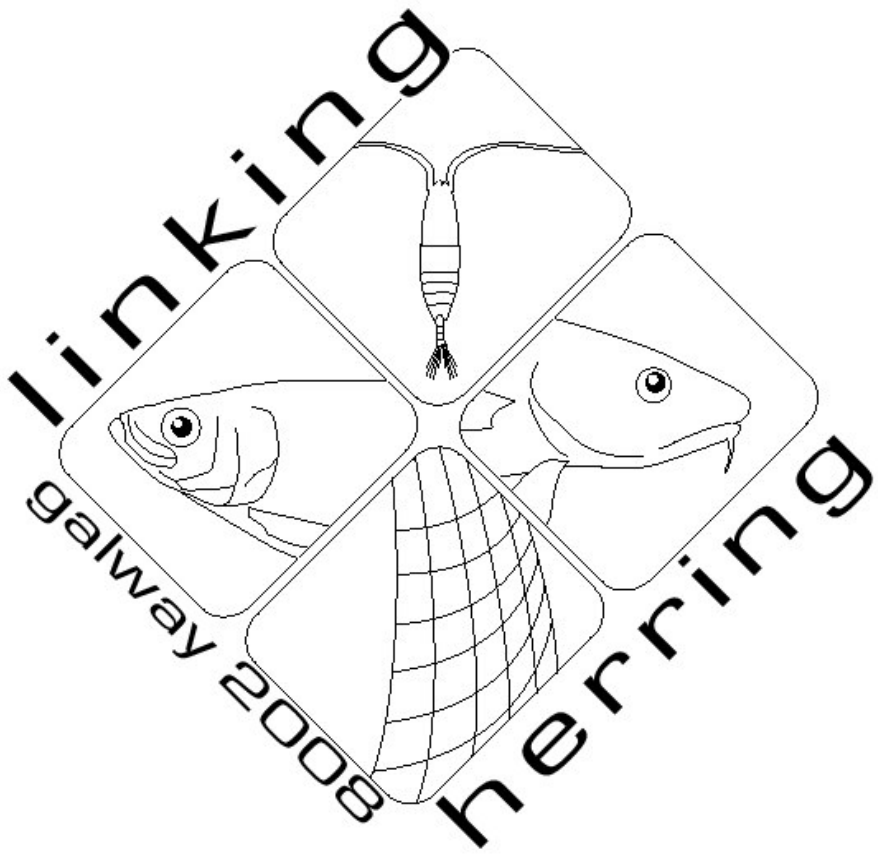
Alexander Trofimov et al.	The influence of oceanographic conditions on abundance of the Norwegian spring-spawning herring at the early life stages
Stanley Rice et al.	Population reclines and lack of recovery of pacific herring in Prince William Sound, Alaska, USA

Session 4: Population integrity Oral presentations

David Secor	**Obstinate nature and response diversity in an Atlantic herring metapopulation**
Arne Johannessen	Mixing of herring stocks within the same school during spawning: support for a metapopulation in Atlantic herring
Jan Arge Jacobsen	Stock identification and biological position of the herring stocks in the Faroe shelf ecosystem
Alexander Krysov	Population and hydrographic aspects of the Norwegian spring-spawning herring migration
Nóirín Burke	Mixing of herring juveniles in the Irish Sea: Temporal trends and environmental drivers
Linnea Flostrand	Investigation of variability in Pacific herring tag recovery rates to elucidate trends in inter-annual spawning site fidelity
Deirdre Brophy	Information from otolith microstructure and shape provides evidence of natal homing in Atlantic herring (*Clupea harengus*)
Guðmundur Oskarsson	Variation in spatial distribution and migration of Icelandic summer spawning herring
Magdalena Podolska	The characteristics of southern Baltic herring infected and non-infected with *Anisakis simplex* larvae using geometric morphometrics
Rob Stephenson	Population integrity and connectivity in NW Atlantic herring: a review of assumptions and evidence
Anna Was	Strategy for genetic subpopulation investigation – multidisciplinary approach into discrimination of the southern Baltic herring
Lotte Worsøe Clausen	Application of otolith shape as a stock identification method in mixed Atlantic herring (*Clupea harengus* L) stocks in the North Sea and western Baltic

Yoshiro Watanabe	Migration of adult Pacific herring spawned in Miyako Bay on the Pacific coast of northern Japan
Deirdre Brophy	Elucidating population structure in juvenile Atlantic herring in Scottish west coast sea lochs: a multi-marker approach
Jens Christian Holst	Norwegian spring spawning herring: population characteristics of a major change in wintering area
Session 4: Population integrity	Poster presentations
Audrey Geffen et al.	Identification of spawning components in mixed aggregations of Atlantic herring (*Clupea harengus*) along the west coast of the British Isles based on chemical composition of otolith cores
Audrey Geffen et al.	Connectivity between nursery areas and spawning stocks of Atlantic herring (*Clupea harengus*) on the West side of the British Isles, based on otolith microchemistry
Steven Beggs et al.	Stock identification of 0-group herring in the Irish Sea using otolith microstructure and shape analysis techniques.
Session 5: Herring in the middle	Oral presentations
Andrew Bakun	**Herring in the middle: a comparative discussion**
Øyvind Fiksen	Seasonal plankton-fish interactions: herring energy storage in relation to light and prey abundance
Robert Emmett	Pacific herring off Oregon/Washington, USA: fluctuations in abundance relative to ocean conditions and their importance to salmon marine survival
Emily King	Bayesian networks between herring and zooplankton in the Irish Sea
Torstein Pedersen	Predation by cod on herring
Irina Prokopchuk	Distribution and feeding ecology of 0-group herring in the Barents Sea in 2002-2006
Natalia Serpetti	Variability in the winter diet of juvenile herring 0-age in four lochs on the west of Scotland
Richard Thorne	Interactions between herring and predators during winter in Prince William Sound, Alaska

Kjell Utne	An individual based model (IBM) for annual herring migrations in relation to food abundance and oceanographic factors
Session 5: Herring in the middle	Poster presentations
Andrey Dolgov et al.	Trophic relations between Atlantic herring juveniles and abundant fishes in the Barents Sea under different climatic conditions
Session 6: Managing change	Oral presentations
Martin Pastoors	**Managing change: people, models and fish (herring?)**
Laurence Kell	Lumpers or splitters? Evaluating recovery and management plans for metapopulations of herring
Steven Beggs	Population structure and migration of Irish Sea herring: implications for assessment
Evelyn Brown	An ecosystem model of Prince William Sound herring: a management and restoration tool
Maurice Clarke	Towards a management plan for Celtic Sea herring
Øyvind Fiksen	Managing herring under uncertainty: what are the benefits of stock information?
Gary Melvin	Oscillating reproductive strategies of Atlantic herring in response to changing environmental conditions
Sigurd Tjelmeland	Objectives and harvest control rules in the management of the fishery of Norwegian spring-spawning herring
John Wheeler	Temporal changes in growth, maturation, and condition of Atlantic herring (*Clupea harengus*) and the potential implications for fisheries management in Newfoundland waters
Session 6: Managing change	Poster presentations
Michail Bodarenko et al.	Recruitment and spawning stock in spring spawning Norwegian herring
Priscilla Licandro et al.	Investigating a possible link between zooplankton changes and recent poor recruitment of herring in the North Sea



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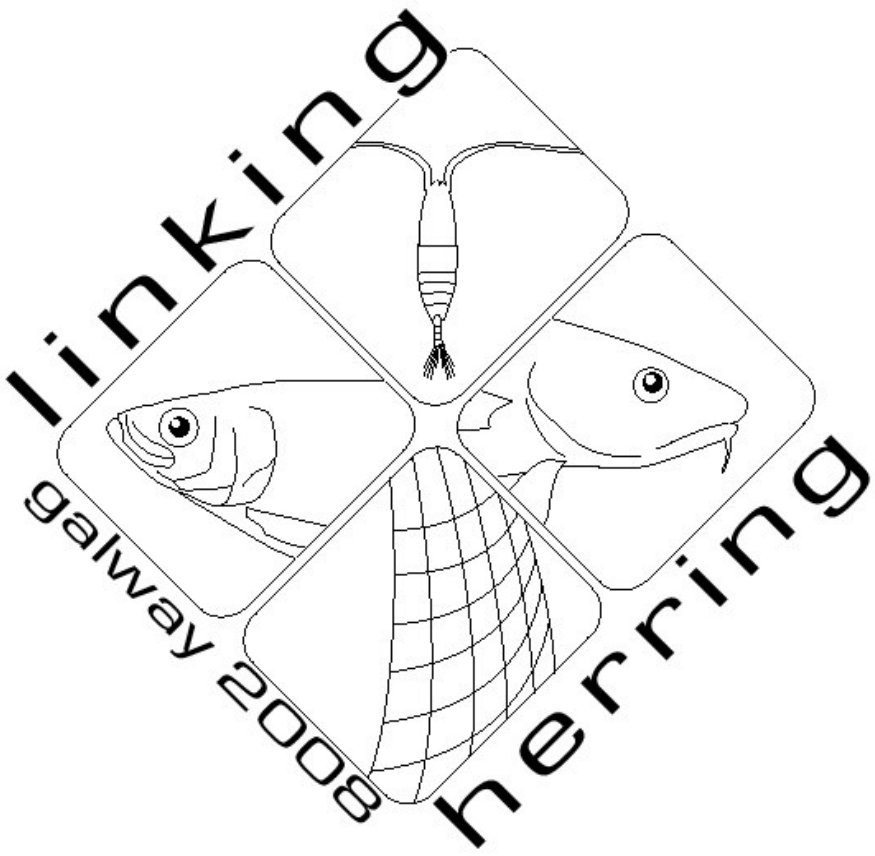


Conference Report

Opening address: Herring, ICES and Ideas

Keynote speaker: Mike Sinclair

This address outlined the development of some ideas generated from herring research within an ICES context. The work of Committee A (1902–1908), under the leadership of Johan Hjørt, led to a shift from "migration thinking" to "population thinking" as the interpretation of fluctuations in herring landings. Other key milestones of this time were from Heincke (ageing, the existence of races) and from Hjørt (application of age-census methodology).

From the 1920s to the 1950s, the focus was on forecasting services for the herring fisheries. The failure of the 1952 East Anglia prediction, due to poor estimation of the 1947 year class, marked the end of this era. Although ultimately unsuccessful, efforts of this period had unintended consequences. The observations with Hardy's Continuous Plankton Recorder have led to hypotheses on the processes that generate recruitment variability (match–mismatch). Hodgson's forecasts, and their failure in 1951/1952, led to the concept of recruitment overfishing.

The collapse of the East Anglian fishery led, in 1956, to considerable debate on its causes, but no consensus was reached. This busy herring year did not result in any specific management actions, but it did mark a turning point as the seed of the recruitment-overfishing concept was planted.

The 1956 events, and comparable global developments associated with other heavily fished small pelagics, enhanced research on stock recruitment relationships and recruitment processes during the 1960s. During this decade, three ICES symposia were either wholly or partly dedicated to herring studies. There was a marked shift from the acceptance of the concept that fishing had little impact on recruitment (Popp Madsen, Zijlstra, and Hempel ; 1961 symposium), to serious doubt that the level of recruitment is mainly independent of spawning stock size (Parrish; 1970 symposium). These consecutive symposia (1961, 1968, and 1970) revealed a changing perspective on the role of fishing on recruitment dynamics, culminating in Cushing's 1975 book, referred to here as the "Grand Synthesis", which defined the concept of recruitment overfishing and established the future agenda for fisheries oceanography. By 1978, the ICES symposium on pelagic stocks produced the "Aberdeen Consensus", considering that without effective management, recruitment overfishing was to be expected.

The recent (1990s) application of Harvest Control Rules (HCRs) in practical terms for herring fisheries has been innovative and "closes the loop", as it were, on the solution of the recruitment-overfishing problem (as advocated by the "Grand Synthesis" and the "Aberdeen Consensus"). The successful implementation of a HCR for North Sea herring illustrates the strength of ICES by effectively bridging the gap between scientific research and advice, a strength that has been a constant factor from Hjørttime through to the present.

Finally, the issue of the "Ecosystem Approach" was considered. Under this approach, conservation objectives have become broader (beyond the target species). For example, the consideration of impacts on bycatch of other species, habitat disturbance, and forage-fish issues. Undoubtedly, ideas such as these will be a focus for ICES in the coming decade.

Session 1: **Counting herring**

Session chairs: Mark Dickey-Collas and Aril Slotte

Keynote speaker: John Simmonds

John Simmonds started the counting herring session with a review of the qualitative and quantitative estimation of herring and its application. He pointed at the wide range of herring population sizes and distribution areas, demonstrating that herring populations are surveyed at various life stages and assessed through a variety of methods. He indentified some criteria for good management information, and presented the historical performance of assessments on some stocks.

This review was followed up with related oral presentations and posters covering the wide distribution of herring from both the western and eastern part of the Atlantic as well as in Pacific waters. Moreover the presentations covered all life stages, from the egg, larvae, post-larvae, 0-group, immature and mature herring. Some presentations concentrated on methods, whilst others presented results of research studies.

Results were given on the use of different data, statistics and modelling tools to improve herring assessment, including Bayesian hierarchical methods for improved integration of herring stock-recruitment knowledge, age-length structured modelling, individual-based models of growth, abundance estimation of breeding herring with genetic data and the use of *a priori* data selection to improve stock assessment.

A modelling framework "Gadget" was presented by **Daniel Howell** as a means to examine biological, ecological and fisheries scenarios involving herring. **Stefano Mariani** presented a model for estimating North Sea herring using genetics data. Though not fully implemented, some conclusions could be drawn about the stock. For instance, the relatively high stock size was considered responsible for the failure to detect genetic differentiation between stocks that we know are largely demographically independent. A model of individual growth in herring was presented by **Tommaso Russo,** where the mean size of each cohort follows the von Bertalanffy equation.

Different methodologies for direct estimation of herring distribution and abundance were presented, covering estimation based on catch per unit effort data, on larvae and young of the year fish, acoustic estimation on both research vessels and commercial fishing vessels, aerial surveys for documenting miles of shoreline receiving milt and scuba dive surveys for estimating density of eggs spawned.

Larval surveys of Baltic herring were used by **Rainer Oeberst** to determine when in the life cycle year class strength is determined. The larval data were used to develop an index of 20mm larvae that showed a strong correlation with recruitment estimated in the stock assessment. It also showed that year class strength was determined by week 20-40 days of age (30 mm). The use of purse seines to measure recruitment was explained by **Jake Schweigert** for Georgia Strait, British Columbia. This method was found to be better at identifying poor cohorts, than strong ones. Recruitment strength appears to be determined in the first 6 months of life.

Claude Le Blanc outlined the use of acoustic data from commercial vessels, as it is used for stock assessment purposes in the southern Gulf of St Lawrence. There was confidence that the minimum SSB index generated was more reliable than fishery-dependent data (gillnet CPUE). Acoustic data were collected opportunistically during trawl surveys of the English Channel (**Corinne Martin)**. The difficulties in using this approach for abundance estimation were clearly described. However useful information on schooling behaviour and migration was collected.

In Prince William Sound, a long series of acoustic surveys was shown to compare well with spawning data, though less well with the age structured assessment (**Richard Thorne**). The survey series offers a

stock index that can be used immediately prior to the opening of the fishery. He emphasised the complexity of acoustics and the need to understand fish behaviour and stock behaviour and their seasonal and temporal changes.

Doug Hay showed that total spawn abundance in British Columbia may be reduced by fishing, but there was no evidence that spatial diversity of spawn was reduced by fishing. However, sea surface temperature appears to have an influence over spawn distribution.

Emma Hatfield presented results of a survey conducted for juvenile 0-group herring west of Scotland and north of Ireland in March 2008. Mean length and growth data suggest that most fish encountered were of winter-spawned north of Ireland origin.

Overall, the presentations given clearly demonstrate the need for a variety of tools and methodologies, given the large scale differences in behaviour and distribution that occur between populations and different life stages. In some areas the best estimate of spawning stock size may come from the counting of eggs or early larvae, whereas in other areas acoustic estimation of the adult fish is a better choice.

Still, the predictive value of estimating herring at an early stage as an index of recruitment to the stock is clearly high, as also demonstrated in the counting herring session. Several aspects may influence abundance estimation in herring, and some of them were also highlighted, including the very dynamic migration and schooling behaviour of this species, the effects of changing climate and inaccuracies in estimated proportion of mature fish. As an example, **Lindsay McPherson** examined inaccuracies in the maturity ogive of North Sea herring. Histological staging confirmed misidentifications at the macroscopic scale. Atresia and misidentifications were put forward as reasons why SSB may be inaccurately estimated. **V**ariability in abundance of juvenile herring in west Scottish sea loch nurseries was discussed by **Emma Hatfield.** These nurseries contain herring that are not from the local, west of Scotland autumn spawning stock. The origin of these fish is likely a mixture of local spring spawners and Irish autumn and winter spawning herring.

John Simmonds gave details of the assessment of North Sea herring: "probably" the best assessment. The assessment is able to rely on separate surveys for larvae, 0-group juveniles, 1-group recruits and adults. Such detailed assessments are only possible through multi-nation research efforts, impossible for smaller, or more localised stocks.

A comprehensive presentation on the assessment of Sitka Sound herring was provided by **Sherri Dressel**. Two survey methods are used, scuba surveys for density of eggs spawned and aerial surveys to estimate miles of shoreline receiving milt. An age structured assessment model used these data and commercial catch at age. A harvest control rule allows for harvests in the range of 10-20% of forecasted biomass, with 0-catch option if a threshold biomass is not forecast.

Mark Payne explained how some problems for the assessment of western Baltic herring were improved. The stock is highly migratory and mixes with other stocks at certain times of the year. Yet no survey contains the stock, at any time of the year. Particular surveys were considered *a priori* to be more appropriate for certain age groups, based on knowledge of the migration. The selection of the most appropriate data seems to have improved the retrospective bias in the assessment.

Beatriz Roel described a stock assessment method for Irish Sea herring where variability in recruitment due to a mixture of native and immigrant juveniles was accounted for. Results showed that better information on juvenile abundance is required, including the relative strength of native and immigrant fish.

However, although the presentations given in the counting herring session clearly suggest that we have taken major steps forward in the assessment of herring populations, they also indicate the need for more research on the topic. Due to the dynamic nature of the herring there will be need for focus on using the right methodology at the right place and the right time of the year.

The session generated a lively debate, particularly the potential use of commercial fishing vessels to collect acoustic data for stock assessment. The two main issues arising from the discussion were:

- Facilitating industry involvement in management via participation in surveys. In this case, there were some lessons from Canadian examples.

- Ensuring that the data generated provided a reliable index of abundance. All agreed that more work was needed to establish reliability of results.

Sean O'Donohue expressed the support of the fishing industry for their involvement in acoustic surveys. He pointed out that there was real possibility for this model to be applied for smaller stocks of herring when funding was not available for full acoustic surveys and that there is a necessity to integrate information from industry in order to get appropriate data at low cost. Suitable protocols are also needed to facilitate this. **Tara Marshall** and **Evelyn Brown** both referred to the Canadian model. Co-management led to the empowerment of the Canadian fleet – in contrast to the situation in the USA where the fleet became disengaged with the process (**Evelyn Brown**).

John Simmonds expressed reservations about using this method of data collection where there was uncertainty about the distribution of the fish due to movement in and out of the spawning area. **Lotte Worsøe Clausen** pointed out that there are ongoing projects that aim to incorporate information from the fishing industry into management (e.g. GAP project) It was noted that Dutch scientists are currently testing the biases of taking data from commercial vessels through simulations. **Mark Dickey-Collas** highlighted the role of Regional Advisory Councils in facilitating this industry involvement. He emphasised the importance of working more closely with industry and maintaining good co-operation. He warned that industry may develop unrealistic expectations of the outcome of their involvement. He also stressed that more work was needed to refine methodologies and data analysis. It was suggested that WGFAST may provide support for this; if this is not in their remit, perhaps their remit should be changed to include it.

The co-management in the Canadian snow crab, lobster and herring fisheries was discussed. Co-management must be transparent and real. Industry have an expectation to be involved in management and in the decision making process. They also want to see the data that is generated. In the Canadian case there was some disillusionment from industry with some feeling that it was not transparent and open. Quota cuts were not appreciated. The success of co-management depended on the fishery; in the lobster fishery there are no quotas so fishers are not interested in co-management. Snow crab fishery is based on quotas so fishers are more involved.

Session 2: **Advances in herring biology**

Session chairs: Mark Dickey-Collas and Deirdre Brophy

Keynote speaker: Audrey Geffen

This session provided insight into recent advances in herring biology research with reference to several stocks from around the world. The session comprised one keynote address, seven oral presentations and four posters. The contributions dealt with western and eastern Atlantic herring (*Clupea harengus*) and Pacific herring (*Clupea pallasii*) populations. Many aspects of herring biology were covered including spawning and reproduction, larval growth and early life history, feeding and foraging behaviour, adult growth rates and maturation, habitat preferences and the often overlooked issue of disease. Some poster presentations gave an alternative perspective from other small pelagic species.

In her keynote address, **Audrey Geffen** gave a comprehensive overview of the biological adaptations of each herring life stage and the variability in these responses which is so characteristic of herring populations. Commercial value, population variability, and the significant evolutionary position of the species were identified as the main drivers of herring research over the last two centuries. More recent advances in knowledge were attributed to developments in acoustic and video technologies, genetics, otolith analysis, behavioural studies and captive rearing. Research into the behaviour of herring in spawning schools was reviewed and the influence of pheromones highlighted. The non-random nature of fertilization was well illustrated by studies of sperm motility and gamete interactions. Parental effects on egg size and larval growth was considered. The question of how herring populations exist in diverse environmental conditions was addressed with a comprehensive review of the adaptations of early life stages to temperature and food supply; the phenotypic plasticity of larval development was highlighted. The issue of juvenile mixing was examined in relation to homing and spawning fidelity and with reference to evidence from otolith characteristics and other population markers. It was proposed that both drift and retention are important and the extent to which fish display fidelity to spawning sites and seasons varies between populations. For adult fish, the relationship between age and fecundity and the role of atresia was emphasised. The contribution of herring research to current understanding of fish evolution and phylogeny was acknowledged. To conclude the speaker emphasised the need to synthesize new information and to reappraise existing theories relating to stock structure, behaviour, tolerance and adaptability to arrive at a clear understanding of herring biology.

Given the implications for survival, fecundity and productivity, it is not surprising that size and growth were the central themes of a number of presentations. Both adult and early life stages were dealt with and variability was investigated at the levels of individuals, populations and species. **Rainer Oeberst** presented data from weekly larval herring surveys in the Greifswader Bodden (Baltic Sea) to examine larval growth rates over a wider range of temperatures than previously investigated in the field or laboratory (5˚C-20˚C). Estimates of mean daily growth were significantly related to surface temperature and this relationship corresponded well with previous reports from the literature. There was no evidence of impaired growth at high temperatures (up to 17.5 °C). Additional parameters (bottom temperature, salinity, larval density, zooplankton abundance) did not appear to contribute to variability in mean daily growth rates.

Loïc Baulier presented a Holling type II functional response foraging model to identify the constraints on size in Norwegian spring spawning herring (maximum observed size 40cm). The variables in the model included prey energy content, prey size and handling time. Model simulations showed that for either definition, "most profitable fish length" (defined in relation to energy availability) was positively related to the energy content of the prey and inversely related to prey handling time.

Maurice Clarke described trends in biological parameters in Celtic Sea herring over the period 1921-2008. Mean weight and length growth rates and condition have declined significantly since the 1970's. This reduction is expected to reduce spawning potential. In addition, a given TAC will remove higher

numbers of fish from the population than before the decline and target SSB (B_{pa}) will be harder to achieve in terms of numbers. The changes do not appear to be due to density dependence.

An unscheduled presentation summarised the results of a meta-analysis examining growth variability across fifteen Atlantic herring stocks (**Mark Dickey-Collas)**. There was considerable variation in weight at age, and in the variability in weight at age; in some stocks this was stable over time while in others it fluctuated. The variation in growth curves between stocks was related to sea surface temperature (SST); growth rate (K) increased with SST while asymptotic weight (W_{inf}) decreased. There was some evidence of a density dependent effect on growth parameters which may be indirectly driven by temperature (coldwater stocks tend to show the highest densities). At the stock level, the influence of temperature and density on growth parameters was not consistent. The need to consider this in scenario testing was highlighted.

One poster presentation dealt with the measurement of growth using scales. Scales from the head of fish were shown to provide more reliable estimates of age at first spawning in and growth in Norwegian spring spawning compared to scales taken from other body parts (**Tatiana Prokhorova**).

Herring diseases were the subject of two oral presentations and one poster. This topic stimulated a good deal of discussion at the close of the session. **Paul Hershberger** described the progression of viral erythrocytic necrosis (VEN) epizootics in juvenile Pacific herring from Skagit Bay in Puget Sound. Monthly monitoring over two years showed that prevalence was high (peaking at 67%) and VEN epizootics persisted for extended periods. The incorporation of previously naïve cohorts into the epizootics shortly after metamorphosis was observed. VEN prevalence in Skagit Bay did not correspond with that in other areas.

The protozoan parasite *Icthyophonus hoferi* was the focus of a presentation by **Jens Christian Holst**. Data, collected over sixteen years, were used to determine if this lethal disease, which caused significant mortality in the Norwegian spring spawning herring stock in 1991, was transmitted directly from the water (density dependant hypothesis) or ingested (feeding hypothesis). The results suggested combined effects of both density and feeding, with direct field observations needed to support the latter.

In the poster session, the results of a laboratory experiment showed that larval Pacific herring are highly susceptible to viral hemorrhagic septicaemia, with survivors partially protected after metamorphosis (**Paul Hershberger**).

One presentation examined spatial distribution of juvenile and adult herring in the English Channel over a long time series (1988-2006) (**Sandrine Vaz**). Geostatisitcal variogram analysis revealed trends in spatial distribution; juveniles were concentrated on the eastern side of the channel while adults were also found on the western side. Habitat models (GLM and quantile regressions) related species abundance to habitat features and environmental conditions. There was good agreement between modelled and observed distributions for juveniles, which showed a preference for coarse sediments, low bedstress and temperature. Models performed less well for adults, which appear to be less dependent on physical habitat.

The poster session also offered an alternative perspective from other small pelagics in the marine and freshwater environments. A preliminary assessment of the economically important round herring *Etrumeus teres* fishery in the Gulf of Suez in the Red Sea (**Azza El-Ganainy** and **M. Sabra**) was presented as well as an investigation of the feeding ecology of the endemic freshwater sardine of Tall Lake in the Philippines: *Sardinella tawlis* (**Papa Rey Donne**).

The session concluded with a discussion of the main topics raised. The issue of disease was a central theme. It was generally agreed that the importance of disease in regulating population numbers had been heretofore largely overlooked. It was suggested that increased emphasis should be placed on research into disease adaptations, resistance and susceptibility. The disease prevalence and mortality rates described in the presentations highlight the need to extend monitoring activities across a wider range of stocks and to increase their temporal resolution. This would allow us to consider disease

within a management perspective. Pacific herring in Prince William Sound (Alaska) were put forward as a model for the integration of parasite monitoring into management programmes. The need for a thorough risk assessment and cost/benefit analysis of such monitoring activities was highlighted although it was accepted that this is difficult given the current information deficit. It was proposed that eco-toxicological techniques may have a potential role in the monitoring of disease responses. Finally it was suggested that ecological literature on the density dependent nature of infections could provide the theoretical background to increase understanding of the impact of disease on herring populations.

The dialogue then moved to the issue of spawning behaviour. The degree of plasticity in the timing of spawning in herring stocks was raised. The need for large scale comparative studies to investigate the mechanisms controlling the timing of spawning at a species level was stressed. It was noted that the failure to detect genetic differences between herring populations in the face of large phenotypic differences may be due to insufficient sensitivity of current techniques and may be addressed by future methodological developments (e.g. non-neutral markers). It was recognised that there is a need for reliable tools to distinguish between spawning groups, regardless of the apparent lack of genetic structuring.

The discussion also dealt with external forces on herring biology. It was apparent from the discussion that a multiplicity of factors need to be considered when examining changes in biological parameters; fishing pressure, predation, environmental conditions and their interactions were all implicated. Changes in spawning behaviour in response to fishing were addressed with reference to observed shifts in the location of spawning in the North Sea and in Norwegian spring spawning herring. Evidence for phenotypic changes in growth rate and maturation in response to fishing was highlighted. The effects of predators on both the mortality and the distribution of herring were also considered. The case of capelin in the northwest Atlantic was cited as an example which highlights the complex influences of environmental changes on population biology. It was noted that mortality during the early life stages outweighs the effects of either fishing or predators. It was remarked that the estimate of natural mortality currently used in stock assessment was arbitrary and that efforts should be focused on refining this estimate. On closing the session the session chairs thanked the participants for their valuable contributions and insightful discussion of the issues raised.

Session 3: Variable production

Session chairs: Richard D.M. Nash and Aril Slotte.

The variable production section was dominated by presentations on eastern Atlantic herring (10 oral presentations and 2 poster presentations) with only one poster presentation on Pacific herring. For the eastern Atlantic the herring stocks considered were Norwegian spring spawners (NSSH) and the North Sea autumn/winter spawning complex (NSH). The principal topics raised for the NSSH were variations in productivity, recruitment and behaviour (as seen in shifts of over-wintering areas), and the suggestion that skipped spawning may occur in this stock. The majority of the work presented on NSH revolved around the current poor recruitment and the reasons for the recent poor survival rates. In addition there was a consideration of potential evolutionary effects on the stock dynamics. Lastly there was a return to the theme in the biology section considering whether all herring are alike with experiments on larvae raised as autumn or spring spawners. In Pacific herring the topic raised was the influence of a number of factors, including disease, negatively influencing the stock recovery process.

Two broad themes were presented, namely dynamics in early life history and secondly dynamics in the adult population. With the recent run of poor recruitment in NSH it was not surprising to have papers exploring the causes of the poor survival in the early life history (larvae) stages. **Peter Munk** presented the effects of physical habitat, namely the influence of frontal systems as a causative factor for the change in survival rates. The conclusions were that larvae survival rates were higher close to fronts and that the change in hydrographic conditions since 1998 has had a detrimental effect on survival and hence recruitment. **Christine Röckmann** presented a variety of physical parameters to examine the habitat of herring larvae. To examine the 30 year time series covering the whole North Sea it was necessary to utilise data from oceanographic models as full station by station physical data do not exist. Habitat preferences were characterised by a 'habitat quotient'. Over the time series there were shifts in habitat prevalence/preference but this will need further analyses. **Susan Lusseau** investigated whether the poor recruitment in the NSH could be linked to diet and/or parasite infections of the larvae in the over-wintering period. The suggestion is that the interplay between available food resources and parasitic infection could be a cause of the poor recruitment or survival. This was evident in the small study area off the east coast of Scotland but this hypothesis needs to be tested over a much larger geographical area and a larger portion of the stock. Variability in survival rate of young stages is well known but the causal effect as illustrated above are difficult to elucidate. In NSSH, **Geir Huse** showed that there appears to be a linkage between abrupt shifts in over wintering areas and survivorship from egg to recruitment as measured in the recruits to spawning stock biomass ratio.

Aril Slotte illustrated the potential importance of predation effects, in this case relating to NSSH. Here the timing of spawning and hence hatch determined the timing of larvae drift up the west coast of Norway to the nursery areas in the Barents Sea. Essentially higher survival occurred in years with early hatching as many of the larvae were north of the main pollack concentrations before they started to actively feed. The theme of determinants of year class strength was furthered by **Alexander Trofimov** for NSSH where a wide variety of physical and biological parameters were used in regression equations to explain the variable survival.

Deborah Davidson examined spatial variability in fat content of juvenile North Sea herring, covering the parts of the stock that spawned in the autumn through to the winter (north to south). A trend in size and fat content from north to south was explained by the higher *Calanus* spp. abundance in the north and lower temperatures.

NSSH and NSH typify two spawning strategies in herring, namely spawning in spring and autumn. **Arild Folkvord** also asked the question (raised in the biology section and also elsewhere in this section) are larvae from different populations really adapted to their respective environmental conditions? Using common garden experiments and crosses between autumn and winter spawners the general conclusion

was yes and no. There were minor differences but it was apparent that herring larvae in general are capable of handling the different environmental conditions.

The theme of differences or similarities between autumn and winter spawners was continued with **Cindy van Damme** examining fecundity schedules in the adults. It appears that herring essentially start maturing and developing oocytes with autumn spawners stopping in the autumn and spawning. In spring spawners there is no arresting of development, a combination of fecundity down-regulation and continued growth leading to the characteristic differences in reproductive strategies between autumn and spring spawners. This finding contrast with earlier assertions that spring spawners develop until the end of the summer, and then cease again till the spawning season.

Continuing the theme of reproductive strategies **James Kennedy** examined the suggestion of 'skipped spawning' in NSSH. The suggestion is that herring will skip their second spawning event. Extensive laboratory and field work was undertaken to test this hypothesis and there was no evidence that this phenomenon is as widespread as suggested from previous studies. This study highlighted the importance of undertaking robust experimentation to investigate inferences drawn from analyses of data there were collected for a different purpose.

The effect of life history parameters, specifically the intrinsic rate of increase of a stock or cohort (r) was investigated by **Hilkka Ndjaula**. In NSSH cohorts prior to the collapse of the stock had negative values of r, indicating that the stock was in a state of decline. The conclusion was that cohort specific r was a unique and informative measure of stock productivity and could be used with other indicators in stock assessments. This measure can also be used as a general indicator of stock productivity (including reproductive investment) and its variability over time. This has implications for stock recovery times. The effect of changes in reproductive strategies was further investigated by **Katja Enberg** who examined the probabilistic maturation norms (PMN) in NSASH and the linkages to fishery induced changes in life-history parameters. Here there were unexplained shifts in the PMN midpoints which may have been caused by environmental effects and/or shifts in the spatial distribution of the stock or its components. The results also illustrate the importance of obtaining good spatial sample coverage for providing a meaningful interpretation of the data and what is happening at the stock level.

Recovery of depleted stocks was covered a few times with **Stanley Rice** making this a central theme of his presentation. The Pacific herring in Prince William Sound, Alaska collapsed after the Exxon Valdez oil spill, yet this stock 20 years later has failed to recover. The causes of collapse are not clear cut, there is the influence of the oil spill plus fishing pressure and relatively low recruitment levels. The reasons for the lack of recovery are even less clear though there is the possible influence of low recruitment, disease and/or variations in available zooplankton. The dynamics of collapse and recovery of fish stocks is complex and not very predictable.

The session generated a lively discussion that covered many of the topics presented. In short there were a number of highlights that are presented here. Disease in herring populations is something that needs to be considered. It appears that there are some regular checks for e.g. *Ichthyophonus* in NSSH. It was unclear if other stocks are regularly screened for disease or whether the range of diseases or prevalence in natural populations is known. There was a suggestion that there should be further investigations in to the differences and/or similarities between autumn to winter spawning herring. There was appreciation for large scale studies that thoroughly examine hypotheses that are inferred from data e.g. the question of skipped spawning in NSSH. The problem of recruitment failure or poor recruitment in NSASH raised questions of variability in natural mortality, however, this topic was left to discussions in other sessions.

Apologies were received from keynote speaker **Nils-Christian Stenseth** who could not attend the conference. However, the keynote presentation was made available to participants and gave details of modelling of the Barents Sea ecosystem, based on long term data series. Herring, being a key component of the ecosystem has important links with cod and capelin. However the fluctuations in herring abundance have proved difficult to model. For instance, herring predation on capelin indirectly affects cod cannibalism, because the latter process is more common when capelin biomass is low.

Session 4: **Population Integrity**

Session chairs: Doug Hay and Emma Hatfield

Keynote speaker: David Secor

The subject matter of presentations in this session varied widely. New conceptual advances were described as well as important observations about distributional changes. The session did demonstrate the robustness and adaptive capabilities of herring, throughout its distribution range. However, although the session provided a synopsis of different kinds of research, conducted in different areas on different populations, few general conclusions were available. Herring show the existence of different spawning stocks that have shown wide fluctuations in abundance, able to recover from very low levels to very high abundances in suitable environmental conditions; the presence of a variety of spawning times/types – in the Atlantic at least – together with evidence of switching of spawning types shows a level of robustness to change. There is an immense amount of plasticity in what we're seeing and if we are to incorporate evidence of population structure into assessment and management of stocks we need to be clear which questions we want to address; if no sensible management of components is possible, for example, there may be no point in discriminating between them. There certainly doesn't seem to be a single rule that applies across all stocks, areas and species but there seems to be a general consensus that maintenance of population diversity and biocomplexity is important.

Using data from Irish and Celtic Sea stocks, **David Secor** (key-note) attempted to compare and assess the outcome of metapopulation dynamics under different scenarios of population connectivity (regulated by various regimes of either straying or entrainment). Modelling showed that the total biomass of the metapopulation would decrease under any of the possible scenarios, as opposed to a baseline reference of complete integrity of the subpopulations (no exchange). In the context of global change, it is important to evaluate such dynamics, as temporal changes in abundance on different spawning grounds may occur either by straying, entrainment, or as a result of within subpopulation fluctuations. All these phenomena have strong implication for the longer-term maintenance of biodiversity and adaptive potential, but under certain density-dependent entrainment conditions, can occasionally lead to the collapse of a subpopulation.

In order to model exhaustively such metapopulation dynamics, it would be paramount to obtain estimates of the actual proportion of the effective migrants exchanged (not just the fish that physically move between locations, but specifically those able to contribute to the spawning for the following generation(s)).

A review of work by **Deirdre Brophy** demonstrates that a large proportion of winter-spawning Celtic Sea herring drift as larvae into the Irish Sea, but then move back into the Celtic Sea to spawn. The maintenance of segregated spawning grounds despite extensive mixing during early life-history stages is evidence of natal homing. Yet, such apparent stock integrity is not currently supported by genetic evidence and, in line with McQuinn's bet-hedging interpretation, might simply represent a relatively momentary phase during Atlantic herring metapopulation evolution. More work would be needed to fully understand the ecological and evolutionary significance of these straying phenomena.

Arne Johannessen showed that contingents of the large Norwegian Spring Spawning (NSSH) stock can enter local isolated fjords and mingle with the local spawners. Life-history descriptors, such as year-class composition and size-at-age, as well as otolith morphology, clearly demonstrate the presence of both local and NSS herring in the same spawning aggregation. Such evidence points at the existence of metapopulation dynamics, possibly of a density-dependent nature, however more research is needed to assess the effective gametic-phase exchange between components.

The Faroe Islands lie at the intersection of the three large stocks: Icelandic summer spawners, NSSH and North Sea autumn spawners stocks. **Jan-Arge Jacobsen** focused on a puzzling strong 1999 year-

class of autumn-spawning herring, suggesting it might represent, and be indicative of, a local, Faroe-specific population. More in-depth analyses would be needed to test this hypothesis.

Alexander Krysov showed data suggestive of a relationship between the extent of herring feeding migrations, temperature and population age structure. Positive temperature anomalies and predominance of older fish were associated with an extension of western herring migrations in the early 1960s. In recent decades the migration was not so westward, which may be explained by an attenuated age structure.

Nóirín Burke reported that removal of winter spawned fish from juvenile abundance estimates improved correlation with adult abundance estimates for the Irish Sea stock. However the underlying cause of the negative relationship between strong south westerly winds and the abundance of winter spawned juveniles in the Irish Sea is unclear.

Advances in the use of coded wire microtags (CWTs) have improved the understanding of the degree of interannual spawning site fidelity in Pacific herring. The technological requirements for recovery of the small magnetic tags, usually in processing plants, preclude this approach in many areas. Nevertheless, despite several confounding processes and sources of bias, both **Linnea Flostrand** and **Yoshiro Watanabe** have called for the need for more tagging. More attempts to employ such methods in Atlantic herring might also contribute to improved assessment.

Guðmundur Oskarsson described annual variation in the location and size of summer distribution of Icelandic herring and cited Corten's adopted migrant hypothesis as a potential explanation for the observed changes.

Rob Stephenson (presented by **Mike Power**) reviewed herring population structure in the western Atlantic. The assumptions about stock structure made by management agencies were examined in the context of current issues and understanding of the theoretical basis of fish stock structure in general and herring in particular. It was recommended to consider a complex population made up of a number of discrete spawning units, whilst affording maximum protection to those units.

Multidisciplinary investigations on western and central Baltic herring, using an integration of genetics, parasite infection, and morphometrics seem to suggest that a proportion of both groups of Baltic spawning fish present complex migratory dynamics which include life-history phases in the Skagerrak and the North Sea. The western Baltic migratory dynamics were previously known but the information on central Baltic herring is new. Results shown by both **Magdalena Podolska** and **Ana Was** failed to identify clear boundaries in either genetics or morphology, which could be explained by either geographic segregation or parasite (*Anasakis*) infection. Data show a very complex situation which will require more work and sophisticated ways to analyse data, if any pattern is to be uncovered.

Lotte Worsøe Clausen illustrated that the use of otolith shape analysis is a powerful tool for the identification of stocks previously identified through genetic markers and otolith microstructure. In some cases, the variation in otolith shape is able to distinguish population units to a finer extent than genetics. This method should be accurately applied to those individuals that appear to "season-switch", which would also further our understanding of the factors (intrinsic and extrinsic) that affect otolith shape development.

Evidence for natal homing was presented by **Deirdre Brophy**. A body of research from the Irish and Celtic Seas reveals that despite extensive mixing during early life, stock separation is preserved in spawning adults. Results indicate that in the region of 40%of winter spawned Celtic Sea fish spend a nursery period in the Irish Sea. Yet the overwhelming majority return to their natal grounds to spawn.

Yoshiro Watanabe (presented by **Brenda Norcross**) showed results of innovative Japanese research that has raised large numbers of young herring to the juvenile stages in culture facilities. These herring were chemically tagged and released. Recaptured herring were found in relatively distant locations (> 300 km) during summer feeding seasons but recaptures were also taken close to spawning areas. The implication of recaptures made close to spawning areas is that the results provide evidence of natal homing.

Deirdre Brophy described an investigation of spatial and temporal variability in hatching date, growth rates and condition in young-of-the-year herring in three Scottish west coast sea lochs. Otolith

measurements and microstructure demonstrated a mixture of hatching times, with peak hatching varying considerably between years. Genetic analysis of the same individuals revealed no genetic substructure between these groups. These results reflect McQuinn's bet-hedging theory in herring and their phenotypic plasticity provides an insurance against environmental change.

Jens Christian Holst described changes in the over-wintering area of Norwegian spring spawning herring. This is the largest herring stock and is broadly distributed during the summer months. During the winter months, however, the herring congregate in 'over-wintering' areas. Remarkably, the distribution of the over-wintering locations has changed in recent years. The strong 1998 and 1999 cohorts did not over winter in the same areas as previous ones. This phenomenon raises the biological issue of how the recruiting cohorts eventually join the older, adult population.

Audrey Geffen using otolith chemistry found that spawning components from west of the British Isles were composed of fish from different nursery grounds, and not necessarily from the same management area. Another poster presentation by **Audrey Geffen** used the same methods to examine the spawning origin of fish in mixed aggregations outside the spawning season. These mixed aggregations consisted of fish from more than one nursery and/or management area. The adopted migrant hypothesis may explain the dynamics of these herring stocks.

Steven Beggs applied otolith shape and microstructure analyses to catches of 0-group herring from the Irish Sea. Results allowed for segregation of data by spawning site origin (Celtic or Irish Sea) that could be used to develop separate recruit indices for each stock.

Session 5: **Herring in the middle**

Session chairs: Øyvind Fiksen and Brenda L. Norcross

Session keynote: Andrew Bakun

This session was introduced with a keynote by **Andy Bakun**. He gave an overview of a range of concepts relevant to the ecological role of herring and other small pelagics. The concepts ranged from those relevant to recruitment processes, such as predator pits and environmental loopholes, but the main body of the talk dealt with herring as a typical representative of a wasp-waist forage fish – a trophic level with low diversity (one or only a few species) and high importance in transferring energy and matter between herbivores and higher trophic level.s One point was that this type of system (wasp-waist-ecosystems) may be regulated both by bottom up and top-down processes, but that understanding the dynamics and biology of the core player, the planktivore, is the key to understand functioning of these systems. A particularly relevant concept to herring is the 'school-mix feedback loop' discussed in the talk, as it may contribute a mechanism for the diverse and dynamic spatial patterns seen in herring.

The session included eight oral presentations that all dealt with various aspects of the trophic position of herring. Herring consume zooplankton and the talks by **Irina Prokopchuk, Natalia Serpetti** and **Øyvind Fiksen** focused on the interactions between herring and their prey. **Emily King** presented a talk on potential competition between herring and jellyfish in the Irish Sea, while **Richard Thorne** and and **Torstein Pedersen** looked at the predation on herring by fish, mammals and birds. In addition, **Robert Emmett** presented an interesting link between oceanographic indices and herring recruitment, as well as how herring recruitment enhanced survival of Coho salmon. In the final talk of the session, **Kjell Utne** showed some simulations from a herring migration model where individuals migrate in response to various environmental cues, prey and some inherent rules.

It is clear that there are signals of strong interactions between herring and its prey. There is possible evidence of density-dependence in foraging (**Irina Prokopchuk**); selective feeding on large and profitable prey (**Natalia Serpetti**); and environmental effects on foraging efficiency may preclude direct links to prey abundance (**Øyvind Fiksen**).

Predators may be regulating herring abundance in some situations. Cod seems to prefer capelin rather than herring, but will switch to herring if capelin is not available (**Tortstein Pedersen**). Pacific herring are attacked by Steller sea lions, humpback whales, birds and fish at different locations and seasons, and may cause particularly high mortality rates compared to Atlantic herring (**Richard Thorne**).

Herring *are* in the middle – and its abundance may be linked with survival of salmon and environmental indices (**Robert Emmet**) or experience declines due to competition by jellyfish (**Emily King**).

It was clear that models need to include prey abundance and spatial environmental signals to understand the dynamic migration pattern of herring populations.

Session 6: Managing Change

Session chairs: Maurice Clarke and Richard D.M. Nash

Keynote speaker: Martin Pastoors

The title of the session recognised the inherent difficulty in managing stocks that are subject to often rapid changes in abundance and biomass. Fisheries and recruitment processes have changed, in ways that have not always been predicted. In total there were 9 oral presentations and two posters. These presentations spanned Norway, Alaska, NW and NE Atlantic. Methods to evaluate management actions and/or the information requirement were presented by **Laurie Kell**; by **Evelyn Brown** and by **Øyvind Fiksen.** Others provided synoptic information on individual stocks (**Gary Melvin**; **Sigurd Tjelmeland; John Wheeler; Maurice Clarke; Mikhail Bodarenko)**. Progress towards understanding typical problems in the information base was reported on by **Steven Beggs** and by **Priscilla Licandro)**

Martin Pastoors, Vice-chair of the ICES Advisory Committee and former member of the ICES Herring Assessment Working Group, delivered the keynote address. Martin explained the assessment/management paradigm as it is in Europe, and how this system has evolved over time. Of particular importance has been the adoption of Harvest Control Rules (HCRs). Many stocks are now managed with such rules, and these are usually subject to a process of Management Strategy Evaluation (MSE). The first stock to be subject to a management plan in Europe, was the North Sea herring, in 1999. This was followed by a plan for Norwegian Spring Spawning Herring (**Sigurd Tjelmeland**). In order to successfully develop management plans, all stakeholders should be involved in an open dialogue from the beginning. The science/stakeholder boundary is not always clearly defined, but it is necessary for all parties to interact. Four principles for development of management plans were suggested: evaluation and reflection; consensus building; participation and transparency.

Gary Melvin demonstrated a marked shift towards autumn spawning in all western Atlantic herring stocks in recent years. The shift is consistent with observed increases in water temperature or associated environmental change. At the edges of the species' overall distribution this can lead to extreme fluctuations in productivity. Declines in growth, maturity and condition from this area were presented by **John Wheeler.** These trends are similar to patterns shown by other authors, in separate sessions, working in areas at the extremes of herring distribution. The need to account for such declines, in managing these stocks was underlined.

Sigurd Tjelmeland presented the first evaluation, through simulation, of the harvest control rule and management plan for Norwegian Spring Spawning Herring. This stock is the largest in the world at present (about 12 million t), though it has recovered from a biomass of less than 200,000 t. Some of the lowest stock sizes produced some of the largest recruitments, and vice-versa. The plan aims to exploit the stock at an $F = 0.125$ when the stock is above target biomass. This approach is somewhat conservative. The imposition of a maximum catch level increases stability in catches over the long term, at the expense of increased yields in periods of high productivity.

Evelyn Brown presented work towards an integrated ecosystem model for the Prince William Sound herring, as a basis for a rebuilding plan. The authors explored limitations preventing recovery of the population which collapsed in 1993, and is currently a stable at a low level. Modules within the model were designed to test specific hypotheses concerning recovery limitations developed from observational data. The project embodies stakeholder interaction.

Maurice Clarke documented progress towards a rebuilding plan for the Celtic Sea stock. The stock has collapsed in the 1970s and only recovered in the 1980s because recruitment was good, though fishing mortality remained at very high levels. This lead to a second collapse, when recruitment failed again. Reducing F from the long term average of 0.6 to around $F_{0.1}$ has a high probability of leading to rebuilding.

A preliminary version of a model to evaluate the long term management and recovery plans for metapopulations of herring west of the British Isles was explained by **Laurie Kell**. The model simulates the development of the metapopulation under different mixing scenarios, corresponding to either discrete stocks or one metapopulation.

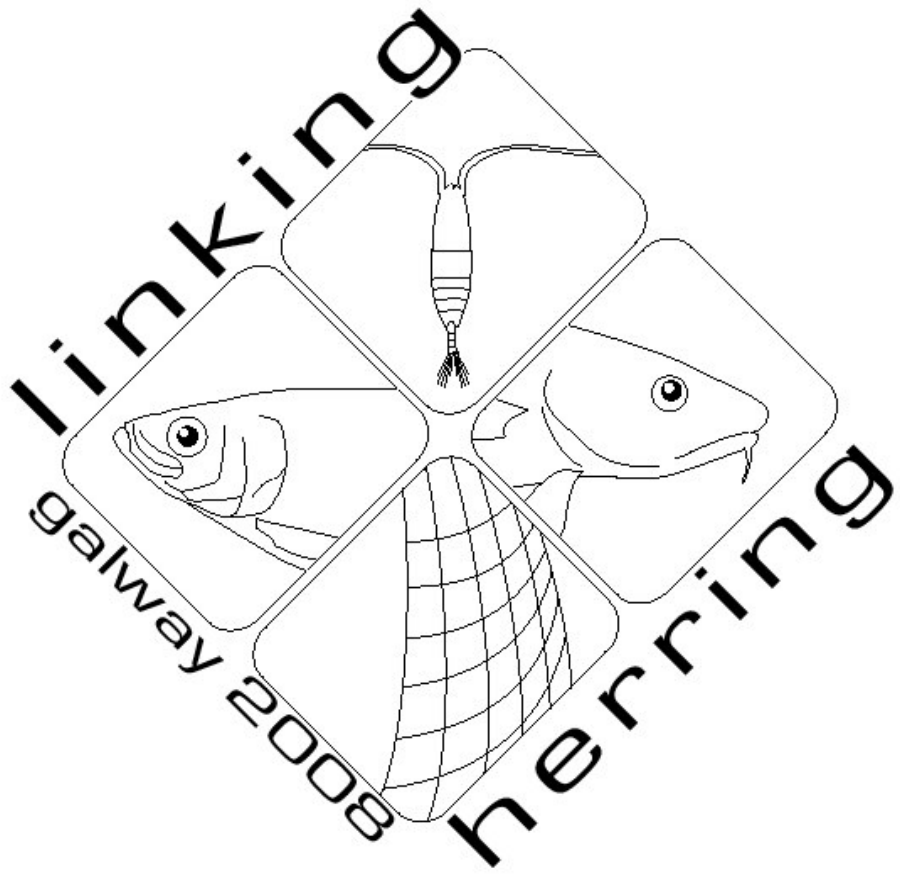
Øyvind Fiksen presented a model that evaluated the benefits, in terms of productivity and fishing opportunities, of collecting various types of stock specific information. Results showed that the value of basic stock information is dependent on the type of harvest strategy applied. If the appropriate strategy is used, then less information is needed. In general it was agreed that if exploitation rates are low, and biomass is kept at a high level then less information is required.

The difficulties in obtaining reliable biomass estimates for a small herring stock in the Irish Sea were illustrated by **Steven Beggs**. Mismatches between catch at age and survey abundance at age data were shown to confound efforts to achieve a reliable stock estimate. **Mikhail Bondarenko** presented stock recruitment modelling for Norwegian spring spawning herring. A positive North Atlantic Oscillation (NAO) index was shown to have been favourable for recruitment. The North Sea herring stock has experienced an unprecedented 6-year period of poor recruitment. A poster by **Priscilla Licandro** investigated the inter-annual variability in recruitment, in this stock, in relation to zooplankton abundance. Preliminary results suggest that the decrease in Calanoid copepods is associated with the declining recruitment of North Sea herring.

Discussion in the session and in the fringes focussed on the need for more information if the stocks are to be harvested at higher rates. Management approaches used in Atlantic Canada (survey, assess, fish) received a lot of positive support from European industry representatives. However, it was noted that European stocks tend to be subject to much higher fishing mortality than many Canadian stocks. Consequently what works in Canada may not be easily applicable in Europe.

Different approaches are required in different stocks, but all management frameworks must be able to adapt to downturns in productivity and/or biological parameters. The frank, constructive exchanges between scientists and industry reflected the importance of stakeholder participation in all stages of development and implementation of management strategies.

conference keynote address:
herring, ICES and ideas



Mike Sinclair

Herring, ICES and ideas

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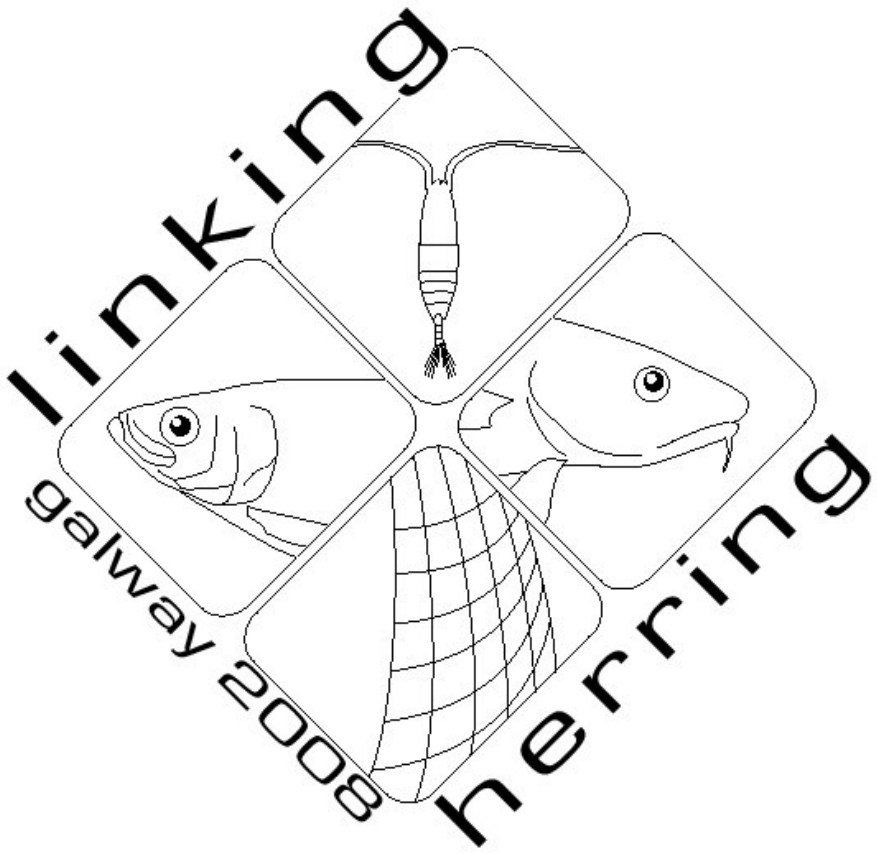
The role of herring fisheries fluctuations in the creation of ICES, as well as extant ideas on the causes of these temporal and spatial fluctuations in the latter half of the 19th century, are summarized. The work of Committee A, the "Migration" committee (involving largely herring) led to new ideas during the 1902-1914 period on respectively fish age and growth, the very existence of spatially defined populations with year-classes having variable strength, the causes of inter-annual fluctuations in abundance, and the expectation of overfishing. The ideas were tested in the Canadian Fisheries Expedition (1915, 1916) under the leadership of the chairman of the "Migration" committee (Johan Hjort). These herring studies within ICES can be said to have generated fisheries oceanography as a discipline. ICES symposia, special meetings and programs in the 1950s and 1960s addressed herring "races" (1956), herring tagging (1957, 1958), and recruitment mechanisms in herring (1968). David Cushing was a key player in these activities, and it is interpreted that the herring observations and discussions led to the Match-mismatch and Migration Triangle hypotheses on spatial patterns of spawning, population persistence, and recruitment variability. The cumulative empirical observations on Atlantic herring coupled with enhanced predictions of spatial patterns of circulation and mixing led in the 1980s to consideration of larval retention as a process underlying population richness, spatial patterns, relative abundance and temporal variability under the Member/Vagrant hypothesis.

The collapse of herring stocks under heavy exploitation generated new ideas of the lack of resilience of pelagic populations. The ICES symposium in 1978 on "The Assessment and Management of Pelagic Fish Stocks", which focused to a considerable degree on herring, is interpreted to have led to a paradigm shift in fisheries management, involving eventually harvest control rules and the Precautionary Approach (PA). This symposium also addressed the nature of recovery of herring populations. Subsequent ICES work on the time scales of recovery of herring populations have re-enforced the new paradigm of fisheries management. The use of simulations for testing harvest control rules was also crucial in the 1990s in preventing another collapse of herring stocks in the ICES area. The present symposium will address the emerging ideas within the ICES community on the role of herring within the Ecosystem Approach to Management (EAM).

Behind the ideas are many rich personalities. It is timely to honour David Cushing, who generated stimulating concepts based to a large degree on herring, as a scholarly member of the ICES "herring men" (and women!) of the past century.

session 1:
counting herring



Oral Presentations

Counting herring - qualitative and quantitative estimation of herring and its application

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Herring populations or in some cases management units are found in the Baltic Sea, North Eastern and North Western Atlantic, Arctic Ocean, and North Eastern and North Western Pacific. The populations vary from the huge Norwegian Spring-Spawning Herring stock with current catches of 1.5Mt per year, to small stocks such as Gulf of Riga herring currently giving catches of 30,000 t per year. In contrast to these two relatively healthy populations, some such as North Sea herring are partially depleted primarily due to natural causes, others such Hokkaido-Saklin are seriously reduced and have shown little inclination to recover from extensive fisheries more than 40 years ago. Herring are surveyed and assessed through a variety of methods. Sources of data come from Larvae surveys, young herring post-larval stage surveys, using fine mesh nets and samplers to provide information on spawning and early life history stages. Bottom trawl surveys are used to give information on juveniles. Acoustic and trawl surveys are used to estimate both juveniles and adults. Surveys are carried out by dedicated research vessel, chartered commercial vessel and some surveys run by fishing industry. Catch per unit effort and industry based surveys are also used to evaluate populations before and during a fisheries. The types of data collected and used to evaluate and manage a range of these stocks are reviewed. The performances of some stock evaluations are presented. Contrasting methods that have worked relatively well with those that have delivered less stable information gives a basis for comparing and contrasting the methods chosen. Form this review; criteria for good management information are identified. The historical performance of assessments on some stocks is presented and reviewed.

Spatial and temporal variation in herring spawn and herring fisheries in British Columbia: biological and management implications.

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We examined herring fisheries and climate variation as factors affecting the timing and distribution of herring spawn. Pacific herring spawn in inter-and shallow sub-tidal areas. Locations and dimensions of spawning sites are easily recognized and quantified by milt or by spawn. For >70 years the distribution and relative abundance of spawning areas have been assessed over the 25,000 km coastline of British Columbia, Canada. In most years the cumulative spawn length is about 200-500 km. Specific spawning sites change and approximately 20 percent or 5,000 km of coastline has been used for spawning at some time in the last 70 years. Using GIS techniques we show that the geographical distribution of fisheries is relatively small, with a lower geographic range than annual spawn distributions. When examined at each of 100 smaller sub-divisions of the coast, we found no instance where a fishery preceded the cessation of spawning at a specific site. The greatest spatial and temporal diversity of spawn occurred during the late 1960's when the total abundance of herring was at an historical low point. We conclude that fisheries may reduce total spawn abundance but there is no evidence that they have limited the spatial diversity of herring spawning. In contrast, there is evidence of change in spatial distribution of spawn in response to sea-surface temperatures.

Age-length structured modelling of Norwegian spring spawning herring in the Barents Sea ecosystem

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The Barents Sea ecosystem has experienced major fluctuations in species abundance over the past five decades. Likely causes include natural variability, climate change, overfishing, and predator-prey interactions. Norwegian spring spawning herring spend a part of their life cycle as juveniles in the Barents Sea, where they form an important part of the ecosystem as both predators and prey. In this study we use a Gadget (Globally applicable Area-Disaggregated General Ecosystem Toolbox) age-length structured multispecies model to analyse the population dynamics and interactions of cod, capelin, herring and minke whales in the Barents Sea. Herring are a prey item for cod and minke whales, and are a significant predator on young capelin. The model was used to examine possible effects of a number of plausible biological and fisheries scenarios, with special emphasis on scenarios and ecosystem effects involving herring.

Estimating the number of breeding North Sea herring using genetic data

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A considerable proportion of the temporal variance in herring demographic fluctuations is believed to depend strongly on environmental variability, hence it is vital, for the purpose of management to refine and improve the methods for estimating the size of the breeding stock. Newly implemented genetic approaches can provide information on the temporal variations of genetic diversity, which reflect to some extent the demographic trends of the breeding population. Linkage disequilibrium (defined as the mean squared correlation of allele frequencies at different gene loci) can provide indirect estimates of the effective size of a population. In particular, in species with overlapping generations –the vast majority of marine species worldwide – data analysed from one single cohort provide the estimate of the number of breeders (N_b) that contributed to the spawning of that cohort, and this should be proportional to that year's estimate of Spawning Stock Biomass (SSB). We analyzed micro satellite data from six consecutive cohorts (1995 to 2000) of North Sea Herring Autumn Spawners (NSAS): we estimated N_b for each cohort and regressed the data against the relevant yearly estimates of SSB. We show that the two data series are correlated and that temporal trends in N_b explain nearly 60% of the temporal variation in SSB.

Using acoustics on fishing vessels to monitor herring spawning dynamics in the southern Gulf of St. Lawrence

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A method is described to monitor the spatial and temporal distribution of herring spawning schools in the southern Gulf of St. Lawrence, Canada, using acoustic data obtained from commercial fishing vessels. A voronoi-natural neighborhood analysis is used to summarize the data into nightly density estimates. Gill netters fishing herring on five geographically distinct and highly dense inshore spawning aggregations collected acoustic data during their regular fishing activities. Herring are also sampled using multi-mesh gillnet strings to determine the size composition of the herring schools. Fishing activity by commercial vessels is presumed to cover the main spawning activity in a given area as the fishery is seldom limited by other factors.

The main hindrance in using the acoustic biomass estimates as a relative abundance index is the unknown spatial and temporal distribution of herring spawning waves or schools within a single area during one spawning season. The analysis of the daily biomass estimates per area, its weekly distribution throughout the season, as well as inter-annual variations give insight on spawning dynamics.

The seasonal density distribution by depth contour and total surface of the spawning areas give evidence of fidelity to area chosen and depth preferences. Size composition from weekly length frequency distributions suggests size-specific migrations onto the spawning grounds with smaller herring present in higher proportions at the beginning of the season. A study of changes in spawning school spatial distribution in a specific area during one season shows variation in geographical location from the beginning to the end of the season.

Year-class index of spring spawning herring in ICES subdivisions 22 – 24 based on the larvae surveys in the Greifswalder Bodden

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Over the last 10 years, it has been suggested that the surveys of herring larvae in the Strelasund and the Greifswalder Bodden can produce a useful index for recruitment of western Baltic spring spawning herring. The proposed method involved projecting forward (using mortality and growth) to estimate the sum of larvae at 30mm in length (N30). Whilst this index showed a significant correlation with some other indices of recruitment, it had very little explanatory power and did not perform well when incorporated in to the assessment. A new method for estimating the year-class strength based on the surveys was developed. The method encompasses the temporal changes in mean growth each year caused by the increase in temperature over each season (usually from 5° to 20°C). The new herring larvae index (N20) is the sum of larvae that reach the length of 20 mm. This reduction from 30 to 20mm reduces the impact of assumptions concerning growth and mortality beyond the length limits of the larvae that were caught and also reduces and the effect of increasing mobility of larvae longer than 20 mm (net avoidance). The N20 Index is highly correlated with the acoustic estimation of age group 1 herring in the western Baltic Sea (R = 0.88). Both estimates are based on different methods, different areas of investigations and different survey periods. The high correlation suggests that the N20 index is an appropriate estimation of the year-class that is about one year earlier than the next estimation. The N20 also performs much better than the N30 when included in the stock assessment. The signal from spawning in the Greifswalder Bodden is important even though other spawning sites supply significant numbers of recruits to the western Baltic spring spawning herring. The signal seen in the Greifswalder Bodden larval herring index is recognizable in surveys of the whole stock years later.

Finding the signal in the noise: judicious data selection improves the assessment of western Baltic spring spawning herring.

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In the art of fish stock assessment, it is common practice to include all available data sources *a priori,* thereby eliminating proper scientific testing of their validity. The Western Baltic Spring Spawning herring (*Clupea harengus* L.) stock, historically difficult to assess in a reliable manner, is such an example. The population is spread between the Skagerrak, Kattegat, the Danish islands and the western Baltic, but the specifics of the distribution are age and season dependent. Whilst the area is covered by four separate surveys, the complex distribution means that no individual survey covers the entire stock, introducing high noise-levels and leading to a poor-quality stock-assessment. Here we examine the temporal and spatial coverage of each survey in terms of current biological understanding and, employing the observed internal-consistency as additional criteria, select the most appropriate data subsets. Analysis shows that the historic assessment method (ICA) and the settings employed therein are appropriate for this stock. Assessments employing this method, but using the revised data set, show greatly improved quality, as judged by both subjective and objective criteria. This work therefore serves as an excellent example of the frequently cited, but often-ignored, view that the judicious choice of input data, based on rational and justifiable selection criteria, can have the determining influence on the ultimate quality of a stock assessment.

A study of variability in the biomass and distribution of clupeid populations in selected Scottish west coast sea lochs

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Juvenile herring and sprat (0, 1 and 2 group) are caught in both acoustic and bottom trawl surveys off the west coast of Scotland. However, these surveys do not survey the many sea lochs and inshore regions, areas historically recorded as nursery grounds for both species. Five fine-spatial-scale acoustic and trawling surveys were prosecuted from January/February 2001 to January 2003 in quarters 1 and 4 in four sea lochs landward of the Isle of Skye. In quarter 1 surveys, sprat had a higher biomass than herring in each loch; in quarter 4 surveys herring biomass approached, and in some cases exceeded, sprat biomass. Biomass of both species varied over an order of magnitude between season and year. The majority of both species caught were juveniles, showing that these lochs do act as nursery grounds, at least in quarters 1 and 4. Possible explanatory factors for this overall variability are position in the loch (both longitude and depth) and temperature (as measured by CTDs taken in each loch during each survey). However, there was no consistency in any of the relationships and most were non-significant. There is a suggestion, in two of the surveys, that some of the variability seen may be due to such factors as tide and weather.

Progress in modelling herring populations: individual-based models of growth

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Managing fish stocks requires quantitative estimation of both population parameters and individual growth, as size is a key predictor of individual performance in survival and reproduction. One of the challenges of understanding trends in population structure is to model how size distribution changes through time. The natural approach in this framework is to devise a model of growth of individuals and then to derive the distribution of the size of a population. We introduce new stochastic individual-based models of growth that enjoy many desirable features. Namely our model: (1) takes into account both the individual and environmental sources of randomness; (2) enjoys both the properties of being increasing and positive; (2) guarantees that the mean size of each cohort follows the von Bertalanffy equation. These models are based on the use of a class of stochastic processes: the subordinators. To test the goodness of our models, we used data of Atlantic herring belonging to the stock of "North Sea Autumn Spawners" of ICES zones IVa, IVb and IVc. The results suggest that this approach could be successfully implemented in the assessment of most commercial stocks.

Acoustic surveys of herring in Prince William Sound, Alaska: a long and successful series

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Acoustic surveys of the adult herring biomass in Prince William Sound (PWS), Alaska, were initiated in 1993 following indications of a herring population crash. The surveys have been conducted at least annually for 16 consecutive years. The initial survey confirmed a population crash that had been undetected by the age-structured assessment (ASA) model at the time. A decade later, the acoustic data were used to implicate the 1989 Exxon Valdez Oil Spill in the herring collapse. The long series of acoustic estimates is positively correlated with two other estimators of herring abundance: a revised ASA model and an aerial survey of the accumulated miles of herring milt along beaches. When the herring milt index is converted to biomass by its regression with the acoustic estimates, the index compares well numerically with estimates from the ASA model over nearly 3 decades. The acoustic estimates offer a timely management approach since they can be made prior to a fishery. A multi-stage survey design is used for herring in PWS. Survey effort is directed by several measures of herring abundance and location. The primary challenge to the approach is to ensure that the major locations of herring are detected and adequately sampled.

Schooling behaviour and distribution of herring: application of acoustic methodology in the English Channel

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In the eastern English Channel, the winter spawning "Downs" herring stock is exploited by different fleets, mainly at the end of the year, during its migration. The rest of the year, this stock component is mixed with the overall population of North Sea herring. However, this pattern seems to have changed recently as, according to fishermen, unusual herring shoals were seen until April while their catches in the North Sea were very low. At the end of January 2007 and 2008, the French RV Thalassa surveyed the Eastern English Channel and acoustic data were recorded day and night. Very dense and continuous shoals of herring were found during these surveys in a very localized area, concentrated along sandbanks, especially during the 2007 prospection. Although, it is very difficult to reliably estimate herring biomass during its migration through the English Channel, the acoustic prospection gave interesting information on the spatial distribution of the observed herring shoals. Their recent evolution and the possible change in behaviour in relation to the local herring spawning area will be discussed

Stock assessment of Pacific herring in Sitka Sound, Alaska

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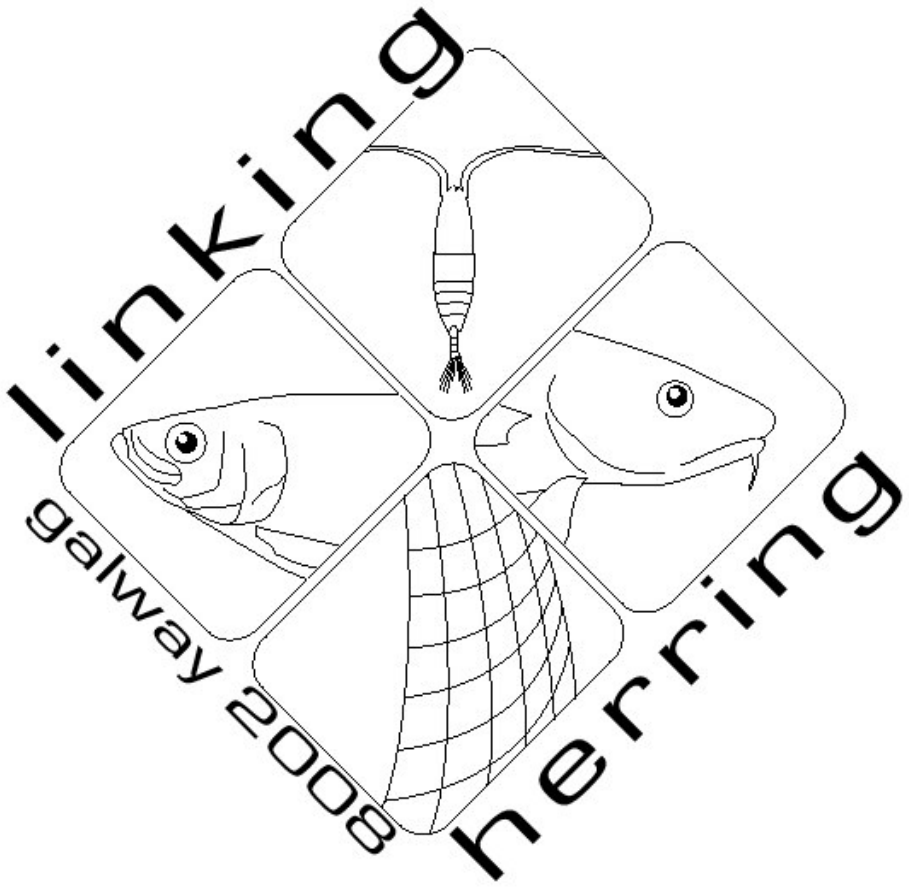
Pacific herring (*Clupea pallasi*) are fished throughout the state of Alaska, United States. Sitka Sound has the highest value Pacific herring sac roe fishery in Alaska, exceeding five million dollars in 2007. Survey sampling for Sitka Sound herring includes aerial surveys for documenting miles of shoreline receiving milt, scuba dive surveys for estimating density of eggs spawned, sampling of both the commercial harvest and the spawning population for age, weight, and length of fish, and sampling of the spawning population for estimating fecundity by weight. A twenty-year time series of each data source is incorporated into an age structured assessment (ASA) model, from which estimates of total abundance and biomass, age-3 recruitment by year, survival, maturity at age, and seine selectivity at age are made. Model estimated survival, maturity, and a spawner-recruit relationship are used to forecast the biomass for the upcoming year. Stock assessment results are used to set the commercial harvest level. Commercial harvest is allowed if the forecasted biomass exceeds a threshold level. In years where the forecasted biomass exceeds the threshold, percent harvest is set on a sliding scale between 10% and 20% of the forecasted biomass.

session 1:
counting herring



Poster Presentations

Exploratory Methot net sampling of herring larvae during the 2008 west coast Q1 IBTS.

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Sampling of overwintered herring larvae was carried out using a Methot-Isaacs-Kidd net, on FRV *Scotia*, from 1-21 March, 2008, covering an area from the west of the Orkney Islands to the north of Ireland (approximately 55°30'N). This is the first survey of this nature to be carried out since 1988. Herring larvae were caught in 40 of the 63 hauls permissible during the survey period. The maximum abundance was 6.65 larvae per m^2. The majority of the herring larvae were caught in the south Minch, around the Inner Hebrides and to the north of Ireland; the more offshore areas to the west showed low abundance and the north and northwestern areas had zero catches. The mean length of larvae overall was 16.5 mm, with the average in all but two hauls below 19 mm. Two hauls had herring in the range 21-32 mm, the length that would be expected for autumn spawners. Using average size at hatch and growth averages from previous studies, it is likely that the majority of larvae were winter spawned, hatching in late January, with a probable origin to the north and west of Ireland (given the area's hydrodynamics). Bio-physical modelling during this time period, coupled with data on average growth and hatch size, will determine the likely origin with more certainty.

Using indices of juvenile (0+) herring for predicting recruitment in Georgia Strait, British Columbia.

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In southern British Columbia herring recruit at age 3, and the recruiting cohort usually comprises between 20-50% of the total population. We estimated the relative abundance of 0+ juvenile herring from purse seine surveys in the Strait of Georgia, from 1991-2007. Our objective was an evaluation of the predictive utility of juvenile surveys for estimating the relative size of the recruiting year class before it enters the fishery at age 3, about 30 months after the survey. Purse seine sets were made in September at ten fixed transects, each with five sampling stations. Age 0+ (age ~5-6 months) were the most common species captured. We compared the numbers and weight of 0+ juveniles with the number of age-3 recruits from the same cohort that was estimated independently, 3 years later, from biological samples and age-structure analyses. Juvenile herring abundance changed significantly among years and there was considerable spatial variation among sampling sites. Although a regression of juvenile abundance and recruits was highly significant the variation about regression line was considerable. This variation precluded the use of the surveys to distinguish between strong and mediocre cohorts. However for two years, 1992 and 2005, the surveys indicated very low juvenile abundance and subsequent recruitment in 1995 and 2008, also was very poor. We conclude that that the surveys have limited value for distinguishing between years of average and good recruitment, but they appear to provide accurate advance information about forthcoming poor cohorts.

Inaccuracies in proportion of Atlantic herring (*Clupea harengus* l.) mature during the North sea herring acoustic survey

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Accurate maturity data is essential for calculation of spawning stock biomass (SSB). Macroscopic maturity staging of North Sea herring has not been validated since 1961, when the staging scale was first produced by Bowers and Holliday.(1961). The aim of this study was to assess the accuracy of macroscopic maturity staging during the North Sea herring acoustic survey. Maturity staging carried out onboard *FRV Scotia* in 2006 and 2007 and *FF Johan Hjort* in 2007 was compared to histological assessment. A total of 188 samples were analysed. Staging error was relatively low onboard *FRV Scotia,* 2006 (21% and 17% error for females and males) but was much higher onboard both *FRV Scotia* (57%, 46%) and *FF Johan Hjort* (47%, 27%), 2007. This lead to the proportion mature being underestimated onboard *FF Johan Hjort* and slightly overestimated onboard *FRV Scotia,* 2007. Furthermore, the histological slides also revealed a high prevalence of atresia. Prevalence was highest onboard *FRV Scotia,* 2007 (43%, n=42) and lowest onboard *FRV Scotia,* 2006 (18%, n=28). High levels of atresia may suggest that some fish classified as mature may be reabsorbing their oocytes and skipping spawning, leading to an overestimation of SSB. Inaccuracies in maturity staging and high prevalence of atresia will, in combination, lead to substantial errors in SSB calculations.

A Two-Stage Biomass model given additional variance in the recruitment index

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An Assessment of Irish Sea VIIa herring using a Two-Stage Biomass model was undertaken. The model was further developed by constraining recruitment variability and reducing the number of catchability parameters to address concerns of over-parameterisation. Also, estimation of the component of the variance resulting from the occurrence of juvenile Celtic Sea herring mixed with Irish Sea herring in the survey area was attempted by introducing an extra parameter: the additional variance (λ^2). A better fit to the data was obtained when recruitment was allowed to vary more freely which is to be expected. Alternatively, when recruitment variability is further constrained the additional variance, although imprecise, represents a large component of the total 1 year-old biomass variability. Additional information on the variability of Irish Sea herring recruitment is required to estimate additional variance in the context of the two-stage biomass model presented.

North Sea herring: Probably the best assessment…

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The assessment of North Sea herring has been used to give advice for catch for more than 20 years. The sources of data are Acoustic surveys, IBTS survey, MIK O group survey Larvae surveys and catch at age data. These are briefly reviewed and their use and changing weight in the assessment over time discussed. The performance of the assessment is examined both in analytic retrospectives of SSB F and retrospective assessments by cohort. The true performance derived from the ICES quality control database is also presented. The poster concludes that the assessment provides an excellent bases for management of this stock.

session 2:

advances in herring biology

Oral Presentations

Advances in herring biology – from simple understanding to complex knowledge

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Reports of herring investigations fill at least two centuries of scientific journals, and both applied and fundamental research has produced groundbreaking concepts in fisheries, population biology, and marine ecology. By the 1970s a firm understanding of herring biology formed the basis for more sophisticated research into populations and biology. At this point herring stocks or populations were delineated, and their migration patterns described. The reproduction and larval biology were characterized in ways that could be applied to fisheries management. However, over the following four decades, new approaches and technology have overturned much of the earlier understanding. Behavioral studies have revealed a repertoire of patterns that extend the concept of schooling. Development of genetics revealed high levels of stock mixing. Application of otolith analysis to larval, juvenile and adult fish revealed the scope of plasticity in growth and life history strategies. Developments in physiological research have revealed that herring are not "primitive" as earlier believed, but rather highly adaptable in their metabolism and nutrition. These advances in knowledge have resulted in fundamental changes in what is known and understood about herring. The results of this complex collection of facts demonstrates how a flexible life history underpins one of the most successful species of marine fish.

Is maximum body size in herring constrained by prey size?

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Adult Norwegian spring-spawning herring (NSSH) build up energy reserves during spring and summer by feeding on small planktonic prey, mainly the late copepodite stages of *Calanus finmarchicus*. NSSH display an indeterminate growth pattern, with growth leveling off at total body length of about 40 cm, but might benefit from a larger size for their seasonal migrations, overwintering and reproduction. We hypothesize that the planktivorous foraging strategy of herring gives rise to constraints on its maximum body size due to reduced foraging efficiency beyond a certain body length. Here we employ a Holling type II functional response foraging model to describe the particulate feeding process of herring. Assuming a fixed handling time, herring may increase its clearance rate by swimming faster, but eventually energy intake will reach a plateau. Beyond a certain body size, the specific energy gain of herring will drop. We explore how environmental conditions and constraints affect this foraging process, and the life-history implications, particularly energy allocation to growth, energy reserves and reproduction.

Mapping herring distribution and habitat preferences in the eastern English Channel.

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The "Downs" herring stock migrates each year in autumn within the eastern English Channel to reach its winter spawning grounds in the area. Since 1988, each year in October, the French RV Gwen Drez surveyed this area using large vertical opening bottom trawling. Both adult and juvenile herrings were captured and their local abundance was assessed. This enabled the production of distribution maps for each life stages of this species using geostatistical analyses over all the available time serie (1988-2006) highlighting both changes in their abundance and spatial location. Habitat modeling based on glm (delineating realised habitat) and quantile regressions (predicting optimal habitat) were used to relate species abundance to depth, temperature, salinity, seabed stress, and sediment type. Stepwise selection resulted in habitat models that described species affinity with a subset of significant environmental variables and that were used to map herring habitats using GIS. Models outputs were compared amongst themselves as well as with observed patterns of distribution obtained by geostatistics. The resulting models will be discussed for each life stage studied. This work will help elaborating guidelines for the conservation and protection of natural habitats of marine living resources in the face of climate change and anthropogenic disturbances.

Recurring viral erythrocytic necrosis (VEN) epizootics in juvenile Pacific herring from Puget Sound

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Persistent epizootics of viral erythrocytic necrosis (VEN) occurred among juvenile Pacific herring in Skagit Bay, Puget Sound, WA and were characterized by high prevalences and intensities of cytoplasmic inclusion bodies within circulating erythrocytes. Prevalence of VEN peaked at 67% during the first epizootic in October, 2005, after which prevalence slowly waned to 0% by August of 2006. A second VEN epizootic occurred throughout the summer of 2007, and was characterized by disease initiation and perpetuation in the age 1+ yr cohorts followed by involvement of the age 0 yr cohorts shortly after their larval metamorphosis to juveniles. The epizootics were limited to Skagit Bay; however, the disease was detected in other populations of juvenile herring throughout Puget Sound and Prince William Sound where prevalence and intensity typically did not correspond to the disease patterns observed in Skagit Bay. The persistence and recurrence of VEN epizootics indicates that the disease is likely common among juvenile herring throughout the eastern North Pacific, and although population-level impacts occur, they are typically covert and not easily detected.

Mean daily growth of herring larvae based on weekly repeated cruises in the Greifswalder Bodden

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Variability in the growth rate of larvae is thought to be one of the major factors contributing to recruitment variability. The surveys that make up the time series of herring larvae abundance in the Greifswalder Bodden (1992-2006) have a weekly resolution over the hatching period of herring. This time series thus provides an excellent opportunity to investigate larval growth through cohort analysis of Rügen spring spawning herring. Few empirical estimates of growth of larval herring exist, especially in temperatures greater than 12°C. In the Greifswalder Bodden, the temperature experienced by the larvae changes over the hatching season from on average 5°C to 20°C throughout the water column and impacts greatly on the growth of the larvae. Mean daily growth of larvae is significantly related to the temperature at the beginning of the growth periods from 5 to 7 days. The change of the temperature between sampling dates and the salinity did not explain the variability of the residuals of the linear regression: Mean daily growth = 0.033 + 0.035 * temperature. Even though it was necessary to make a number of assumptions concerning potential size selective mortality and/or gear selectivity, which are necessary with this kind of approach, this study showed that growth of herring larvae was not negatively influenced by temperature up to 20 °C.

Long term trends in biological parameters of Celtic Sea herring

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Herring in the Celtic Sea and the south coast of Ireland are at the extremity of the species' distribution in the northeast Atlantic. The stock has supported fisheries for centuries and continues to be economically important. The stock collapsed in the 1970s due to poor recruitments and high fishing mortality. It has recently collapsed again and its current status is uncertain. Data series for the period 1921 to 2008 are available for this stock. They show long term fluctuations in mean length at age over the period 1921 to 2008. Mean weights at age were highest when the stock collapsed in the 1970s. As the stock recovered the mean weights declined. Though recent stock size has been as low as during the previous collapse, mean weights are now the lowest observed in the series. Growth rate data are also presented showing the fast and slow growing year classes. The trends over the long time series in biological and stock assessment data are presented, and implications for the management of this stock are discussed.

Variability in herring growth: Comparison among North Atlantic stocks

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The effect of temperature and density dependence on the growth of Atlantic herring (*Clupea harengus*) is studied through a comparative approach applied to 15 North Atlantic stocks. The Von Bertalanffy equation is used to describe the growth of each stock, both on average over the whole period studied and for each cohort. Water temperature was found to be a determinant factor for herring growth at the species level. Among North Atlantic herring stocks, those living in cold water areas exhibited a lower growth rate (*k*), higher longevity and a higher asymptotic weight (*winf*) than those living in warmer water. The average *winf* of a stock was also positively correlated to average density, but this relationship was most likely explained by the negative correlation between stock density and mean temperature. At the within stock level, when looking at the variability in growth parameters between cohorts, *winf* was still significantly negatively correlated to temperature, but this effect was no longer significant for *k*. When considering a single stock, the range of temperature experienced is probably too narrow to see an effect on growth, an effect which may be confounded by other factors, such as density dependence. According to this macroecological pattern, global warming should enhance growth of the youngest ages but the counterpart would be a reduced growth for the older individuals and a shorter lifespan.

Long-term shift of successful hatching onset of Western Baltic spring spawning Baltic herring (*Clupea harengus*)

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Climate change, specifically the global warming of sea temperatures, may affect distribution and reproduction cycles of marine organisms. The influence of climatic conditions on herring stocks in the Western Baltic Sea is well described and analyses have utilised data back to the medieval period. While most analyses study recruitment strength, we investigated the timing of hatching onset as one crucial factor to reproduction success. In this work, we analysed long-term data on herring larval development in the main spawning area of Western Baltic herring near Rügen Island since 1977. Data was derived from a survey series covering an important spawning ground for this herring stock in the Greifswalder Bodden (ICES subdivision 24) for 30 yrs in weekly intervals during the entire spawning period: the Rügen Herring Larvae Survey (RHLS). The analysis revealed a significant shift of successful spawning onset over the 30 years (average shift 0,9 days/year), while cessation of hatching appeared not to change over time. This indicates an extension of the spawning period, and a potential influence of global change on the reproduction of commercially exploited fish stocks in the Baltic Sea. A variety of different measured and modelled parameters was tested in order to identify the causes of the shift of spawning onset: local and regional mean, max and min. air and water temperature, North Atlantic Oscillation Index, ice coverage, last ice or frost days, number of ice and frost days. A significant correlation between number of ice and frost days and shift of hatching onset could be identified. Such a dependency of the timing of reproduction from environmental variables is well known from terrestrial ecosystems and frequently used to determine the response of ecosystems to climate change. The RHLS, as the probably most extensive long-term phenological data set on herring larvae growth, provides a unique basis for the development of an integrated model linking key parameters influencing fish reproduction and climate change.

Investigating the factors contributing to the *Ichthyophonus hoferi* outbreak in NSSH *Clupea harengus* 1992-2007

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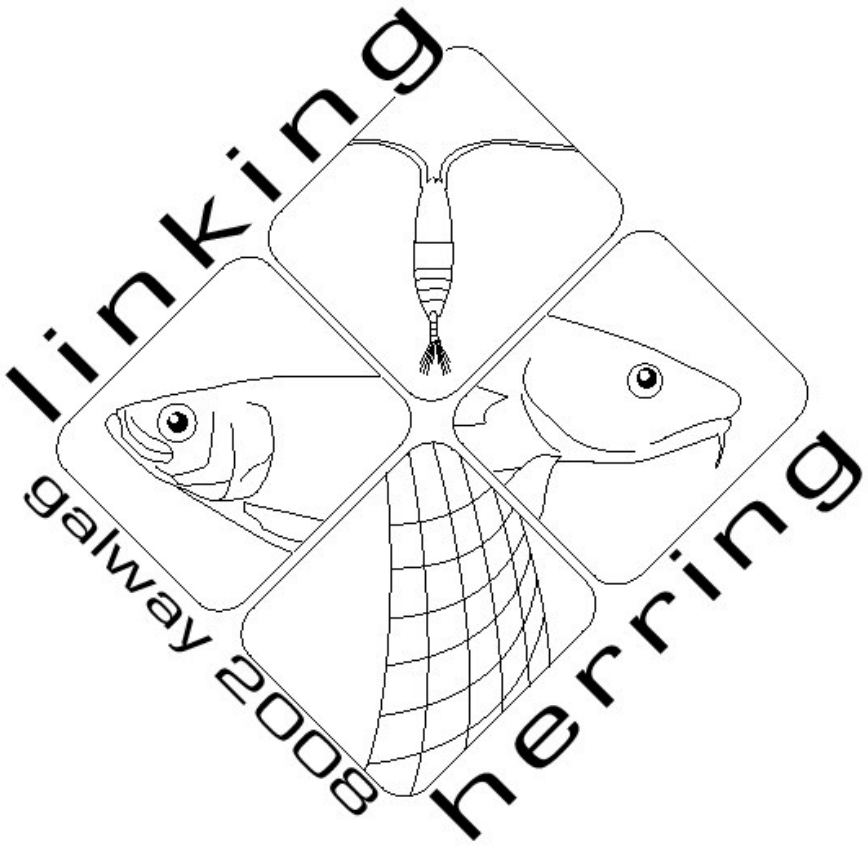
The increase of marine diseases over the past decades has important consequences for endangered species and economy, but often the drivers of the epizootics or disease cycles are poorly known. Therefore, the detection of the outbreak origin or reservoir is a challenge. The *I. hoferi* outbreak in herring detected in 1991 caused statistically significant additional mortality to the stock since the disease is thought to be lethal in herring. Transmission of the pathogen is hypothesized to be oral (ingestion of spores from the water or by feeding on infected material) or density-dependent (depending on the number of infected individuals in the population releasing spores into the water). We group available data (spawning stock biomass SSB, zooplankton abundance, density in overwintering areas, recruits,…) into these two hypotheses and analyse the spatio-temporal disease course over 16 years. Preliminary results show that prevalence is spatially higher in the open ocean feeding areas in summer and temporally positively correlated with zooplankton abundance. Peaks in the outbreak could be best explained by pulses in recruitment, but not by total SSB. We will give guidelines on how to improve the sampling scheme in epizootics, since there was huge bias in sampling effort and timing.

session 2:

advances in herring biology



Poster Presentations

Preliminary assessment of the round herring, *Etrumeus teres*, stock in the Gulf of Suez, Red Sea, Egypt.

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The round herring (*Etrumeus teres*) is one of the most economically important pelagic fishes in the Gulf of Suez; it constitutes more than 20% of the total purse seine catch. The population biology and status of the species were established by using size frequency distribution. The von Bertalanffy growth function estimates were: L_∞= 27.235 cm, K= 0.533 year^{-1} and t_o= -0.435 years. The values of total mortality (Z), natural mortality (M) and fishing mortality (F) coefficients were 4.18, 0.874 and 3.31 year^{-1} respectively. The estimated fishing mortality rate was substantially greater than the target (F_{opt} = 0.437 /yr) and the limit (F_{limit} = 0.583 /yr) biological reference points. The current exploitation rate (E_{curr} = 0.79) is higher than that generates optimum yield per recruit by more than 25%. Two harvesting strategies of different age-at-first capture (t_c) under three levels of natural mortality (M) were evaluated using Beverton-Holt yield-per-recruit model (Y/R). Higher yield could be obtained by increasing the current t_c (1.27 yr) to the age at first maturity (t_m =1.69 yr) for all M values used. The results indicate that the round herring stock in the Gulf of Suez is subjected to heavy exploitation and needs urgent management regulations. For improving and developing its production a reduction in fishing effort and mesh-size regulations are required.

Larval Pacific herring are highly susceptible to viral hemorrhagic septicemia and survivors are partially protected after their metamorphosis to juveniles

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Laboratory-reared, specific pathogen-free (SPF) Pacific herring were susceptible to waterborne challenge with viral hemorrhagic septicemia virus (VHSV) as early as 9d post-hatch, and susceptibility persisted throughout the 70-90 d larval and post-metamorphosis juvenile periods. Among SPF larvae, cumulative mortality was significantly greater ($p < 0.001$) in VHSV-challenged groups (93%, 62%, 43%, and 56% in 9d, 44d, 54d, and 76d larvae; respectively) than in naïve controls (52%, 22%, 21%, 1%; respectively). Among post-metamorphosed SPF juveniles, cumulative mortality was also significantly greater ($p < 0.0001$) in VHSV- challenged groups (71% and 70% in age 89d and 1+ yr juveniles; respectively) than in naïve controls (2% each). Metamorphosed juveniles that survived a VHS epizootic as larvae demonstrated partial protection against subsequent challenge with VHSV. Cumulative mortality was significantly less among juvenile groups that survived a prior VHS challenge as larvae (53-77%), than among positive control groups that were exposed to VHSV for the first time as juveniles (93-97%). Magnitude of the protection, measured as relative percent survival, was a direct function of larval age at first exposure and was likely a reflection of gradual developmental onset of immunocompetance. These results indicate the potential for easily overlooked VHS epizootics among wild larvae in regions where the virus is endemic and emphasize the important role of early life history stages of marine fishes in ecological disease processes.

Updates on the feeding ecology of the endemic freshwater sardine of Taal Lake Philippines, *Sardinella tawilis* (Herre 1927)

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Taal Lake is home to several economic and ecologically important species, the freshwater sardine, *Sardinella tawilis* is known to be of foremost importance among them due to its endemicity to Taal Lake and its importance in local fisheries being first in terms of production. Recently, the dwindling catches of the freshwater sardine and the decline in the water quality in Taal Lake because of the proliferation of fish cages and the introduction of alien species have brought more attention to the plight of the *Sardinella tawilis* and the other native organisms that reside in Taal Lake. Studies on fish diets are important in determining the impact of fish to its prey and the ecosystem where it is found. This paper reviews the previous studies on the diet of the *S. tawilis* from the first organism observed to be present in the diet of the *S. tawilis*, the silverside *Hepsetia balabacensis* (1927) to results obtained from studies conducted from 1970-2003 which consists mostly of technical reports and unpublished theses to the most recent studies which were finished in 2005. Using the available information from these papers, we would be able to trace the different techniques employed by fish biologists and ecologists in studying the diet of the freshwater sardine. We would also be able to compare and contrast the data which have been gathered on its diet and how this information gives clues as to how the *S. tawilis* is coping with changes in its habitat and threats brought about by over exploitation. Lastly, this paper would help shed light on the current status of research on the *S. tawilis* and how some institutions are gearing towards helping better understand this still enigmatic resident of Taal Lake.

Differences in calculation of growth rate by scales from various body parts of the Norwegian spring spawning herring

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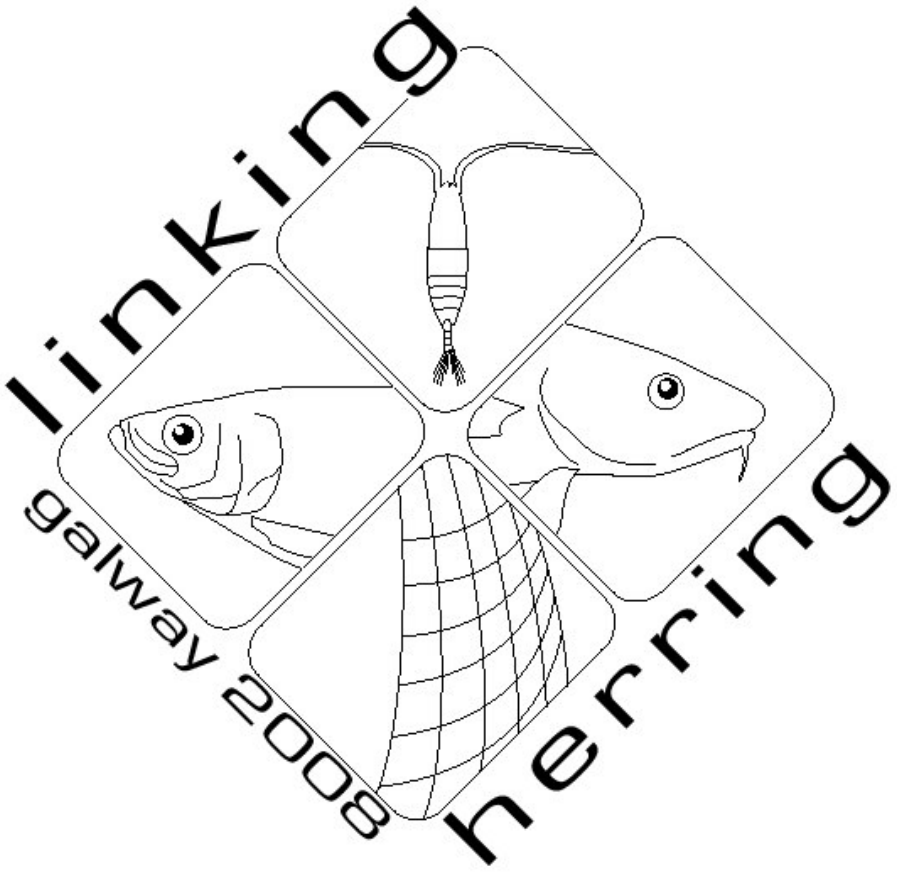
The paper uses the data of the Norwegian Sea herring collected in February 2005. There were 4 determined herring body parts on which the scale-covering is present after fish having been taken by trawl: near head, near the pectoral fin, in the middle of body, in the area of tail. The scales taken from tail is not suitable to read age, since the annual rings corresponding to age older than 7, practically, are not registered. The scales from all body parts are suitable to determine the age of the first spawning and the formula of scales. To study the components of herring stock important are the increments in the first years of individual life that indicate the conditions in which a specimen has grown up. When calculating increments, their smallest deviations from the average were found for the scales taken near the head. The scales taken in the area of pectoral fins have irregular shape, the registering structures are formed in different directions not uniformly therefore the work with it is difficult. Thus, to study the structure of herring spawning stock by analyzing the age of the first spawning and the size of annual increments the scales taken near head is the most suitable.

session 3:
variable production



Oral Presentations

Variable production the role of recruitment and survival under external forcing

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The paper will present a suite of results on the time series modelling of marine systems, only some of which are on herring, most of which being on cod. Results from (i) modelling long-term data on the Skagerrak system combining genetic-structuring analysis with statistical time series modelling, (ii) modelling the Barents-Sea/Lofoten system, and (iii) ecological interactions within a plankton community deduced from statistical modelling of time-series data. One example (iv) will be on herring (from the Sea of Japan). The basic message will be: there is much information hidden in long-term monitoring data, particularly if combined with properly developed statistical modelling techniques – much more than ecologists typically think.

(Presented *in absentia*, as a poster)

Environmental and genetic influence on growth strategies in herring larvae

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Common garden experiments were undertaken to study the effect of environmental (food and light) and genetic conditions on growth in herring larvae. Prey densities were maintained constant at one of two nominal levels (low: 40 nauplii per l and high: 1200 naupli per l) during the experimental period, while temperature was kept constant at 10°C. Eggs of autumn spawning North Sea herring were fertilized by cryopreserved sperm from males of Norwegian spring spawning herring and fresh sperm of autumn spawning North Sea herring males, respectively. Offspring of the two groups were mixed in replicated treatment tanks. The heterozygote hybrid group (spring paternal origin) was marked with a fluorescent dye, alizarine complexone, and the homozygote group being unmarked. Mean growth rates in terms of standard length, dry weight and otolith radius were significantly influenced by food availability, photoperiod and genetic background. In general, growth improved with increasing prey densities. Vernal photoperiod was more favourable for growth than autumnal light regime and light regime was increasingly more important with age (and size) for both crossing groups. The heterozygote hybrids (paternal spring origin) experienced significantly better growth than did homozygote autumn spawning groups at identical environmental conditions. The results are discussed in relation to differences in larval growth strategies between spring and autumn spawning populations.

Linking environmental factors to spatial and temporal variation in fat content of North Sea herring

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North Sea herring are noted for their plastic life history. Maturation and spawning depend on individual energetic condition. Condition, in turn, is dependent upon environmental factors e.g. food abundance and temperature. The North Sea is spatially and temporally heterogeneous with respect to both of these factors. The aim of this study is to determine how fat content of North Sea herring varies spatially and temporally, and whether this variation is dependent on *Calanus* spp. abundance, and temperature. Individual herring data were collected in June - July of 2006 and 2007. Using kriging, fatmaps (visual representations of herring fat content throughout space) were generated for juveniles in both years. A clear south-to-north increasing gradient was evident in both. This trend remained after the confounding effect of length was removed. The northern North Sea had consistently higher *Calanus* spp. abundance than the south throughout 2006 (data supplied by the Continuous Plankton Recorder Survey). The north also experienced lower temperatures in July 2006. Both of these factors could contribute to the higher fat content observed in juvenile herring collected in the north. The average fat content observed in 2007 was markedly lower than in 2006. Future research will investigate whether this is due to a decrease in *Calanus* spp. abundance. The implications of interannual variation in fat content for maturation and reproductive potential (atresia) will also be assessed.

Fisheries-induced life history changes in North Sea herring (*Clupea harengus*)

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Fishing changes not only the population abundance of the target species, but also its population dynamics and life-history traits. A number of studies have shown that life history traits related to the timing of maturation can respond quickly to fishing mortality. Because changes in such life-history traits feed back into population dynamics and, consequently, may also affect the yield and thus profitability of a fishery, we need better understand the factors that hasten or hinder such changes. In this study we analyze how fisheries have affected the maturation process of an economically important herring (*Clupea harengus*) stock, the North Sea (NSH) herring. The harvest of North Sea herring targets both mature and immature individuals. Life-history theory predicts that under this kind of mortality regime fisheries can be expected to induce an adaptive decrease in the age at maturation. The preliminary results suggest that there has indeed been such a shift towards earlier maturation at smaller size in North Sea herring. This kind of studies are critical for testing theoretical predictions, and will facilitate our understanding under which conditions large life history changes can and cannot be expected. Such understanding is needed for evolutionarily enlightened management of marine biodiversity.

Induction and occurrence of skipped spawning in Norwegian spring-spawning herring

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It has been suggested that up to 50% of Norwegian spring-spawning herring will skip their second spawning event. The phenomena of skipped spawning in NSS herring was inferred from the lower than expected numbers of second time spawners on the spawning grounds. However, in field samples only two herring which were found to be skipping reproduction has ever been documented. In an attempt to determine if a large proportion of herring do indeed skip their second spawning event we performed two experiments designed to coerce herring to skip spawning. The experiments were also designed to test if there was a critical period in which food level can influence fecundity and the prevalence of skipped spawning. The laboratory experiments were undertaken in parallel with a 3 year field sampling program to try and determine skipped spawning in the wild. It appeared that skipped spawning can occur under laboratory conditions but this was in fish that were of a very low condition (Fulton's k <0.6). Almost all herring in the experiment began oocyte development and every herring caught in the summer months had begun ovary development. The reason that almost all mature herring begin ovary development is probably due to the extended time in which it takes herring to bring their gonads to full maturity. Female herring begin ovary development in July, two months before the end of their feeding season. At this stage the herring will not know how much energy will be available for ovary development. It thus takes an optimistic view and develops a very high number of oocytes, which are then down regulated through atresia, to a number that can be sustained with its ambient energy reserves.

Reproductive capacity of the Norwegian spring spawning herring

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The paper uses PINRO's data on reproductive capacity of the Norwegian spring spawning herring for 1951-2007. The data on herring population biomass and year-class abundance, catch, and percentage of mature individuals were taken from the reports of the ICES Working Group (Anon, 2007).
Studied were variations of population fecundity (PF) and year-class strength of the Norwegian spring spawning herring in 1951-2004. Three levels of the spawning population size and herring PF, guarantying, optimal and critical, were established. The optimal level is the most interesting in practical respect. During 22-year period, from 1967 to 1988, when PF was much lower than the optimal level, mainly poor year-classes appeared except for the strong 1983 year-class, when there were exclusively favourable conditions for herring survival at early stages, and for the average 1985 year-class, when the conditions were good. On the contrary, during 16 years, from 1989 to 2004, with the recovery of minimal level and its further increase, the appearance of 7 strong, 5 average and only 4 poor year-classes of herring was recorded.

Recruitment failure in North Sea herring: a gut feeling?

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The North Sea herring stock has experienced serial poor recruitment since 2001 despite the presence of a large spawning stock biomass. The primary cause is low survival rates of larvae in the over-wintering period, though the underlying mechanisms are not yet understood. This study investigates diet and parasite infection as potential causes for the poor over-winter survival. Herring larvae caught off the northeast of Scotland (56°N - 57.5°N, eastwards from the coast to 1°W) in February of each year in the period 1995 – 2008 were dissected to identify and enumerate prey items and parasites present in the alimentary tract. The samples selected for analysis included larvae from year classes with a wide range of survival rates, whilst the geographic range was constrained to an area in which larvae were present in all years and where there was a parallel data set on the composition and abundance of zooplankton taxa. We compare our findings to an earlier study of diet and parasite infection of herring larvae in the same region from a period characterised by good over-winter survival. The results show marked inter-annual variations in feeding incidence, gut content composition and parasite prevalence, which we relate to year class survival.

Effects of hatching time on year-class strength in Norwegian spring spawning herring

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The effects of multiple factors on larval survival (R_0/SSB) in Norwegian spring spawning herring (*Clupea harengus* L.) during 1987-2004 were tested with a regression model. The factors tested were mean hatching date (beta=-0.76, p=0.010), hatching temperature (beta=0.28, p=0.241), wintering temperature (beta=-0.14, p=0.679) and percent recruit spawners (beta=0.09, p=0.767), where the beta coefficients gives the relative contribution of each independent factor. The significant negative relationship between hatching date and larval survival contradict with the hypothesis that temperature fluctuations result in variable recruitment due to temperature related growth and survival of the larvae. The fact that hatching date decreased with wintering temperature (r=-0.65, p=0.003) and increased with percent recruit spawners (r=0.61, p=0.007), rather indicate an indirect effect on larval survival, due to early spawning in years with high temperature during gonad development and delayed spawning in years with low wintering temperature and/or strong recruitment to the spawning stock. Early hatching could be favourable for larval survival as the larvae may drift away from coastal areas with potentially high predator pressure before the predator pressure increases during spring. Support for this hypothesis was found in the activity of the purse seine fishery on saithe (*Pollachius virens*) along the Norwegian coast, indicating that the saithe became fully active two months earlier in the area 62°-67°N compared with areas further north. Accordingly, field data and larval drift models demonstrated that the majority of the early hatched larvae drifting northwards would have passed 62° -67°N at the time the saithe became fully active in this area.

Reproduction and recovery rate of Norwegian spring-spawning herring

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Classical population ecology suggests that the intrinsic rate of population increase (*r*) is a key determinant of the resiliency of individual populations. The extinction risk of marine fish stocks and the rate at which collapsed stocks recover are also considered to depend on *r*. *r* combines several key life history traits, including natural mortality, growth, maturation, and fecundity, into a single index representing the dynamic balance between the production of offspring and the subsequent losses of those offspring through natural mortality. We tested the hypothesis that stock decline is associated with low or negative values of *r* and stock rebuilding is associated with high, positive values of *r* on the Norwegian Spring-spawning herring. This stock has gone through three distinct periods; high abundance from the 1930s to 1970, very low to collapse state during the 1970s to late 80s and then the recovery period in the recent years. From cohort-specific life table, life history models were used to estimate trends of *r* and net reproductive rate (Ro). These were compared to quantify how much the population resiliency has changed between successive time periods of collapse and rebuilding. Such knowledge will help in identifying the causes and consequences of the variation in stock reproductive potential.

Herring: change in climate, change in habitats?

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The habitat of North Sea herring over the last 30 years is described in terms of the environment which each life stage inhabits. In addition to a characterisation of habitat tolerances and preferences of the herring, we investigate whether the habitats have changed in recent years. The aim of the investigation is to identify the environmental conditions that are crucial for certain herring life stages. Emerging from the ongoing EU-project RECLAIM, emphasis is hence put on climate change issues: Is the North Sea herring stock vulnerable to climate change due to modification/limitation or expansion of tolerable habitat? Habitat mapping is also one approach that allows us to investigate causes for the poor larval survival since 2002. In addition, the results can help to improve research survey design for stock monitoring as temporal and spatial adjustments to coverage may be possible and stratification of surveys may be improved by accounting for correlative environmental variables. We combine empirical data on herring abundance from ICES surveys with a coupled hydrodynamic ecosystem model (ECOSMO). This allows us to cover the larval as well as juvenile and adult life stages. ECOSMO provides various hydrographic parameters (e.g. temperature, salinity, bottom shear stress, temperature and salinity based indices of stratification and frontal development) and biological parameters, such as phyto- and zooplankton abundance weekly from 1958 to 2004 at a 10 km horizontal resolution. Changes and trends in these environmental variables in North Sea habitat for each herring life stages can thus be described and interpreted with regard to potential climate change.

Oceanographic influence on the early life of herring at North Sea spawning grounds

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Studies at the spawning grounds of North Sea herring suggest linkage between the performance of hydrographic fronts and the early life of the autumn spawned herring larvae. Acknowledging the oceanographic variability of the North Sea we ask to which extent the newly hatched herring larvae experience variable environmental conditions, and to which extent such variability is reflected in their survival and recruitment. In the study we investigate the inter-annual variability in hydrography and herring spawning at important grounds in the North Sea for the period 1993-2007. We used data from the International Herring Larvae Surveys (IHLS), where the standard oblique hauls for herring larvae were paralleled with measurements of surface and bottom temperature and salinity. Further we used length information from the catches of larvae to estimate their survival probability. During the period the spawning took place basically at the same geographical position while hydrographical characteristics varied, and consequently the larvae hatched into different environments. Changes might be gradual over a period of years, as seen by the general decline in bottom water density during the last decade 1998-2007. The recent oceanographic changes are paralleled with a decline in larval survival and herring recruitment, and a comparison to the preceding period indicates that specific hydrographic conditions related to water density and frontal performance have a detrimental effect on recruitment.

Fecundity regulation in North Sea autumn and winter spawning herring

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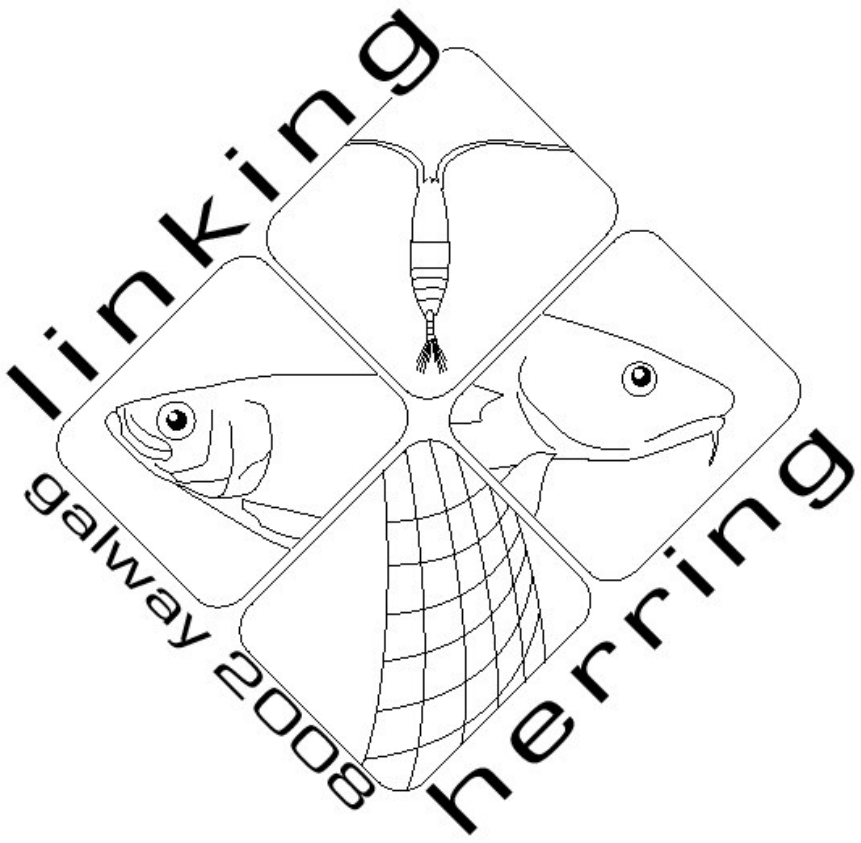
Atlantic herring *Clupea harengus* have contrasting strategies for ovary development, with genetically similar fish "choosing" different spawning seasons. Both oocyte development and the resulting eggs are different in size and energy content depending on spawning season. In the North Sea two different spawning types are distinguished, autumn and winter spawners which spawn in different areas. Both spawner types mix in summer in the Central North Sea summer feeding area. Females of both spawning types start the oocyte development in April-May. Oocyte development is regulated by energy content of the females. Through the maturation cycle fecundity is down regulated through atresia. While autumn spawners spawn after summer, the oocyte development and down regulation of fecundity in winter spawners continues, resulting in larger eggs and lower fecundity. For both spawning types the relationship between lipid content and fecundity throughout the maturation cycle will be shown. The variation in lipid content for both spawning types is large. Although the autumn spawners in this study are on average larger both in length and weight, the lipid content of winter spawners is higher.

session 3:
variable production



Poster Presentations

Peaks in recruits to spawner ratio correlates with abrupt changes in herring wintering areas

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The world's largest herring stock, the Norwegian spring spawning herring, spends four winter months in dense concentrations. Recruiting cohorts typically adopt the migration pattern of the spawning stock. However, during the last 50 years the stock has occupied at least six discrete wintering grounds, spanning from high seas to narrow fjords. We here show that large-scale changes in herring wintering area take place when abundant recruit cohorts appear. The ratio in abundance between four year olds and five year and older herring is on average 12.9:1 in the years when changes in wintering area take place compared to 0.4:1 in years without changes. The wintering areas vary greatly with regards to temperature and distance to the feeding and spawning grounds, features that affect energy expenditure heavily. Rather than being strictly optimized the establishment of wintering areas seems to be governed by general school cohesion mechanisms with the transmission of socially learnt migration routes disrupted if the recruits are too numerous.

Population declines and lack of recovery of Pacific herring in Prince William Sound, Alaska, USA

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The Prince William Sound (PWS) population of Pacific herring collapsed in 1993, four years after the *Exxon Valdez* oil spill. The debate about the cause of the collapse of the fishery has been hotly debated. Highly toxic polynuclear aromatic hydrocarbons (PAHs) significantly damaged herring embryos in 1989, the effects of which were no longer detectable after 1990. Strong recruitment of the 1988 year class in 1991 marked the recovery of the populations from the direct toxic effects of the oil spill. Epidemiological analysis identified three risk factors for the 1993 population crash: 1) relatively biomass from 1988 to 1992, i.e., a susceptible host; 2) relatively low zooplankton population in 1991 and 1992, i.e., environmental conditions contributing to poor condition of herring in the winter; and 3) the presence of disease, i.e., VHSV and filamentous bacteria. Linkage of the 1993 collapse with the 1989 oil spill cannot be proved or disproved, and reasons for the lack of recovery are perplexing. PWS herring recruitment was depressed due to VHSV and life spans were shortened by *Ichthyophonus*. Other natural factors such as climate, interspecies competition, suboptimal recruitment, condition prior to the winter starvation period, and predation may be contributing factors. Continued diseases cycles may be the parsimonious reason for the current status of herring in PWS, however the lack of recovery is most likely due to multiple factors.

The influence of oceanographic conditions on abundance of the Norwegian spring-spawning herring at the early life stages

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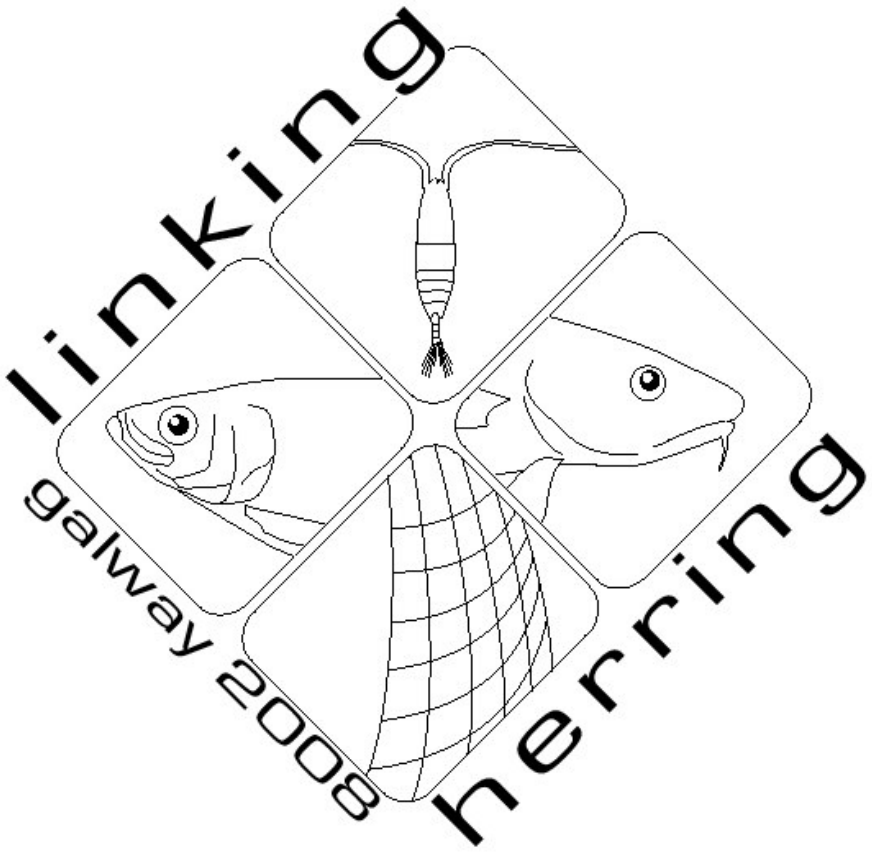
The aim of this paper is to develop an approach to estimating 0-group herring abundance using a set of oceanographic and biological parameters determining the abundance. The oceanographic parameters were a length index of the Barents Sea frontal zones, an indicator of water stratification in the spawning areas, temperature and density differences between the bottom and surface in the spawning areas, wind-driven and total volume fluxes through the sections crossing the main currents of the Barents Sea, an autumn-winter North Atlantic Oscillation index and water temperature in the Kola Section; the biological ones – total and spawning stocks of herring as well as its population fecundity. The regression equations for the indices of 0-group herring abundance were built. They show a quite close relationship between the chosen parameters and the 0-group herring abundance indices: the index of absolute abundance (r=0.85-0.90) and the area index of abundance (r=0.81-0.89). The built equations can be used for restoration and estimation of the indices of 0-group herring abundance. The paper is oriented to be used further within the complex approach to the study of herring abundance forming.

session 4:

population integrity



Oral Presentations

Obstinate nature and response diversity in an Atlantic herring metapopulation

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Obstinate nature (Cury 1994) refers to generation after generation use of the same spawning ground, resulting in population inertia to environmental change. Controversy centers on whether spawning site fidelity in Atlantic herring (*Clupea harengus*) is due to breeding philopatry (genetic imprinting) or entrainment (social facilitation). Regardless of mechanism, diverse and interacting spawning contingents are recognized as operating with varying degrees of independence to environmental conditions. In community ecology, the manner in which individual species or guilds independently respond to the same set of environmental conditions and thereby contribute to stability is termed response diversity. Here, in an age-structured model, we evaluate the consequences of response diversity in a hypothetical metapopulation composed of Celtic and Irish Sea Atlantic herring populations. Simulations were constructed to examine the effects of population interchange and recruitment covariance on metapopulation stability and productivity. Recruitment cycles based upon the NAO Index were imposed with varying correlations between the two spawning groups ($r = -0.5$ to $+0.5$). Interchange was modeled as 5 to 15% straying rates (assuming breeding philopatry), or as 25 to 75% entrainment rates into the dominant spawning contingent according to its numerical advantage. Simulations showed that levels of interchange and response diversity influenced metapopulation stability. Further, the underlying mechanism of interchange between discrete spawning groups - straying or entrainment - had a strong influence on metapopulation stability and productivity.

Mixing of herring stocks within the same school during spawning: implications for the metapopulation concept

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Populations of Atlantic herring are believed to form a metapopulation. Spring- and autumn spawning populations of herring have overlapping distribution outside the spawning period, but so far spatial overlap during spawning has not been demonstrated. For approximately 6000 years a herring stock has existed in a semi-enclosed marine ecosystem in western Norway (Lindåspollene). This local stock feeds and spawns in a restricted area, only connected with the outside fjord through a narrow sill. During 2005-2007, possible spatial and temporal mixing of herring stocks was investigated before and during spawning. Local Lindås herring and Norwegian spring spawning herring (NSS) were found within one main school, and the catch in the upper and lower part of gillnets showed that the populations were mixed within the school. Local herring dominated within 100 meters from the school centre, whereas NSS herring became more frequent with increasing distance and dominated >1000 meters from the main school. NSS herring were markedly younger than local herring, but of similar length, weight and maturation stage. Spent fish from both stocks were observed in the main school. Taken together, these findings demonstrate that interbreeding between the two populations is likely, thus supporting the metapopulation concept in Atlantic herring.

Stock identification and biological position of the herring stocks in the Faroe shelf ecosystem

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Within the areas bordering the Faroes at least four herring stock components exist including the Norwegian spring-spawning herring, Icelandic summer-spawning herring, the Faroese autumn-spawning herring, and the northern part of the North Sea herring stock-complex. The paper clarifies the biological position of the various stock components in the mixture of both spring- and autumn-spawning herring stocks occurring in the Faroese area, and secondly confirms the existence of a local "Faroese autumn-spawning herring" stock. The biological position of this local stock has recently been identified, due to the high recruitment in 1999. This year-class has been followed since, mostly from samples taken in the local fjords and on the banks east of the Faroes. From analysis of otolith types, age distribution, maturity, larval growth, it is confirmed that a local Faroese autumn-spawning herring stock exists at Faroes.

Population and hydrographic aspects of the Norwegian spring-spawning herring migration variations in the 20th century

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The paper uses PINRO's data on reproductive capacity of the Norwegian spring spawning herring for 1951-2007. The data on herring population biomass and year-class abundance, catch, and percentage of mature individuals were taken from the reports of the ICES Working Group (Anon, 2007). Studied were variations of population fecundity (PF) and year-class strength of the Norwegian spring spawning herring in 1951-2004. Three levels of the spawning population size and herring PF, guarantying, optimal and critical, were established. The optimal level is the most interesting in practical respect. During 22-year period, from 1967 to 1988, when PF was much lower than the optimal level, mainly poor year-classes appeared except for the strong 1983 year-class, when there were exclusively favourable conditions for herring survival at early stages, and for the average 1985 year-class, when the conditions were good. On the contrary, during 16 years, from 1989 to 2004, with the recovery of minimal level and its further increase, the appearance of 7 strong, 5 average and only 4 poor year-classes of herring was recorded.

Mixing of herring juveniles in the Irish Sea: Temporal trends and environmental drivers

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Celtic Sea herring (*Clupea harengus*) show extensive movement into the Irish Sea during their first year of life where they mix with resident fish. This influences the assessment of Irish Sea herring as juvenile abundance at Irish Sea nursery grounds does not provide a reliable recruitment index. Otolith microstructure can be used to separate Irish Sea autumn spawned and Celtic Sea winter spawned juveniles and could be incorporated into routine monitoring of the fishery. Otolith microstructure was used in this study to estimate the proportion of winter spawned individuals in samples of 1-group herring collected in the western Irish Sea between 1993-2004. These proportions were combined with data from the Irish Sea stock assessment to produce separate abundance estimates for each component. Temporal trends were analysed in relation to environmental variables. The abundance of 1-group winter spawned Celtic Sea juveniles in the Irish Sea was related to wind patterns in the previous winter/spring period. Abundance estimates for 1-group Irish Sea juveniles were correlated with abundance estimates for 3-group fish from the same year class, estimated from commercial catches and acoustic survey data ($r > 0.8$, $p<0.05$). These findings have important implications for the monitoring and assessment of herring in the Celtic and Irish Sea and the prediction of recruitment to the fishery.

Investigation of variability in Pacific herring tag recovery rates to elucidate trends in inter-annual spawning site fidelity

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The first Pacific herring tag-recovery study on the west coast of Canada began in 1936 using internal belly tags and subsequently, two other studies using external Floy anchor tags and coded wire microtags (CWTs) have ensued. Different sampling designs and approaches were required for each type of tagging study due to changing harvesting practices, fish processing methods, and data collection protocols. A primary objective of these studies has been to better understand the degree of inter-annual spawning site fidelity as a basis for stock structure in support of fisheries management. The most recent study from 1999-2006 investigated the efficacy of using CWTs to estimate homing and dispersal rates as a comparison to the earlier studies. Similarly to earlier studies, the CWT sampling design for tag release and recovery was affected by the abundance, and spatial and temporal distribution of spawning fishing. However, unlike results from previous studies, we adjusted sample sizes of tag recoveries by the sizes of the tag release groups and by estimates of recovery sampling intensities by gear type, the latter done using independent estimates of the recovery populations. Although the results indicate high uncertainty due to confounding process rates, the CWT data have provided greater resolution of recovery variability, spawning site fidelity and insight into the strengths and limitations of these types of studies.

Information from otolith microstructure and shape provides evidence of natal homing in Atlantic herring (*Clupea harengus*)

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Reproductive exchange between seasonal and geographic assemblages of Atlantic herring (*Clupea harengus*) is widely debated. Discrete population theories predict that spawning season fidelity and natal homing maintain population integrity. Conversely, spawning aggregations may represent interconnected subgroups within metapopulations. Ten years of research on Irish and Celtic Sea herring reveals that despite extensive mixing during the early life stages, stock separation is preserved in spawning adults. Otolith microstructure analysis has shown that large numbers of winter-spawned herring disperse into the Irish Sea as larvae, where they mix with the resident autumn spawned population. The migrant component remains in the Irish Sea throughout the juvenile phase but do not recruit to the adult spawning stock. Winter-spawned fish that are retained close to the spawning grounds in the Celtic Sea grow faster and mature earlier than the migrants in the Irish Sea. The two groups show variation in otolith shape and outline analysis of the first winter ring can be used to determine the nursery ground origin of adult fish. This technique was applied to collections of spawning adults from the Celtic Sea. The results indicate that ~40% of these winter-spawned fish spent their nursery period in the Irish Sea confirming that despite extensive dispersal during early life, Celtic Sea migrants return to their natal population to spawn. This the first study to demonstrate natal homing in Atlantic herring and it offers valuable insights into the mechanisms maintaining population structure.

Variation in spatial distribution and migration of Icelandic summer spawning herring

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Available information on the fishery of the Icelandic summer spawning herring (*Clupea harengus,* L.) and results from research cruises are used to describe how the distribution of the main component of the fishable stock and the overwintering grounds have changed during the period 1978-2006. The reasons for the observed changes in the stock's distribution are examined, which includes exploration of sea temperatures, stock size and size of incoming year classes to the adult stock. The herring stock collapsed due to overfishing and environmental changes during the late 1960s, but since 1972 the spawning stock has gradually increased from around 10 to 800 thousand tonnes in 2006 with a simultaneously geographical variation in the distribution. A graphical exploration of the herring distribution suggest that it is possible to distinguish between five transition phases over the period, which is supported by the center of gravity of the fishery. On a large scale, there is no clear indication that the sea temperature is affecting the observed changes in the distribution. Similarly, the observed modifications in the herring distribution were not conclusively related to stock size or year class strength. The results are considered to provide supports to previous theories explaining herring migration patterns, including the existence of inertia for changes in migration pattern because of site-fidelity and also that the distribution could be in some cases be affected by a lack of "guidance" of older herring.

The characteristics of southern Baltic herring infected and non-infected with *Anisakis simplex* larvae using geometric morphometrics

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For herring assessment in the Baltic, ICES has distinguished western stock (waters west of Bornholm) and central stock (waters east of Bornholm, excluding Gulf of Riga and Bothnian Bay). However, herring infected with *A. simplex* larvae is present along the southern Baltic coast, which indicates that these fish migrate outside the Baltic. The aim of this study was to compare samples of Rügen herring from German waters with herring from the Pomeranian Bay (western Polish coast) and the Gulf of Gdansk (eastern Polish coast). Samples were collected during the spawning season in 2005 from four locations - in German (the Mecklenburg Bodden, the Greifswalder Bodden) and Polish waters (the Pomeranian Bay, the Gulf of Gdansk). Landmark-based geometric morphometrics was performed to quantify the body shape of herring. Discriminant Analysis was applied to assign individuals to a particular stock of western or central Baltic herring. The presence of *A. simplex* larvae was used as a marker for herring feeding migration to the North Sea. Infected herring occurring in the spawning grounds of the Baltic Sea represented both western and central Baltic stocks, which supports the hypothesis that both stocks of herring migrate outside the Baltic. The characteristics of herring from Polish western coast and German waters were similar, which suggests that these fish represent the same stock.

Population integrity and connectivity in NW Atlantic herring: a review of assumptions and evidence

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The issue of herring population structure has been debated scientifically for more than a century. Population integrity, distribution, and connectivity have become an increasingly important problem for both resource evaluation (e.g. concern for the use of appropriate modelling approaches) and management (e.g. increasing attention to the preservation of intra-species diversity and the complexity of mixed stock fisheries). In recent decades there has been considerable advance in the scientific information related to herring population structure, but recent papers continue to reveal a spectrum of conclusions related to population integrity and connectivity at various scales. This paper reviews herring stock structure in the western Atlantic by addressing specifically the current assumptions being used in management, and the validity of scientific evidence on which these assumptions are based. Traditional stock structure hypotheses are placed in the context of recent theoretical constructs of bio-complexity and the importance of population diversity under the evolving ecosystem approach for management.

About the causes of morphogenesis of pacific herring *Clupea pallasii*

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There are two morphs of Pacific herring *Clupea pallasii* formed in the Pacific Ocean: marine and coastal. The marine morph is wintering at sea, the coastal – near the shore, in lagoons or small estuarine inlets. The boundaries of the morph's distribution differ at the South and the North. The marine morph spreads more southern. The coastal morph occupies the Arctic waters, where the marine morph is absent. The Arctic origin of Pacific herring makes to suggest that the coastal morph is more ancient. During the Glacier Epochs herring distribution was concentrated inside small estuarine inlets. The adherence to the motherland flows stays in the Subarctic waters for now. However, herring spawning grounds in the coasts with developed lagoon shores are larger *vs.* the grounds in the sites with less motherland flow. So, the populations from these coasts demonstrate higher abundance, more extensive and durable migrations and use to winter at sea. The populations which spawning grounds are situated within the littoral zone of small lagoons demonstrate their life history similar to the Arctic one.

Strategy for genetic subpopulation investigation – multidisciplinary approach into discrimination of the southern Baltic herring

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Sustainable exploitation of living resources requires the conservation of biodiversity of ecosystems and is an important issue at the European and global scales due to the accelerating impacts of man. The necessity of using a multidisciplinary approach to fish stock assessment is well accepted, and information on population genetic structure, combining spatial and temporal scales, is of fundamental importance to the management of marine fisheries. Using all sources of information on the species and on its possible interactions with other inhabitants of ecosystem effective way of discrimination stock could appear. The aim of this study was to determine stock adherence of spring spawning herring, distributed along the southern Baltic coast in Polish EEZ, into Western (W) or Central Baltic (C) stocks. Applying multidisciplinary approach in the study, we combined data from analysis of 9 the most informative microsatellite loci with morphometric and meristic characteristics of herring infected and noninfected with parasite Anisakis simplex. Presence of the parasite indicates that infected fish migrated outside the Baltic. Exact test of allelic distribution between pairs of populations suggested a presence of two populations on the Polish coast. The groups W and C separated on the basis of morphometric and meristic data analysis were also tested against genetic differences. Fst pairwise analysis showed statistical differences at the level P=0.05. Both, Fst and Exact test analysis show the presence of infected herring in both stocks Western and Central Baltic.

Application of otolith shape as a stock identification method in mixed Atlantic herring (*Clupea harengus* L.) stocks in the North Sea and western Baltic.

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The origin and reproductive interactions of sympatric, spatially separated spawning components of Atlantic herring (*Clupea harengus*) have received long-standing interest. For stock assessment and/or management purposes, the herring populations in the North Sea and adjacent areas are split into stocks with different spawning times (winter, spring and autumn). Otolith shape analysis has been used to discriminate between populations for a variety of species and for herring this approach has had increasing success with development of imaging techniques and statistical methods. Here we use otolith morphological traits (otolith shape and larval otolith microstructure) to discriminate between different populations of adult Atlantic herring (*Clupea harengus*). The otolith shape was found to clearly discriminate between different spawning populations. The overall success on a subset of 5 spawning groups was 75%, with no less than 64% correct classification. The identified distances between populations based on otolith shape matched previously obtained genetic distance values and were, when combined with the otolith microstructure, able to discriminate between populations that are spatially different but spawning in the same season.

Migration of adult Pacific herring spawned in Miyako Bay on the Pacific coast of northern Japan

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We tagged and released 500 adult Pacific herring *Clupea pallasii* captured after spawning by a set net in Miyako Bay on the Pacific coast of northern Japan in winter of 2003 and 2004. A total of 114 tagged fish were recaptured during the period of 38 months after release. Based on the seasons and locations of recaptures, the adult herrings were found to have left Miyako Bay shortly after spawning, migrated north in spring along the Pacific coast, and reached Funka Bay in Hokkaido Island about 300 km north of Miyako Bay in summer. In the spawning season during January and April of the following year of the tagging, 18 adults from the 2003 released group and 14 from the 2004 released group were recaptured in Miyako Bay. Together with the reported migration ecology of juvenile herrings released in Miyako Bay, the local population of Pacific herring in Miyako Bay was found to seasonally migrate north and south between Miyako Bay for spawning and Funka Bay for feeding.

Elucidating population structure in juvenile Atlantic herring in Scottish west coast sea lochs: a multi-marker approach

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Atlantic herring (*Clupea harengus*) exhibits large spatial and temporal variation in life-history parameters and population structure. In particular, the structure and distribution of most juvenile aggregations are poorly understood. We investigated spatial and temporal variability in hatching date, growth rates and condition in 0-group herring over-wintering in three sea lochs in western Scotland (Lochs Nevis, Duich and Kishorn) collected over three years (2001, 2002, 2003). Otolith measurements and daily increment counts indicated that the samples comprised a mixture of juveniles that had hatched in autumn, winter, and spring. Peak hatching times and larval otolith growth rates showed considerable fluctuations between years. This variability in early life history traits also partly explained temporal differences in fish size and condition. Information from otoliths was combined with genetic data to determine if the observed heterogeneity had a genetic basis. No genetic substructure was detected at nine neutral microsatellite loci, using a variety of groupings. The results suggest that the juvenile assemblages originate from the same demographic stock. Variability in life-history traits (which may still be under strong genetic control) may reflect the plasticity of herring phenotypes, which allow this species to adapt to environmental variability.

Norwegian spring spawning herring: population characteristics of a major change in wintering area

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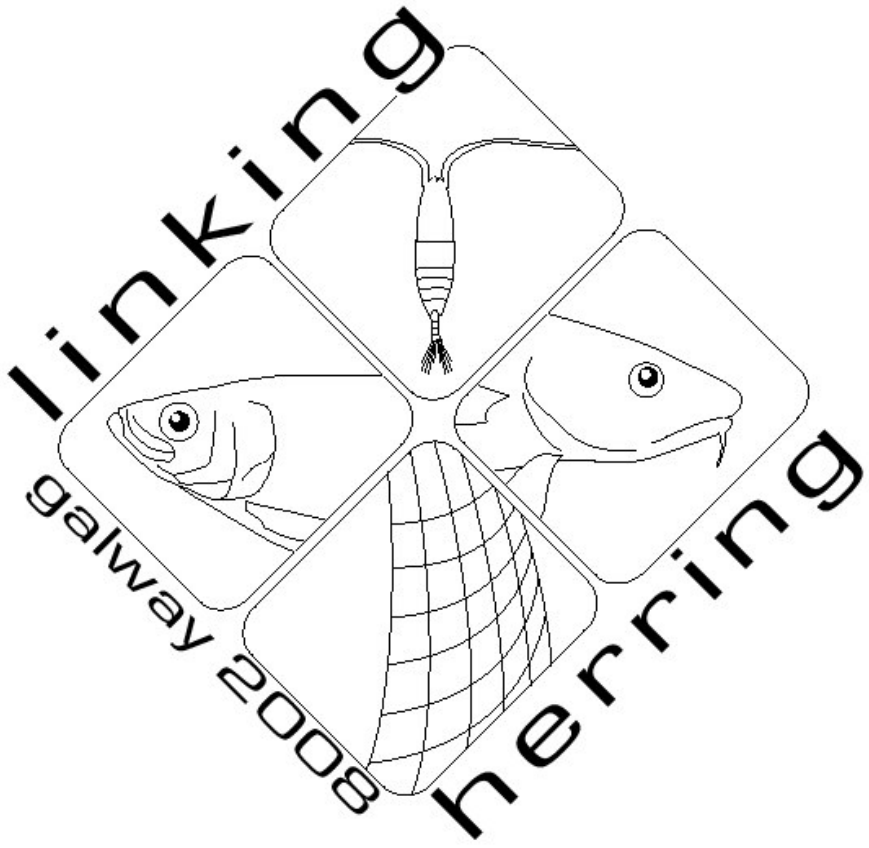
The Norwegian spring spawning herring is a widely distributed, highly migratory stock inhabiting large parts of the NE Atlantic. It is by far the potentially largest herring stock in the world with total stock levels up to close to 20 million tonnes. The stock is characterized by large variation in characteristics like stocks size, recruitment, distribution and migration pattern. The seemingly least stable component in the yearly migration cycle is the wintering area and only since 1950, 6 such areas have been described. During the period 2002-2007 the herring stock changed its wintering area from fjords in northern Norway to oceanic areas off northern Norway. This paper is a description of the population characteristics related to this change, with particular focus on geography, biomass and year-class structure. It also includes a discussion on general characteristics and mechanisms underlying changes in wintering area in this stock.

session 4:

population integrity



Poster Presentations

Identification of spawning components in mixed aggregations of Atlantic herring (*Clupea harengus*) along the west coast of the British Isles based on chemical composition of otolith cores

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Herring along the west coast of the British Isles are thought to comprise a series of discrete stocks, with separate and distinct spawning locations, that are assessed individually. The contribution from different spawning components within mixed aggregations of herring outside of the spawning season was estimated using Integrated Stock Mixture Analysis (ISMA) based on otolith chemical composition data. Spawning herring from eight spawning grounds were used to determine the baseline populations. There were significant differences between some spawning groups in the otolith concentrations of Li, Na, Mg, Mn, Sr and Ba, but many of the spawning samples were heterogeneous and classification among spawning groups ranged from 3 – 55%. Four mixed aggregations were sampled off the west coast of Scotland, north-west Ireland and in the Irish and Celtic Seas. Each of the mixed aggregations contained at least three spawning group components. Off the north-west coast of Ireland the mixed aggregation consisted primarily of fish spawning in one Management area, namely VIaS, but in other areas (VIaN, Irish Sea and Celtic Sea) the mixed aggregations consisted of fish from at least two other management areas. The current system based on assessments for individual spawning components will probably not provide robust information for management advice. This study suggests that most herring along the west coast of the British Isles are not exploited in isolation, thus a discrete stock approach is inappropriate when estimating population dynamics, especially when based on the catch equation.

Connectivity between nursery areas and spawning stocks of Atlantic herring (*Clupea harengus*) on the West side of the British Isles, based on otolith microchemistry

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The chemical composition of otolith cores was used to discriminate between juvenile herring sampled at 6 presumed juvenile nursery ground locations along the western coasts of the British Isles. The relative concentrations of Li, Na, Mg, Mn, Cu, Sr and Ba produced otolith signals corresponding to three main groupings of nursery ground fish representing the Irish Sea, the Scottish Sea Lochs and the Minch. These patterns were used in a discriminant analysis model to investigate the connectivity between juvenile nursery areas and eight different spawning aggregations of herring. The results suggested that the spawning groups are made up of individuals from a number of different nursery areas, that originate from a range of management areas. A north-south divide was also indicated, with the otolith signal of juveniles from southern nursery areas being represented more in the southern spawning groups, and vice versa. The degree of mixing and connectivity observed suggests that the adopted-migrant hypothesis may explain the dynamics of herring populations to the west of the British Isles. Managers of both fisheries and coastal zones should consider the connectivity of herring populations when developing policy.

Stock identification of 0-group herring in the Irish Sea using otolith microstructure and shape analysis techniques

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Presented are the preliminary results from an investigation into the use of otolith microstructure and shape analysis to distinguish the seasonal origin of 0-group herring in the Irish Sea. The ultimate goal of this work being the generation of an annual recruitment index for use in the assessment process of Irish Sea herring. The Irish Sea acts as a nursery ground for juvenile herring originating from the Irish and Celtic Seas and possibly Clyde spawning grounds (Bowers, 1964; Brophy and Danilowicz, 2002). This mixture of juveniles has prevented the generation of accurate recruitment indices for stock assessment purposes in the area. Using otolith microstructure and shape analysis techniques previously employed in the Irish Sea (Brophy and Danilowicz, 2002; Burke et al., 2007) we separate juvenile herring caught during annual acoustic surveys into their seasonal spawning components. The proportions of each component are estimated spatially and the total biomass estimated adjusted accordingly.

session 5:
herring in the middle

Oral Presentations

Herring in the middle: a comparative discussion

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Herring belong to a group of small, planktivorous fishes that also includes sprat, sardines, anchovies, and various more tropical analogs. Fishes of this group tend to build such high abundances that a single species often dominates its entire trophic level within a marine ecosystem. Because of the resulting community configuration, featuring many species at the lowest trophic levels, many at the upper trophic levels, but constricted to no more than a very few important species at a mid-level (reminiscent of the body form of a wasp, in which flows of information and material between complex, multifunctional, relatively large thoraxial and abdominal body segments must pass through a very narrow tubular waist segment), these ecosystems have sometimes been called *wasp-waist ecosystems*. The involved fish species typically have complex life histories, resulting in radical variability that may propagate to both higher and lower trophic levels. In addition, their populations have two key attributes: (1) they operate as the lowest trophic level that is mobile and consequently are capable of relocating their area of operation according to their own internal dynamics; (2) they have a tendency to be intimately involved in unstable dynamic feedback loops in the trophic system that may, for example, precipitate abrupt regime shifts. In this presentation, characteristic aspects of wasp-waist populations and their apparent effect on the dynamics their ecosystems are addressed from a comparative point of view, drawing on the speaker's long experience in anchovy-sardine systems. Unique aspects of herring biology (e.g., their demersal spawning mode rather than the pelagic spawning mode that is the more universal pattern among small *wasp-waist* forage fishes) and ecology (e.g., possibility of adaptive plasticity in positioning of spawning sites) are examined and interpreted. Certain prevalent assumptions are questioned.

Seasonal plankton-fish interactions: herring energy storage in relation to light and prey abundance

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When both prey and predator are seasonal migrants, their interactions depend on migration phenology and the seasonal timing of life cycle stages. Here we study a large-scale predator-prey interaction where Norwegian spring-spawning herring feeds on the copepod *Calanus finmarchicus* – both species with extensive seasonal migrations. Norwegian spring-spawning herring increase their body condition considerably during a few weeks in early summer. We explore three hypotheses on this rapid fattening of herring using data on seasonal prey (*C. finmarchicus*) availability, herring body condition, and a model of daily ingestion rate as a function of seasonal solar irradiance and prey abundance. *C. finmarchicus* has an annual life cycle and spends winter in diapause at great depth. During spring and summer, there are two generations of *C. finmarchicus*: first the ascending and reproducing overwintering generation G0; then the developing generation G1. The data give some support to the hypothesis that Norwegian spring-spawning herring time its feeding migration to the presence of G0, but less support for matching the presence of large lipid rich G1 individuals. The foraging model, on the other hand, suggest that light-related constraints on foraging efficiency are as important as prey abundances in determining seasonal patterns of herring body condition. We suggest that Norwegian spring-spawning herring may not be critically dependent on a match with peak abundances of its main prey because longer days and increased irradiance as the season progresses ensure high food intake even at relatively low prey densities. Therefore, the *Calanus*-herring interaction in the Norwegian Sea does not seem particularly vulnerable to phenology changes of *Calanus*. Changes in water clarity may however lead to markedly changed foraging conditions for pelagic fish such as herring. Physical constraints on foraging are important to consider when evaluating the potential for trophic cascades and robustness of ecosystems to climate change.

Pacific herring off Oregon/Washington USA: fluctuations in abundance relative to ocean conditions and their importance to salmon marine survival.

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Pacific herring (*Clupea pallasii*) are a valuable prey resource for many species of marine mammals, birds, and fishes off the US west coast. While often relatively abundant, the population of Pacific herring off Oregon/Washington supports only a limited commercial fishery. We have been tracking the abundance of Pacific herring and other forage fishes off Oregon/Washington since 1998 by systematic trawling surveys. These data indicate that the recruitment, and thus abundance, of Pacific herring is linked to oceanographic conditions, particularly ocean temperatures and the abundance of cold-water copepods. This research also indicates that Pacific herring may play a critical role in salmon population dynamics. Zero-age Pacific herring are prey for juvenile salmon during their first summer. Furthermore, juvenile and adult Pacific herring may reduce juvenile salmon mortality by acting as alternative prey (instead of juvenile salmon) for large piscivores. As these Pacific herring are at the southern range of their distribution, future climate change may alter ocean environmental conditions enough where they hinder successful Pacific herring recruitment. Reduced herring abundance has the potential to adversely affect Northwest salmon populations and other living marine resources.

Bayesian networks between herring and zooplankton in the Irish Sea

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Bayesian network inference algorithms provide a robust framework to help understand changes within zooplankton communities, and the consequences of these changes for commercial fish stocks. Here we employ a Bayesian approach to better model the trophic links between secondary zooplankton production and herring stocks in the Irish Sea. Particular attention is paid to the dietary preferences of herring and historical variations in zooplankton abundance (as detected by continuous plankton recorder surveys.)We grouped the zooplankton into 5 groups corresponding to herring feeding preference, and compared the Bayesian networks for 1971-85 and 1985-2000. There were three changes of interaction between the plankton species. Using naïve Bayes Classifiers we found that herring stocks changed from being correlated to copepod abundance and decapod larvae, to being correlated with fish larvae and other zooplankton species, suggesting a change in herring food preference. The overarching goal is reconstructing changes in herring abundance during the period of marked decline throughout the 1970s and 80s. These findings will also be considered in a broader ecological context of top-down control of herring populations and the potential threats posed by expansive jellyfish aggregations.

Predation by cod on herring

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Herring form major pelagic fish stocks in boreal and sub-arctic ecosystems where cod is a major piscivore. Predation mortality from cod on herring and the role of herring as a food source for cod are important aspects of food-web structure in these ecosystems. This study investigates the predator-prey interaction between cod and herring in areas adjacent to Norway. The zero-hypothesis is that cod preying on herring prey have the same prey size-selection and functional response as for other prey than herring. Predation by cod on a large size range of herring was also assessed with regard to predation intensity, -mortality and consumption by cod. Data from large herring larvae (38-40 mm in length), juvenile herring of age 0 and 1 (40-250 mm) from Norwegian coastal areas, and large mature herring (250-380 mm) from the over wintering area of the Norwegian Spring spawning herring in northern Norway are analysed. The new results on the cod-herring predatory interaction were compared with results from other ecosystems, and the role of herring-cod interaction for food-web dynamics was assessed.

Distribution and feeding ecology of 0-group herring in the Barents Sea in 2002-2006

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0-group herring was studied in 2002-2006. Abundance indices of the 0-group herring in the study period were maximal in 2004 and minimal in 2005. In 2002, 2004 and 2006 an intensive drift of the 0-group herring was observed in the northern Barents Sea, to the east of the Bear Island, while in 2002, 2005 and 2006 they were spread to the east of the Barents Sea. Plankton biomass in August-September 2002 and 2006 in the upper 50-m layer varied from 2 to 1050 mg. $\cdot m^{-3}$, and on average was 94 and 113 mg $\cdot m^{-3}$, respectively. *Calanus finmarchicus, Oithona similis* and *Temora longicornis* dominated the plankton community in terms of number and biomass. Diet of the 0-group herring was found to consist of 30 food organisms of 10 phyla. Feeding intensity of the 0-group herring fluctuated by years and was the highest in 2006 and the lowest in 2003. Different copepods, larval and adult euphausiids were the main prey consumed. Stomach fullness indices of the 0-group herring were estimated to be high mostly in areas of their low abundance, with no food competition between individuals.

Variability in the winter diet of juvenile herring 0-age in four lochs on the west of Scotland

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Herring juveniles (*Clupea harengus* L.) were collected during four surveys of selected Scottish west coast sea lochs (Carron, Duich, Hourn and Nevis), in November 2003, January 2004, November 2004 and January/February 2005. Stomachs of 470 fish (8-20 cm total length) were analysed. The dominant prey categories were euphausiids, calanoid copepods, decapod larvae, appendicularians and fish larvae. Several feeding indices analysed (FI%, FIw%, H', IRI%, Cn% and Cw%) showed significant variations between different cruises and lochs. At a similarity level of 40%, diet analysis showed four groups, with significant differences in the IRI% (combined index) between January 2004 and November 2004, and Lochs Nevis and Carron. The Shannon-Wiener diversity index (H') of the diets and the indices of numerical (Cn%) and weight importance (Cw%) in the stomachs also showed significant differences between cruises, lochs and depths. Euphausiids were important prey, although their abundance in the diet varied significantly between cruises and depths. In deeper water their abundance in the stomachs increased and dietary diversity decreased. Appendicularians were most abundant in the diet in Loch Duich in November 2004. Analysis of dietary selectivity in January/February 2005 in relation to field abundance of prey, showed that herring selected larger and more energy rich prey, such as euphausiids, when these were abundant in the water column.

Interactions between herring and predators during winter in Prince William Sound, Alaska

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The Pacific herring population in Prince William Sound collapsed following the *Exxon Valdez* oil spill in 1989 and has not recovered. Predation is believed to be a factor inhibiting recovery. An extensive research program on predator impacts began in 2000, initially driven by concerns over the effect of the reduced herring abundance on an endangered Steller sea lion population. The effort includes acoustic surveys of herring and their fish predators and aerial, visual and infrared surveys of marine mammals and seabirds. Strong associations were observed between herring and both Steller sea lions and seabirds on several spatial scales. Steller sea lions predate on herring primarily at night and often in large groups. Larger piscivorous seabirds dominate the winter avian community and display strong spatial correlations with adult herring. Smaller seabirds have strong spatial correlations with juvenile herring, which over-winter in more shallow bays and inlets. Humpback whales and walleye pollock also exhibit heavy predation pressure on the herring. Humpback whales use transmitted sound to echo-locate schools and occasionally form bubble curtains around large schools. Marine mammal and seabird predation was observed throughout the winter, but was most intense on pre-spawning and spawning aggregations. Adult pollock were observed foraging heavily on age-0 herring in sheltered bays and inlets during fall.

An individual based model (IBM) for annual herring migrations in relation to food abundance and oceanographic factors

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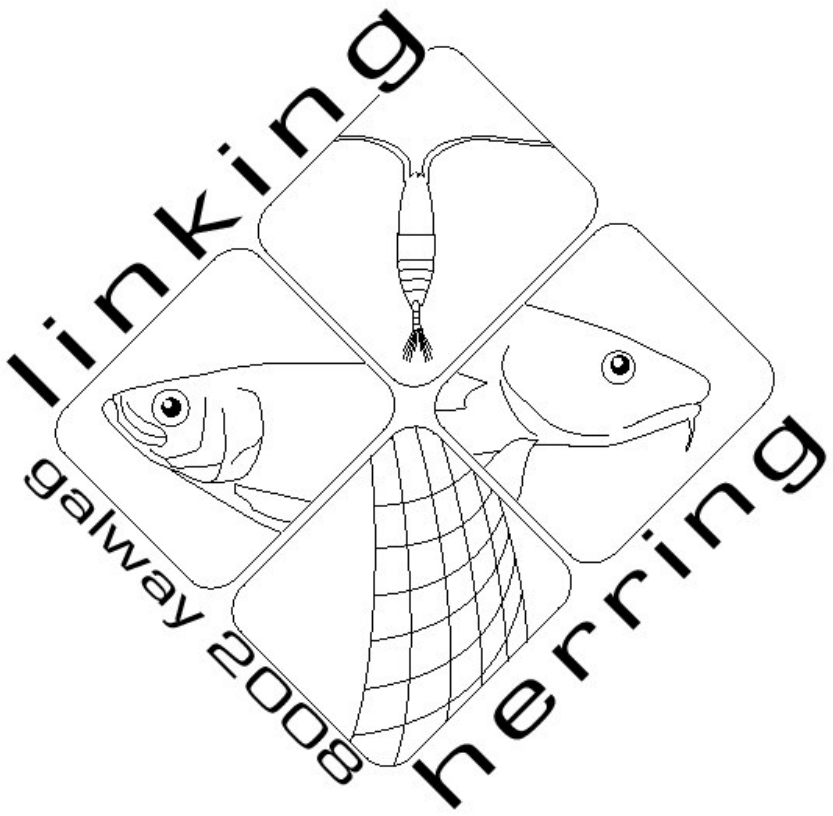
Norwegian-Spring-Spawning (NSS) Herring (*Clupea harengus*) performs annual long distance migrations between spawning, feeding and overwintering areas. There is a lot of knowledge about the general distribution pattern, but several questions remain yet to be answered about the physical and biological factors influencing the migration pattern. An individual based model (IBM) with super-individuals has been developed to study the migration pattern of NSS herring. This model is developed as part of a project addressing interactions between pelagic fish in the Norwegian Sea. Thus, the main focus in the model is the feeding period. The herring migration is assumed to be predictively motivated at a global scale and reactively motivated at a local scale. The herring population is initiated from VPA-data on January 1, and the simulation is run over a year. Currents, bottom topography, water temperature and zooplankton are provided from the NORWECOM biophysical ocean model. Herring growth and prey consumption is estimated by using a bioenergetics model. Here we introduce the model and validate it through a comparison with time series of herring distribution from surveys. We also investigate how different assumptions about model parameters affect the migration pattern. The model performs well in recreating the migration pattern of herring in different years. The results show that the migration model is sensitive to the temperature and zooplankton parameterization.

session 5:
herring in the middle



Poster Presentations

Trophic relations between Atlantic herring juveniles and abundant fishes in the Barents Sea under different climatic conditions

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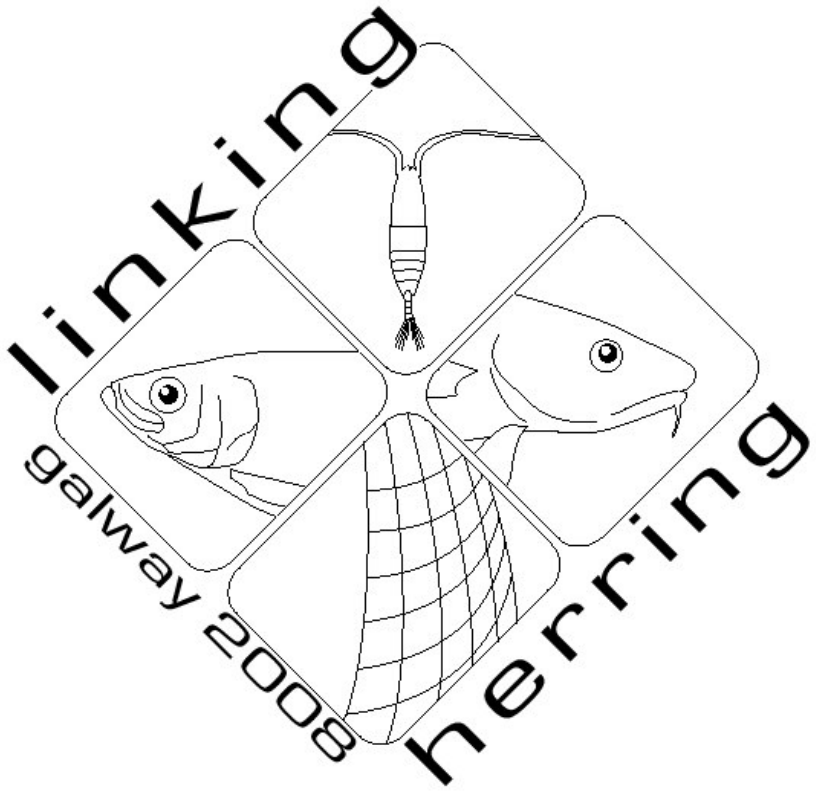
Based on the data on feeding of the most abundant fish of the Barents Sea (cod, haddock, saithe, Greenland halibut and other) during 1984-2007, dynamics of herring availability and its importance in fish diet are analyzed in relation to oceanographic conditions (warm and cold periods), abundance of herring and other food organisms and peculiarities of spatial overlapping herring and its predators. Spatial-temporal, seasonal and long-term variations of cod feeding on herring are described. Size composition of herring from cod and other fish stomach is considered. Annual consumption of different age groups of herring by cod is calculated.

session 6:

managing change



Oral Presentations

Managing Change

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Many herring stocks are now managed with harvest control rules. These rules are often rigorously tested through simulation prior to their instigation. However as with most simulations, the assumptions made are crucial to determining the projected population dynamics. It is often assumed that the past gives us insight into the dynamics of the future. This is often not the case. North Sea herring is a prime example; both the fisheries and recruitment dynamics have changed in ways that were not predicted. The fisheries changed in response to management measures and recruitment changed, in response to changes in the environment. Can the scientists that provide the fisheries advice ensure that their advice remains robust despite the changes in the productivity of systems, or the potential changes in fisheries in response to that advice? And how can the interaction between science, stakeholders and managers be shaped in such a way that it is effective in achieving long-term sustainable fisheries?

Lumpers or splitters? Evaluating recovery and management plans for metapopulations of herring

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A key concept in fisheries science and management is that of the stock, which implies that a particular stock is isolated from other stocks of the same species, is self-sustaining and that catches can be recorded and regulated by stock. The concept of a stock or population is also central to the fields of ecology, evolutionary biology and conservation. However the lack of a common objective definition of a stock (rather than qualitative descriptions such as "a group of organisms of the same species occupying a particular space at a particular time") means that management advice based upon total allowable catches and temporal and spatial management regulations may have ecological and evolutionary impacts. We evaluate long-term management and recovery plans of metapopulations through simulations for a case study based upon herring to the west of the British Isles. These stocks are currently assessed and managed by management area, although there is evidence of much mixing between stocks (in terms of connectivity, migrations and exploitation). The simulations test the sustainability of fishing on the west coast of the British Isles under two hypotheses corresponding to either discrete stocks or mixing between stocks, and where the assessment process assumes either discrete stocks or one metapopulation.

Population structure and migration of Irish Sea herring: implications for assessment

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The Irish Sea herring stock has traditionally been assessed using integrated catch analysis (ICA), a separable VPA model. An annual acoustic survey, timed to coincide with the spawning period, is used to tune this model. The fishery operates during the spawning season, with the majority of landings arising from one operational unit. The activity of the fishery is influenced by a spawning closure along the east coast of the Isle of Man from 21st September- 15th November. The closure was put in place to prevent excessive fishing mortality during spawning. Analysis of catch at age data reveals inter-annual variation in the proportion catch at age. This effect is shown to be significantly associated with the age 2 year classes, the most abundant in numbers at age in the stock. In addition results from the acoustic survey time-series show an annually oscillating pattern of herring biomass distribution. This apparent shift in herring biomass between the eastern and western coasts surrounding the Isle of Man is thought to be associated with the timing of migration to the spawning grounds. The implications for the assessment of this stock are discussed.

An ecosystem model of Prince William Sound herring: A management and restoration tool

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The main goal of this project is to produce a spatially-explicit, life-stage compartmentalized, and ecosystem-based herring model that will provide reliable guidance to both future fishery management and ecological invention for the Prince William Sound (PWS) herring population. The data feeding model equations and model simulations will be fully housed in a dynamic, web-based GIS (called EASy) that we have developed specifically for marine applications. The model is used to test hypotheses regarding the lack of recovery of the PWS herring population with a central hypothesis that the population is currently in a low-density, stable state trapped by trophic structure. Sub-hypotheses explaining the low-density state include lingering effects of EVOS (community structure changes), climate change affecting food resources, disease, a predation trap, and a rupture in the integrity of the spatial stock structure and these factors are represented within the model. Models representing the disease and predator trap as well as the spatial stock integrity will be described in addition to empirical evidence and data suggesting the existence and effects of these regulating factors. Model development requires the construction of the life-cycle model, compilation of a database used to tune and test the model, and development and maintenance of the GIS system housing the model and database. The currency of the model is abundance, individual weight so the life cycle model includes survival/mortality sub-models as well as a bioenergetics model driving growth. Sub-models for foraging, predation, and disease will be described. Spatial explicitness is achieved by developing a life cycle for local regions within PWS and allowing the populations within those regions to communicate with one another. Public access is important to the project and will be achieved by making the model application web-based.

Towards a management plan for Celtic Sea herring

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Herring in ICES Divisions VIIaS, VIIg and VIIj are assessed together and managed by means of a combined TAC for the so-called Celtic Sea stock. The stock is only exploited by Ireland, and the fishery is managed in conjunction with a local stakeholders' advisory committee. SSB has declined since the late 1990s and is now considered by ICES to be below B_{pa} and possibly below B_{lim}. In 2007, ICES advised that fishing should not proceed unless accompanied by a rebuilding plan. This paper presents a scientific approach to the development of a rebuilding plan, and the development of plan to manage the stock in the longer-term. This work straddles the boundary between traditional advisory process and a necessarily more adaptive approach. Best approaches, based on the existing knowledge base, are presented.

Managing herring under uncertainty: What are the benefits of stock information?

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Fisheries managers make decisions based on stock abundance estimates subject to process-, observation- and model uncertainties, and considerable effort is invested in gathering information about stock size. However, only a few studies have evaluated benefits in terms of productivity and continuity of harvesting from collecting such information. In this study, we develop an age-structured population model resembling Norwegian spring-spawning herring (NSSH, *Clupea harengus* L.), containing 16 age-classes and a density-dependent and stochastic recruitment function. We then evaluate how uncertainties in population estimates influence annual yield, spawning stock biomass and variation in annual harvest, using proportional threshold harvesting and the current harvest control rule for NSSH as harvesting strategies. We also investigate the effect of variation in recruitment, natural mortality rates and gear selectivity (when fish become vulnerable to fishing). Results show that the value of information is quite sensitive to the harvest strategy employed. If the harvest strategy is appropriate, the benefits of information are low, and less information about the stock is necessary. The NSSH harvest control rule demonstrates a remarkable stability, under which increased stock information has very little effect on yield and spawning stock biomass. Decreased uncertainty will in general decrease year-to-year variation in harvest and the frequency of fishing moratoria. Also, the value of information for decreasing variation in annual harvest is reduced under high recruitment variability, as variability in harvest is large even with perfect stock information.

Oscillating reproductive strategies of Atlantic herring in response to changing environmental conditions.

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Herring are broadly distributed on the western Atlantic from Cape Hatteras to Greenland, but reproductive activity is restricted to the central portion of the distribution from Cape Cod to northern Newfoundland. The temporal distribution of spawning within this range extends from early spring ice-out to late fall. Two spawning groups, characterized by the timing of metamorphosis to juveniles are recognized, spring and fall spawners. Inter-stock latitudinal variation in the proportion of spring and fall spawners is also common and a function of fishing mortality and environmental variability. At the southern extreme spawning occurs almost exclusively in the fall while in the north it is primarily spring. Mid-range, both spawning groups can be observed with spawning occurring throughout the entire season. Evidence suggests that the reproductive success oscillates between spawning groups and is reflected in recruitment variability. We postulate that the temporal dominance of one spawning group over another is an adaptive reproductive strategy responding to changing environmental conditions, and is analogous to the latitudinal difference. In most years environmental conditions are more favorable to one group or the other. Dominant or strong year-classes can occur for one or both spawning groups in the same or adjacent years when conditions are right. At the distributional extremes, stocks are restricted to a single spawning group where broad scale environmental changes can introduce large inter-annual variability and limit the reproductive success and recovery potential of a stock. The reliance of a stock on a single spawning group near the limits of distribution may account for longer than expected times to recover to target levels.

Baltic herring stocks - winners and losers of ecosystem change due to climate and over fishing

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Herring (*Clupea harengus*) is an essential component of the Baltic ecosystem being typically a food item for the top-predator cod (*Gadus morhua*), exerting a strong predation pressure on zooplankton populations and being a competitor with sprat (*Sprattus sprattus*), the other major clupeid in the system. The Baltic Sea hosts a number of different herring populations with a considerable economic importance for the bordering countries. These populations inhabit local ecosystems with different abiotic and biotic conditions. Consequently these herring populations show different trajectories of population abundance, a result of variable patterns in growth and recruitment, but also in exploitation patterns. Recently major reorganizations of the Baltic ecosystem involving regime shifts and tropic cascades have been shown. These changes in ecosystem structure have been caused by climate-induced changes in hydrography and unsustainable fishing pressure. They resulted in a decrease of cod, an increase of sprat and reductions in zooplankton populations. Here we investigate changes in growth and recruitment of the different Baltic Sea herring populations in relation to the observed ecosystem changes. We show that generally populations inhabiting the shallow Gulfs and not suffering from competition with the large sprat stock show positive trends in recruitment, but density-dependent growth reductions. Growth and recruitment of the open-sea herring stock in contrast declined in parallel due to food-limitation and competition with sprat. Our results demonstrate the various direct and indirect effects climate and fishing exerts on local herring populations.

Objectives and harvest control rules in the management of the fishery of Norwegian spring-spawning herring

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The main element in the management of the Norwegian spring-spawning herring is to conduct the fishery on the basis of a maximum fishing mortality of 0.125, a measure that has been implemented in a formal harvest control rule decided by the Coastal States. The robustness of this rule has, however, not been rigorously tested through simulations, which is the goal of the present paper. Several different recruitment relations are estimated on historic replicates of the stock as calculated by the assessment model for herring, SeaStar. During prognostic simulations a recruitment model is selected probabilistically for each historic replicate on the basis of Akaike weights. In addition to the assessment made by ICES alternative assessment settings are used in order to investigate the sensitivity of the harvest control rule to a range of plausible assessments. The paper discusses if the management objectives are met by applying the present harvest control rule, and explores alternative harvest control rules that may give better long-term stability of catches.

Temporal changes in growth, maturation and condition of Atlantic herring, (*Clupea harengus*) and the potential implications for fisheries management in Newfoundland waters.

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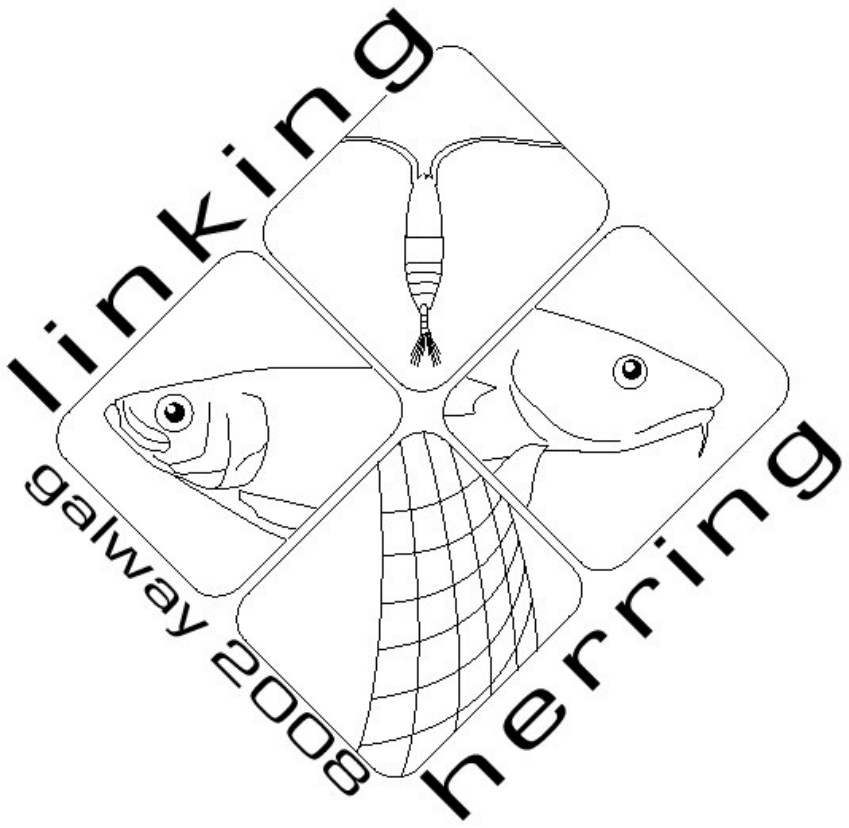
There are five recognized herring stocks in the coastal waters of northeast and southeast Newfoundland. Population sizes declined precipitously through the 1970s. Maturation age and size also decreased substantially, but not until the late 1980s. Maturation declines were similar for males and females and for fish from the northeast and southeast coasts. We investigated whether there is support for changes in maturation being a result of stock declines in the 1970s, environmental changes in the late 1980s, or both. Growth rates and body condition decreased concurrently with changes in maturation. This indicates that declines in maturation age and size were not a compensatory response to reduced density. However, the results indirectly support the hypothesis that these populations have evolved a different maturation trajectory. Current management measures include a minimum allowable fish size of 29 cm in the commercial fishery. When set in the 1970s, this approximated the length at 50% maturity within the stocks. Over the past decade, fishers have encountered increased percentages of under-sized herring in their catches. They contend that if herring growth rates are slower and if herring are maturing at smaller sizes, fishery managers should reduce the minimum allowable size. The merits of this proposal are discussed.

session 6:

managing change



Poster Presentations

Recruitment and spawning stock in spring spawning Norwegian herring.

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The precautionary approach dictates that unless it is scientifically demonstrated that there is no relationship between the parent stock and subsequent recruitment, such a relationship should be assumed to exist, even if the data are ambiguous. Since abundance and biomass of the spring spawning Norwegian herring stock are dominated by only a few outstanding year-classes it was considered of interest to find out an existence and a form of such a relationship. Three forms of Beverton-Holt's model, two forms of Ricker's model, Cushing's and Shepherd's models were used for the analysis of data on spawning stock biomass, population fecundity and abundance of year-classes 3 in the period of 1907-2002. None of the models resulted in satisfactory estimations – deviations of actual figures of year-classes' abundance from the theoretical ones exceeded hundred and thousand percent, which makes these models application for predicting purposes somewhat problematic. An alternative method, which incorporates environmental impact on survival during early life history, was also used to reveal the stock-recruitment relationship existence and the form of it. For a generalized environmental conditions factor a survival index was taken of a year-class, which is a ratio between the year-class abundance at age 3 and the spawning stock biomass or population fecundity. Three types of survival conditions were revealed to be recurrent in different years, i.e. propitious, moderate and unfavorable conditions. Within each of these types dependence of recruitment on spawning stock can be described by means of regression equation with the determination coefficients of 0.756 - 0.959. A comparison was made by means of principal component analysis between survival index fluctuations and North Atlantic Oscillation (NAO) Index, one of the main factors of climatic variations in the North Atlantic. The comparison has shown that propitious survival conditions are associated with positive phase of NAO.

Investigating a possible link between zooplankton changes and recent poor recruitment of herring in the North Sea.

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An unprecedented period of six sequential years of poor production has occurred in the North Sea autumn spawning herring stock since 2002. The failure in herring recruitment is occurring during the larval over-wintering period and has been associated with environmental changes driven by hydroclimatic variability recently observed in the North Sea. Here we compare the interannual variability in herring recruitment with the changes in zooplankton, the prey of herring larvae. Chronological clustering indicates a contemporary change in the herring and plankton time series after 2001, possibly related to changes in sea surface temperature that occurred at the end of the 1990s. Recent changes in plankton composition, biomass and phenology during the seasonal period of herring recruitment are also analysed. The sensitivity of the plankton ecosystem dynamics and biomass to changes in water temperature was explored using a 1D individual based ecosystem model (LERM). The consequent impact on herring is also hypothesized. LERM was designed to make the first-ever ecosystem simulation for predicting fisheries recruitment, a pre-requisite for an ecosystem approach to managing fisheries.

Linking Herring: Symposium Participants, The National University of Ireland, Galway, Ireland. 29th August 2008.

Linking Herring: Conference Venue, The National University of Ireland, Galway.

Linking Herring: Poster Session, Arts Millennium Building NUIG, Galway, Ireland. 29th August 2008.

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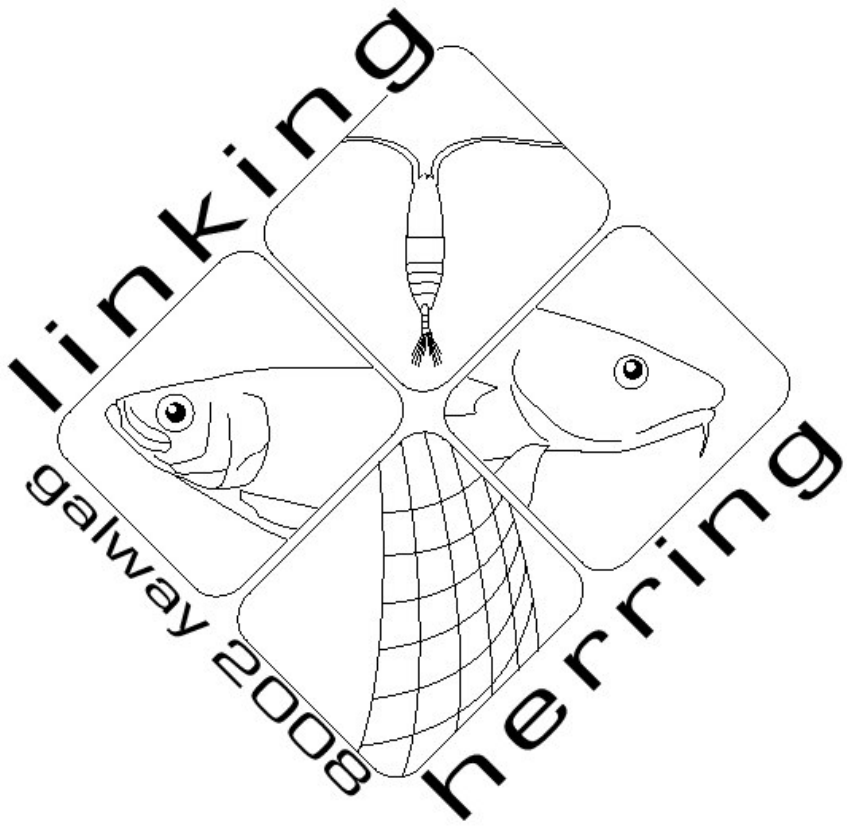

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