JOHAN HJORT SYMPOSIUM

on Recruitment Dynamics and Stock Variability

Bergen, Norway
7-9 October 2014

Programme & Abstracts

Johan Hjort Symposium on Recruitment Dynamics and Stock Variability
Bergen, Norway, 7–9 October 2014

Host:
Institute of Marine Research

Sponsored by:
The Research Council of Norway
ICES

Supported by:
Directorate of Fisheries (Norway)
Bergen Kommune

In cooperation with:
Hotel Scandic Bergen City
Hjort Centre for Marine Ecosystem Dynamics

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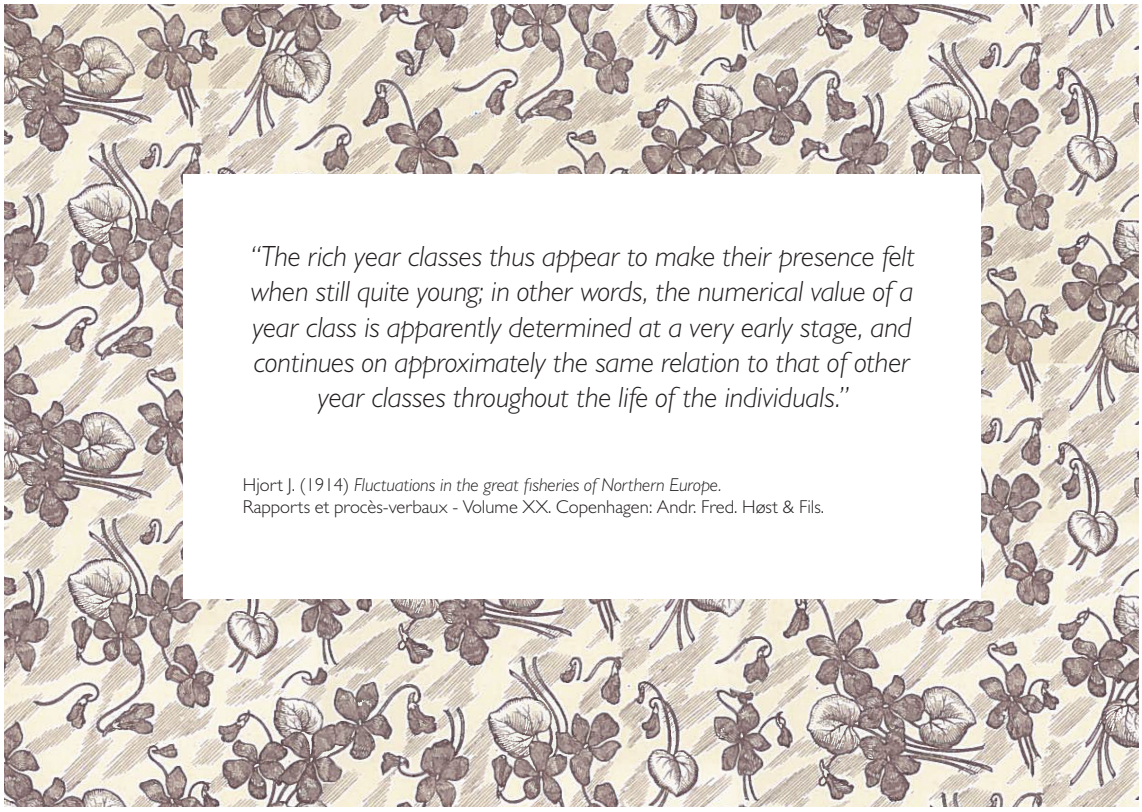


"The rich year classes thus appear to make their presence felt when still quite young; in other words, the numerical value of a year class is apparently determined at a very early stage, and continues on approximately the same relation to that of other year classes throughout the life of the individuals."

Hjort J. (1914) *Fluctuations in the great fisheries of Northern Europe.* Rapports et procès-verbaux - Volume XX. Copenhagen: Andr. Fred. Høst & Fils.

Contents

Welcome address

JOHAN HJORT SYMPOSIUM on Recruitment Dynamics and Stock Variability

In 2014, it will be 100 years since Johan Hjort published his seminal book 'Fluctuations in the Great Fisheries of Northern Europe'. The importance of this volume cannot be overstated, particularly Hjort's new conceptual ideas about the formation of strong year classes based on age determination from fish scales. His view that year-class strength varied over time was in sharp contrast to the prevailing theory that migration was the cause of fluctuations in abundance. In his 1914 volume, Hjort introduced the key concept of a 'critical period' for larvae in relation to availability of prey. Subsequently, he also introduced the concept of variable larval advection as a cause for recruitment variability. In 2014 there have been a number of significant events which honour Johan Hjort's achievements with include Hjort specific sessions in large meetings e.g. The Annual Larval Fish Conference, the publication of a special issue of the ICES Journal of Marine Science (H. Browman (ed.) Fluctuations in the great fisheries of northern Europe – Commemorating 100 years since Hjort's 1914 treatise), and of course this Symposium.

Hjort is widely considered to be the father of fisheries science. In addition to his wide-ranging research interests, Hjort also appreciated the important management and societal implications of fisheries. He served as the first fisheries director in Norway (1906–16), was central in the development of ICES (President 1939–48), and helped to launch joint research activities (e.g., in the North Sea) and extensive cruise programmes (e.g., with the research vessel Michael Sars in the Norwegian Sea). Hjort also collaborated extensively with research institutions abroad. His close co-operation with eastern Canada stands out as one clear example.

Hjort (1914) states that 'the object can never be fully attained; new questions will constantly arise, as the knowledge obtained creates the demand for new, and it will always be possible to increase and intensify our comprehension of the vital conditions affecting the organisms in question'. Therefore, in this symposium, we will address the level of knowledge about these vital rates (natural mortality, growth and recruitment) and explore integrated studies including environmental drivers within an ecological framework. In particular, we ask whether modern techniques (such as individual based models and large-scale analytic tools) have made reliable predictions possible.

This Symposium will explore Johan Hjort's legacy through oral and poster presentations given in six theme sessions:

- Spawning dynamics and parental effects
- Early life stages and 'the critical period'
- Spatial aspects and drift
- Natural mortality and growth
- Environmental drivers of fish population dynamics
- Exploratory analyses, uncertainty and predictions

As co-convenors of this Symposium and on behalf of the Scientific Steering Committee (SSC), we welcome you to Bergen, Norway, the city where Johan Hjort undertook much of his seminal work in Fisheries Research, and we wish you an insightful and productive Symposium.

Symposium Co-Convenors: Olav Sigurd Kjesbu, C. Tara Marshall and Svein Sundby
Chair of the SSC: Richard D.M. Nash

General information

Information/Registration desk

The Information and Registration desk will be located in the lobby of Hotel Scandic Bergen City, and will be open at these times:

Monday 1600—1800
Tuesday From 0800

Presentation preview

Technical assistance will be available for the presentation room, and is available for uploading of the presentations. The presentations must be uploaded in due time before the scheduled presentation time, if possible a day before.

Social events schedule

Monday 6 October 2014

Reception
1900–2100 Directorate of Fisheries – Strandgaten 229, Bergen
Refreshments will be served

Tuesday 7 October 2014

Poster session
1700–1930 Hotel Scandic Bergen City

Wednesday 8 October

Conference dinner
1930– Håkonshallen, Bergenhus Festning

Social events and tours

For the weekends 3-5 October and/or 10-12 October:

Those who would like to see more of the city and the surrounding area during the following weekend, we recommend contacting the Bergen Tourist Information, Torget.

Very popular tours we can recommend are:

Norway in a Nutshell
by Fjordtours, http://secure.fjordtours.com/tour/Tour.aspx

Price: From NOK 1145
A daytrip with bus, fast ferry and train into the magnificent Sognefjord, up into the high mountains, returning through valleys and fjords to Bergen. This tour is also going the opposite way, through the valleys into the mountain and down into the Sognefjorden and back to Bergen.

A day in Hardanger
http://www.tidefjordcruise.no/index.cfm?id=342571

Price: From NOK 1239
Tours with coach/fast ferry out of Bergen and into the beautiful Hardanger fjord area, into the mountains if you like, and back to Bergen.

City sighseeing
http://www.tidereiser.com/sightseeingtours

Price: From NOK 200
Guided coach tours within and around the city of Bergen, including to the home of the composer Edvard Grieg.

Museum visits:
Natural, historical or art museums are all available by foot within the city centre

Map of Bergen

Programme

Monday 6 October, 2014
Venue: Scandic Bergen City/Directorate of Fisheries

	1600–1800	Registration	Scandic Bergen City
	1900–2100	Reception	Directorate of Fisheries

Tuesday 7 October, 2014
Venue: Scandic Bergen City

	From 0800	Registration	
	0900–0910	Tore Nepstad, Olav Kjesbu, Norway	Welcome
	0910–0940	Julia Blanchard, UK	Opening Keynote: Fisheries in the face of environmental variation and change
Spawning dynamics and parental effects	***0940–1010***	***Fran Saborido-Rey, Spain***	***Keynote: Fish spawning dynamics***
Chair: Joanne Morgan, Canada	1010–1025	Höffle H., *et al.*	Do eggs collected in egg surveys accurately reflect adult fecundities?
Coffee/tea	*1025–1100*		
	1100–1115	Michalsen, K., *et al.*	Population differentiation of Coastal cod and North East Arctic cod
	1115–1130	Frugård Opdal, A. & Jørgensen, C.	Long-term change in a behavioural trait: changed spawning locations and truncated demography in Northeast Arctic cod
	1130–1145	Lowerre-Barbieri, S.K., *et al.*	Assessing reproductive behavior, an integrative approach applied to red drum, *Sciaenops oscellatus*
	1145–1200	Silva, A.V., *et al.*	Birthdate distribution of sardine *(Sardina pilchardus)* juveniles: environmental and parental effects on survival
	1200–1215	Mikkelsen, N., *et al.*	Spawning dynamics of the Balsfjord herring, an outpost of Pacific herring in the Atlantic
Lunch	*1215–1315*		

Early life stages and 'the critical period'	***1315–1345***	***Myron Peck, Germany***	***Keynote: Parallel advances in recruitment theory and the ecophysiology of marine fish early life stages***
Chair: Øyvind Fiksen, Norway	1345–1400	Neuheimer, A.B., *et al.*	Atlantic cod and bloom phenology: Exploring "critical period" adaptation across a species' range.
	1400–1415	Ottersen, G., *et al.*	Standing on the shoulders of Hjort - or in his shadow?
	1415-1430	Takahashi, M., *et al.*	Interannual variations in growth rates during larval stage of jack mackerel *Trachurus japonicus* in the East China Sea: Implications for juvenile survival in the demersal habitats
Coffe/tea	*1430–1500*		
	1500–1515	Chimura, M., *et al.*	Factors determining the recruitment of walleye pollock *Gadus chalcogrammus* in the Sea of Japan off Hokkaido Island, Japan
	1515–1530	Robert, D., *et al.*	A multi-species analysis of variability in the link between feeding success and growth during the larval stage of fish: implications for the existence of a critical period
	1530–1545	Durant, J.M., *et al.*	Match-mismatch and climate warming, what can we expect?
	1545–1600	Geist, S., *et al.*	Distribution and condition of coastal pelagics larvae in relation to environmental conditions in the northern Benguela Current
	1600–1615	Folkvord, A., *et al.*	Impact of hatch-date on early life growth and survival of Mueller's pearlside *(Maurolicus muelleri)* larvae
	1615–1645	General discussion, both sessions	
Poster Session	1700–1730	2 minute poster presentations	
	1730–1930	Viewing posters	

Wednesday 8 October, 2014
Venue: Scandic Bergen City

Spatial aspects and drift	***0900–0930***	***Geir Huse, Norway***	***Keynote: Closing the loop: Full life cycle models for pelagic fish stocks.***
Chair: Pierre Petitgas, France	0930–0945	Hart, P., *et al.*	Exploring decision rules of a migrating exploited population of edible crab using an individual based model
	0945–1000	Sundby, S.	The principles of vertical distribution of fish eggs in the world oceans
	1000-1015	Lacroix, G., *et al.*	Impact of climate change on larval recruitment of sole in the North Sea
Coffe/tea	*1015–1045*		
	1045–1100	Frugård Opdal, A., *et al.*	Long-term stability in modelled zooplankton influx could uphold major fish spawning grounds on the Norwegian continental shelf.
	1100–1115	Langangen, Ø., *et al.*	Spatial variations in mortality in pelagic early life stages of a marine fish *(Gadus morhua)*
	1115–1130	Petitgas, P., *et al.*	Growth-dependent spatial distribution and mortality in the anchovy of the Bay of Biscay
	1130–1145	Slotte, A., *et al.*	Use of otolith microstructure analyses to study the relation between larval hatching time, growth and survival in Norwegian spring spawning herring
	1145–1200	Munk, P.	A century of early life history research – the case of the European eel.
Lunch	*1200–1300*		
Natural mortality and growth	***1300–1330***	***Pierre Pepin, Canada***	***Keynote: How can understandingvariations in egg and larval vital rates enhance our capacity to forecast recruitment variability? Revisiting Hjort's thesis to determine if we have done what was needed.***
Chair: Richard D.M. Nash, Norway	1330–1345	Bogstad, B., *et al.*	The early life-history dynamics of Northeast Arctic cod: levels of natural mortality and abundance during the first three years of life
	1345–1400	Akimova, A., *et al.*	The survival of early life-stages of Atlantic cod (*Gadus morhua*) in the North Sea and the role of changes in predation pressure
	1400–1415	Shoji, J. *et al.*	Daytime predation refuge for juveniles or nighttime foraging ground for predators? Two contribution pathways of seagrass beds to production of coastal fishery resources in the western North Pacific
Coffe/tea	*1415–1445*		
	1445–1500	Uriarte, A., *et al.*	Assessing natural mortality of anchovy from surveys' population and biomass estimates

	1500–1515	Shelton, P.A. & Morgan, M.J.	Regulation of fluctuating fish stocks – examples of two kinds of compensation in six depleted groundfish stocks from the Northwest Atlantic
	1515–1530	Folkvord, A., *et al.*	Strong Norwegian spring spawning herring year classes after 1904 - how have they affected growth of subsequent year classes?
	1530-1535	Fouzai, N., *et al.*	More predators but lower predation: Effective predator avoidance in a behavioural model for larval cod
	1535-1540	Schismenou, E., *et al.*	Environmental effects on anchovy *(Engraulis encrasicolus)* and sardine *(Sardina pilchardus)* early growth in the North Aegean Sea (eastern Mediterranean)
	1540-1545	Johannesen, E., *et al.*	Consumption and growth in a seasonally varying environment
	1545-1550	Johannessen, T.	Proposal of a general solution to the recruitment puzzle in marine organisms
	1550-1630	General discussion, both sessions	

Conference dinner
Venue: Håkonshallen, Bergenhus Festning (Håkon's Hall, The King's banqueting hall) 1930–23:00
Hjort dinner Speaker: Michael Sinclair - Hjort, the man

Thursday 9 October, 2014
Venue: Scandic Bergen City

Environmental drivers - fluctuations and change	***0900–0930***	***William Cheung, Canada***	***Keynote: Global vulnerability of fish recruitment to climate change: insights from Hjort's legacy***
Chair: Coleen Moloney, South Africa	0930–0945	Holt, R.E. & Jørgensen, C.	Local Adaptation of Behaviour and Life History across North Atlantic Cod Stocks – A Model for Current and Future Climates
	0945–1000	Drinkwater, K., *et al.*	Cod and climate changes: Performance of previous projections
	1000–1015	Skern-Mauritzen, M., *et al.*	Do modeled zooplankton abundances increase the hindcast and prediction strength of fish recruitment models?
Coffe/tea	*1015–1045*		
	1045–1100	Landa, C.S., *et al.*	Climate and abundance affects distribution of a sub-arctic fish stock – a case study on North-east Arctic haddock
	1100–1115	Salvanes, A.G.V., *et al.*	Spatial dynamics of the bearded goby and its key fish predators off Namibia vary with climate and oxygen availability

	1115–1130	Sofia, A. Ferreira, A., *et al.*	How can we distinguish between competing explanations of year class strength?
	1130-1135	Castillo-Jordán, C., *et al.*	Co-incident recruitment patterns of southern hemisphere fisheries
	1135-1140	Campanella, F., *et al.*	Modeling habitat selection of European anchovy *(Engraulis encrasicolus)* at different life stages in a highly productive ecosystem (Adriatic Sea)
	1140-1145	Twatwa N.M.	Temporal and spatial variability in environmental controls of three small pelagic species in the southern Benguela
	1145-1150	Malta, T., *et al.*	Long term variations in the population dynamics of Iberian sardine (Sardina pilchardus) and its relation to environmental conditions and exploitation history
	1150-1200	Plenary discussion	
Lunch	*1200–1300*		
Exploratory analyses, uncertainty and predictions	***1300–1330***	***Cóilín Minto, Ireland***	***Keynote: Can we and should we reunite recruitment and stock assessment science?***
Chair: Mark Dickey-Collas, Denmark	1330–1345	Subbey, S., *et al.*	A parsimonious approach to modeling temporal scales and patterns of fish population variability
	1345–1400	Skagen, D.	Identifying and explaining time trends in recruitment
	1400–1415	Howell, D., *et al.*	Unquantifiable uncertainty in projecting stock response to climate
Coffe/tea	*1415–1445*		
	1445–1500	Frank A., *et al.*	Correlations, causalities, and the prediction of fisheries time series
	1500–1515	Dankel, D.J., *et al.*	Propagation of uncertainties in fisheries science for advice: the case for confidence interval harvest control rules (CI-HCRs)
	1515–1530	Cadigan, N.	Modelling the uncertain stock dynamics and noisy catch and survey data for northern cod, with emphasis on short-term projections for catch advice
	1530–1615	General discussion, both sessions	
	1615–1645	Brian Rothschild, USA	Summing-up
	1645–1700	C. Tara Marshall, Scotland	Concluding remarks and closing of Symposium
	1700	Symposium closes	

Invited speakers

Julia Blanchard – Opening keynote
Department of Animal and Plant Sciences
University of Sheffield
United Kingdom

Geir Huse – Keynote
Spatial aspects and drift
Institute of Marine Research
Bergen, Norway

Fran Saborido-Rey – Keynote
Spawning dynamics and parental effects
Instituto de Investigaciones Marinas Vigo
CSIC,
Spain

Pierre Pepin – Keynote
Natural mortality and growth
Northwest Atlantic Fisheries Center, St John
Fisheries & Oceans Canada
Canada

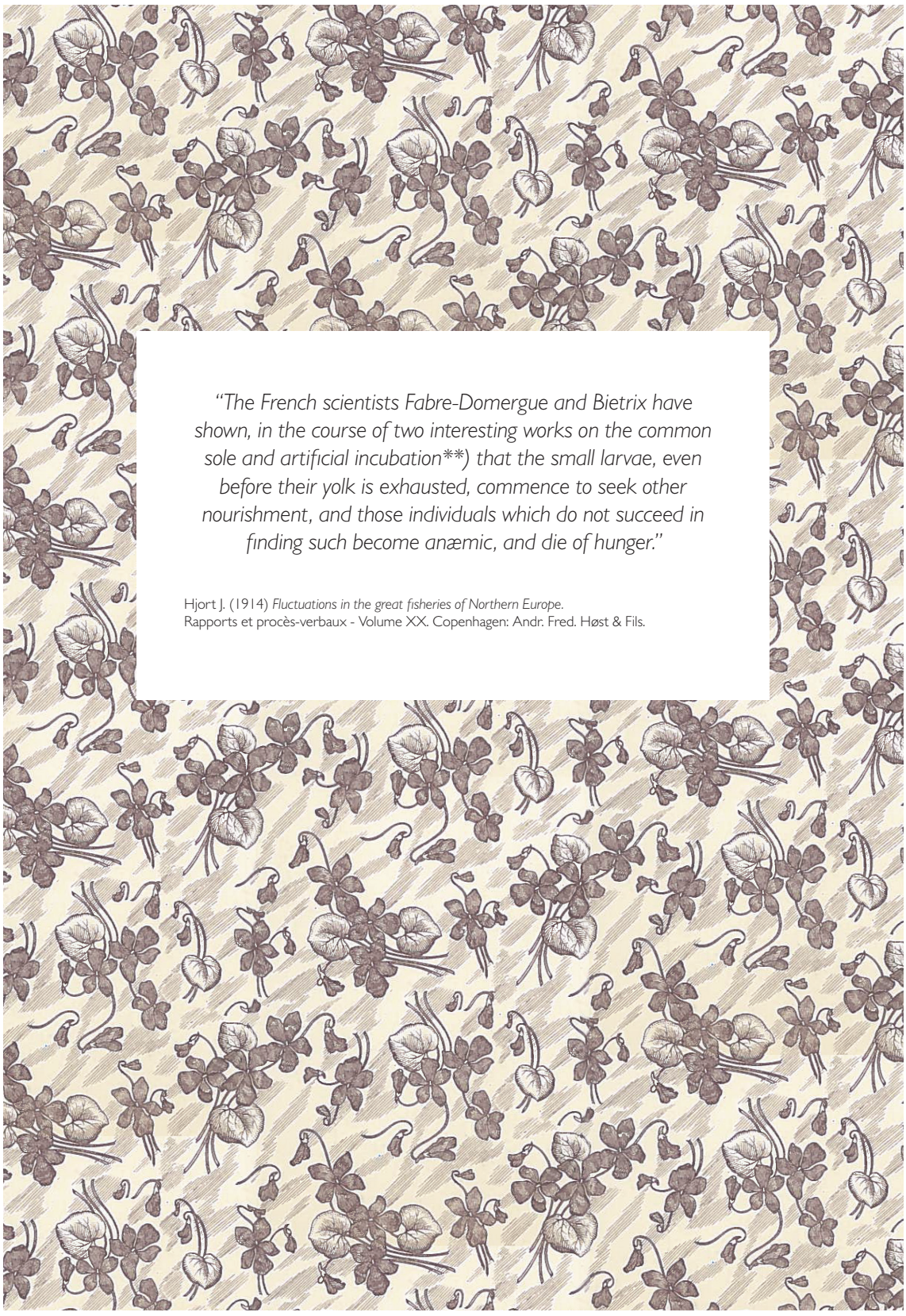
Myron Peck – Keynote
Early life stages and 'the critical period'
Institute of Hydrobiology and Fisheries Science
University of Hamburg
Germany

William W.L. Cheung – Keynote
Environmental drivers - fluctuations and change
Changing Ocean Research Unit, Fisheries Center
University of British Columbia
Canada

Cóilín Minto – Keynote
Exploratory analyses, uncertainty and predictions
Marine and Freshwater Research Centre
Galway Mayo Institute of Technology
Ireland

Brian J. Rothschild
Hjort symposium program summing up
School for Marine Science and Technology
University of Massachusetts, Dartmouth
USA

Michael Sinclair
Hjort dinner Speaker
Bedford Institute of Oceanography
Dartmouth
Canada



*"The French scientists Fabre-Domergue and Bietrix have shown, in the course of two interesting works on the common sole and artificial incubation**) that the small larvae, even before their yolk is exhausted, commence to seek other nourishment, and those individuals which do not succeed in finding such become anæmic, and die of hunger."*

Hjort J. (1914) *Fluctuations in the great fisheries of Northern Europe.* Rapports et procès-verbaux - Volume XX. Copenhagen: Andr. Fred. Høst & Fils.

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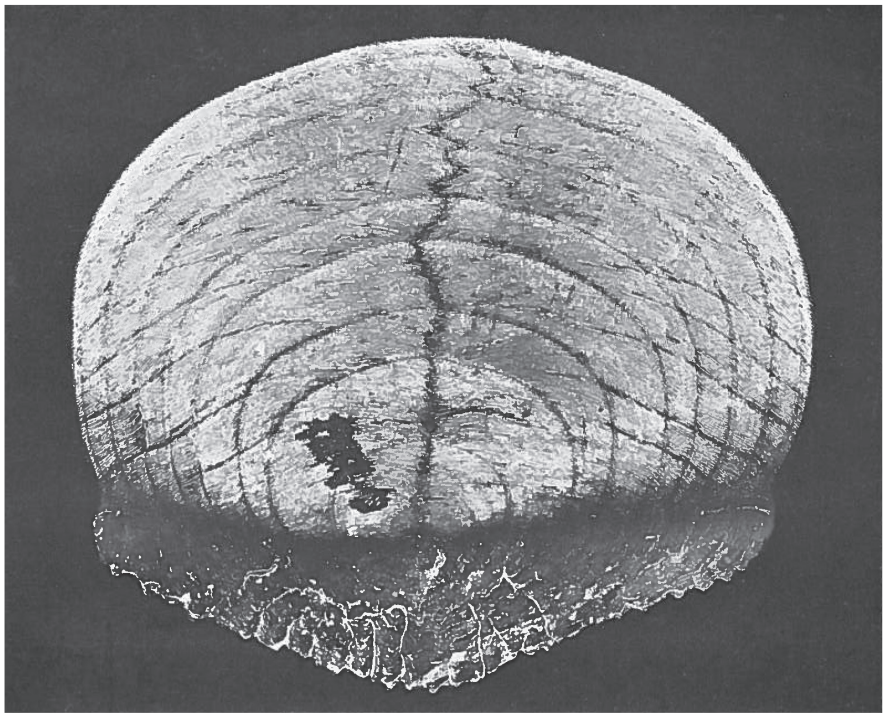

Fig. 9. Herring scale with 8 winter rings inside the edge (LEA phot.).

Hjort J. (1914) *Fluctuations in the great fisheries of Northern Europe.*
Rapports et procès-verbaux - Volume XX. Copenhagen: Andr. Fred. Høst & Fils.

Abstract - Opening keynote

Fisheries in the face of environmental variation and change

Julia Blanchard

The past century has witnessed unprecedented declines in fish stocks and human-induced climate change, although as shown by Hjort, large environmentally driven fluctuations in fish stocks are also the norm for many fisheries. Recent climate change projections for global fisheries have focused on long-term change, due to the limitations of climate models for resolving short-term dynamics. However, for appropriate management responses to be made, climate change impacts should also be interpreted in the context of natural variability. By linking patterns of variation in primary production, fish and fishing fleets, I will discuss the potential for predicting global thresholds for the combined effects of climate and fishing that account for natural variability. Given the large uncertainties associated with current fisheries status in most of the oceans, such global-scale analyses may help to provide a first step towards informing more detailed regional ecosystem studies and adaption strategies under climate change.

Abstracts - Oral presentations

Spawning dynamics and parental effects

Chair: Joanne Morgan, Canada

Keynote: Fish spawning dynamics

Saborido-Rey, F., and Morgan, M.J.

Spawning dynamics is a complex balance that fish parents must address, involving the selection of the spawning habitat, seasonality, duration, frequency, fecundity, and the degree of parental care. This complex of traits determines the reproductive strategies that differ greatly between species and that have been shaped by evolution to optimize ecological niche use. However, this species-specific optimization does not imply lack of plasticity; on the contrary, in fish those traits are highly plastic to accommodate a changing environment, and hence the parents have the adaptive capacity to modify these traits. These are typically size dependent in fishes leading to a trade-off between growth and reproduction, reflected in an energetic dynamic that interacts with the fluctuating environment. Size, age, condition and other parental features influence timing of reproduction, fecundity and spawning habitat in all species analysed. Fisheries, a size-selective pressure, can greatly impact spawning dynamics and in consequence recruitment, population productivity and fisheries sustainability. Management should consider the spawning dynamic as a whole, beyond the simple concepts of spawning ground or spawning season.

Do eggs collected in egg surveys accurately reflect adult fecundities?

Höffle, H., Vikebø, F., and Kjesbu, O.S.

Stock reproductive potential (SRP) of adult females can be estimated by either summing up their potential fecundities or by collating realized fecundity data from egg surveys. Both approaches contain uncertainty, introduced by factors like sampling error, movement, stock size structure and atresia. In the literature, studies on how well SRP derived from total potential or realized fecundities compare are rare. North East Arctic (NEA) cod (*Gadus morhua*) is a regularly surveyed stock, for which time series for spawning stock size, demography and abundance of planktonic eggs on the main spawning grounds around the Lofoten islands date back to the 1980s and partially to the 1970s. Here, we test for the existence of any parallelism between NEA cod SRPs as derived from total potential and realized fecundity estimates. Using an ocean circulation model (ROMS) to back-calculate the origin of late stage eggs, while determining their potential parent fish from the adults' likely migration path and the average swimming speed (0.2 m s-1), we examine what may drive potential deviations between the two SPR estimates.

Population differentiation of Coastal cod and North East Arctic cod

Michalsen, K., Subbey, S., Fernø, A., Nilsson, J., and Johansen, T.

The mechanisms behind the separation of the two cod populations the Norwegian coastal cod (NCC) and the Northeast Arctic cod (NEAC) are not fully understood. Mature cod were tagged with Data Storage Tags on their main spawning grounds outside Lofoten, and the spatial dynamics, environmental factors and genetic structure of individual fish were analysed. A regular migration pattern was observed, characterised by a synchronous ascent towards the surface at dusk, a relatively stable period at up to 14 hours, interrupted by dives to deeper waters and eventually a synchronous descent at dawn. Based on the time and place of the observations and the absence of alternative explanations, the vertical movements are interpreted as reflecting spawning behaviour. Further, a difference in habitat occupation was observed between NEAC and NCC. These patterns are explained by optimal hydrographical conditions for maturation in deep, warmer waters and increased egg dispersal close to the surface, that differed between the two cod stocks, in combination with mate selection during ascents and that this optimum do vary between cod stocks.

Long-term change in a behavioural trait: changed spawning locations and truncated demography in Northeast Arctic cod

Frugård Opdal, A., and Jørgensen, C.

Harvesting by humans may be a potent driver of demographic change and contemporary evolution, which both may have great impacts on animal populations. Research has focused on changes in phenotypic traits that are easily quantifiable and for which time series exist, such as size, age, sex, or gonad size, whereas behaviour has proven more elusive. Here we analyse potential drivers of long-term changes (1866-1969) in a behavioural trait for Northeast Arctic cod, namely spawning location. During this time period, spawning ground distribution has fluctuated with a trend towards more northerly spawning. Spawning location is analysed against a suite of explanatory factors including climate, fishing pressure, density dependence, and demography. We find that demography (age or age at maturation) had the highest explanatory power for variation in spawning location, while climate had a limited effect below statistical significance. Although climate effects may take indirect routes through demography or feeding distribution, we argue that fishing mortality, either through demographic or evolutionary change, has served as an effective driver for changing spawning locations in cod.

Assessing reproductive behavior, an integrative approach applied to red drum, *Sciaenops oscellatus*

Lowerre-Barbieri, S.K., Walters, S., Bickford, J., Murphy, M., Tringali, M., and Winner, B.

Advances in technology and increased efforts at integrative science are changing how we assess productivity in marine fishes. Although reproductive behavior determines the environment eggs first encounter, fertilization rates, entraining oceanographic conditions first encountered, and predator fields, we are only now beginning to have the technology to assess the importance of reproductive behavior on reproductive success. In this study, we used aerial surveys of spawning aggregations, capture-based sampling, telemetry, and genetic analysis to assess spatio-temporal behavior and its potential impact on stock productivity. We hired a purse seine and its crew to capture red drum aggregations during the spawning season in 2012 and 2013 on known spawning grounds off Tampa Bay, Florida. A portion of these fish were selected for surgical implantation of acoustic tags (2012, n=60; 2013, n=40). Aerial surveys monitored nearshore spawning habitat off Tampa Bay, south to its nearest estuarine neighbor, Charlotte Harbor in 2012 and 2013 (n=20 dates, approximately 260 Km per date). Aggregations were categorized as to size and date, time, and location recorded (2012, n=6 aggregations; 2013; n=17 aggregations). No aggregations were sighted off Charlotte Harbor during the 2012 sampling season, possibly due to a red tide occurring at this time as in 2013 aggregations were detected throughout most of the transect area. Biological and genetic samples were taken from 1800 fish in 2012 (3 aggregations) and 3400 fish in 2013 (6 aggregations). Spawning fraction was aggregation-dependent, ranging from 1% to 85% in 2012. Acoustic telemetry indicated that most fish use a home range larger than the area between Tampa Bay and Charlotte Harbor. Fish occurred on the Tampa Bay spawning grounds almost exclusively associated with the spawning season. Spawning site fidelity was high, with 92% of the fish detected in both years returning to the Tampa Bay area during the spawning season.

Birthdate distribution of sardine *(Sardina pilchardus*) juveniles: environmental and parental effects on survival

Silva, A.V., Soares, E., Nunes, C., Oliveira, P.B., Meneses, I., and Silva, A.

Sardine (*Sardina pilchardus*) spawning season in northwest Portugal is long and show a peak during winter months. Birthdate distributions of sardine juveniles sampled between 2007 and 2009 revealed that a high proportion of individuals were born during summer months, especially in 2008. Relationships between birthdate distributions, environmental conditions (sea surface temperature, chlorophyll a, upwelling) and female reproductive activity and condition were investigated using Generalized Additive Models. Growth during larval and early juvenile stages was back-calculated from ring width and compared between seasons and years. Summer born individuals were likely the offspring of bigger and fatter females than winter born individuals of the same cohort and showed faster larval growth associated with higher water temperature and enhanced productivity.

Spawning dynamics of the Balsfjord herring, an outpost of Pacific herring in the Atlantic
Mikkelsen, N., Pedersen, T., and Falk-Petersen, I-B.

The Balsfjord herring stock spawns repeatedly in the intertidal zone in Balsfjord (69oN), northern Norway and show a spawning dynamics that is very different from the adjacent Norwegian spring spawning herring. Herring eggs that were deposited mainly on macroalgae substratum in the upper shore are exposed to air, direct sunlight and fluctuating temperature and experience high mortality. Spawning dynamics of Balsfjord herring was investigated in two surveys in April 2014. Spawning had taken place in the intertidal zone at four locations in the inner part of the fjord. Survey one was conducted by boat using aqua scope and underwater-video and survey two was conducted by walking at low tide. The eggs were adhered to each other and substratum, mainly *Ascophyllum nodusum*, *Fucus vesiculosus* and *Fucus serratus*. No eggs were found at the sea bottom. That the collected eggs were in two different stages of development and gillnet catches during the first survey contained both spent and mature herring, show that spawning had taken place twice with about one month between the two spawning waves.

Early life stages and 'the critical period'

Chair: Øyvind Fiksen, Norway

Keynote: Parallel advances in recruitment theory and the ecophysiology of marine fish early life stages
Peck, M.

Starting with the work of Hjort, I review the development of various recruitment hypotheses highlighting process understanding gained from oceanographic studies conducted on the early life stages of different species in various marine ecosystems. Central to building these hypotheses were advances in our understanding of how physical and biological processes interact to affect growth and mortality and how physiological constraints and the behavioural repertoire change during larval ontogeny. Larvae from the tropics to polar regions display large differences in traits critical to transport dynamics such as the thermal sensitivity and development rate of embryos (reviewed in 58 species within 26 families) and the time required for larvae to deplete yolk reserves (64 spp, 20 families). Foraging dynamics are affected by key traits such as the size at hatch (32 spp, 12 families) and morphological changes during development (45 spp 22 families) with larvae from families in the tropics displaying 5- to 10-fold greater swimming speeds than those from families in either temperate or polar regions (105 spp, 22 families). Differences in metabolic losses (53 spp, 30 families), suggest nearly 7-fold increases in foraging requirements for larvae from 5 and 25°C to offset starvation. Finally, larvae can have much more specific diet requirements than previously thought (57 spp, 20 families). I argue that continuing to advance our understanding of the ecophysiology of early life stages will be needed if we hope to gain a cause-and-effect understanding of how the environment regulates year class success in marine fishes

Atlantic cod and bloom phenology: Exploring "critical period" adaptation across a species' range
Neuheimer, A.B., Payne, M.R., and MacKenzie, B.R.

Atlantic cod (*Gadus morhua*) populations exhibit remarkably similar life histories despite spanning wide ranges in latitude (40 to 80°N) and climate (e.g. -1 to 20°C). In previous work, we demonstrated that temperature-standardized spawning time (i.e. the thermal constant of spawning) shows systematic and parallel declines with increasing latitude for populations on both sides of the Atlantic (Neuheimer & MacKenzie, in press, Ecology). Here we explore these patterns as evidence of adaptation (i.e. countergradient variation) to growing season timing by comparing estimates of first-feeder- and prey-timing proxies for populations across the species' range. We discuss the implications of our results for recruitment (year-class strength) both past and in the future via match-mismatch hypotheses in spring-bloom systems and beyond (e.g. autumn spawners).

Standing on the shoulders of Hjort - or in his shadow?

Ottersen, G., Bogstad, B., Yaragina, N., Stige, L.C., Vikebø, F., and Dalpadado, P.

This talk is inspired by a review we recently made on the early life population dynamics of the Barents Sea cod stock, and E.D. Houde's stimulating 2008 paper Emerging from Hjort's shadow (J. Northw. Atl. Fish. Sci 41: 53–70). I here evaluate the main results and hypotheses put forth by Hjort a hundred years ago in light of present knowledge, exemplifying from BS cod research. There is little doubt that not only scientific quality, but Hjort's strong personality and his role in building fisheries science in Norway and ICES helped the propagation of his thoughts. Still, although some of the ideas may seem rather simplistic today, they did lay an important part of the foundation for fisheries oceanography. The year-class paradigm and the importance of recruitment for fluctuations in stock abundance remains fundamental to research and management. The critical period hypothesis was too narrow, disregarding, e.g., density-dependence in the juvenile stage, but developed to the match-mismatch hypothesis (Cushing). The (aberrant) drift hypothesis inspired the migration triangle (Harden-Jones) and member-vagrant hypotheses (Iles & Sinclair).

Interannual variations in growth rates during larval stage of jack mackerel *Trachurus japonicus* in the East China Sea: Implications for juvenile survival in the demersal habitats

Takahashi, M., Sassa, C., Nishiuchi, K., and Tsukamoto, Y.

Early-stage juveniles of jack mackerel *Trachurus japonicus* changes their habitats from surface to demersal layers in the shelf break regions of the East China Sea (ECS). Abundances of juveniles in the near-bottom layer have been used as an indicator of recruitment in the stock assessment. We examined interannual variations in somatic growth rates during early and late larval stages of *T. japonicus* in relation to environmental conditions in the surface layer in April 2005 – 2010. Annual mean growth rates during the late larval stage ranged from 0.52 to 0.57 mm d-1 positively correlated with concentrations of Paracalanidae copepodites as a main food item for larval *T. japonicus* but not with ambient temperature. The juvenile abundance in the near-bottom layer was represented better by growth rates during the late larval stage than did by those during the early larval stage. These results suggest that accelerated growth rates during the late larval stage due to preferable food conditions enhance successful survival during changing habitats from surface to demersal layers for *T. japonicus* in the ECS.

Factors determining the recruitment of walleye pollock *Gadus chalcogrammus* in the Sea of Japan off Hokkaido Island, Japan

Chimura, M., Tanaka, H., Yamashita, Y., and Honda, S.

For the walleye pollock stock distributing in the Sea of Japan off Hokkaido, the recruitment, defined as the number of age-2 fish, is determined mainly by the abundance of age-0 pelagic juveniles in recent years. While the variations in the annual egg production were relatively small, the age-0 juvenile abundance varied significantly from year to year during 2006-2013. The juveniles of high-abundance year class mainly had hatched in a short period, from late February to middle March, and originated from eggs spawned in February. On the other hand, the juveniles of low- and middle-abundance year class had hatched over a long period, from January to March, and most of them originated from eggs spawned in January. The late-hatched juveniles grew faster than the early-hatched ones, which might be advantageous to the larval survival. Therefore, the production of eggs in February and subsequent early survival would be important factors determining the recruitment of this pollock stock.

A multi-species analysis of variability in the link between feeding success and growth during the larval stage of fish: implications for the existence of a critical period

Robert, D., Pepin, P., Bouchard, C., Dower, J.F., Falardeau, M., Fortier, L., Jenkins, G.P., Levesque, K., Llopiz, J.K., Meekan, M.G., Murphy, H.M., Ringuette, M., Sirois, P., and Sponaugle, S.

Variations in larval fish growth rates are the result of the feeding environment experienced by each individual. Here we investigated the relationships between average growth, feeding and variability in individual growth rates across a range of taxa based through a synthesis of studies in which stomach content and otolith growth

were measured in the same individuals. Instantaneous measures of feeding success were highly variable and demonstrated a positive yet somewhat limited association with growth rates across all taxa. The strength of the feeding-growth relationships among taxa, and cohorts within taxa, was reflected in the autocorrelation of individual growth rates, suggesting that stable growth is achieved through consistent feeding success. While a positive correlation was found between feeding success and growth in all taxa, supporting the growth-survival paradigm during the larval stage of fish, the much stronger association between these vital rates, and the higher growth serial correlation in fast growing species indicates that the potential for an early 'critical period' regulating survival could vary among species and reach a maximum in fast-growing fish.

Match-mismatch and climate warming, what can we expect?

Durant, J.M., and Ottersen, G.

In the context of global ecosystem changes driven by long-term modification of environmental conditions, we expect climate change to lead to a decoupling of the food web. Here we explore effects of climate change on temporal dynamics of pelagic fish populations. We hypothesize that recruitment success depends on the degree of temporal overlap with prey and explore how the dynamics might change in a warmer climate. To do so, we explore the effect of climate change on two synthetic built pelagic fish populations based on published relationships between environment and abundance and phenologies; one in an Arcto-boreal biome and the other in a temperate biome. Recruitment is assumed to be controlled bottom-up by prey availability in a match-mismatch relationship (sensu Cushing). Using IPCC climate projections, we examined the outcome of a 35-yr simulation of fish population dynamics in both seas. The main objective of this theoretical study is to enhance our understanding of the similarities and differences in how temperate and sub-Arctic marine ecosystems may respond to the anticipated future climate change.

Distribution and condition of coastal pelagics larvae in relation to environmental conditions in the northern Benguela Current

Geist, S.J., Ekau, W., Kunzmann, A., and Bohata, K.

Larvae of the three major coastal pelagic species in the poly-pulsed northern Benguela Current upwelling system, Sardinops sagax, Engraulis encrasicolus and Trachurus capensis, showed highest abundances during austral summer, the season with lowest upwelling activities. Sardinops sagax larvae were rare and more restricted to areas with colder water temperatures, whereas the other two species occurred over a greater temperature range and showed a wider spatial distribution during cruises conducted within the interdisciplinary research project GENUS (Geochemistry and Ecology of the Namibian Upwelling System, 2009-2014). Condition factor was either similar between seasons or higher during summer compared to spring. This finding suggests that usually sufficient food concentrations are available also during quiescent upwelling periods when shelf retention is high. However, at extraordinary high densities S. sagax larvae had a poor nutritional condition indicating a density effect. Correlations of larval abundance and condition with microzooplankton groups are currently undertaken. Our findings shed light on early life history traits possibly relevant to explain the different recruitment success of coastal pelagic species in the northern Benguela.

Impact of hatch-date on early life growth and survival of Mueller's pearlside (*Maurolicus muelleri*) larvae

Folkvord, A., Gundersen, G., Albretsen, J., Asplin, L., Kaartvedt, S., and Giske, J.

Early life growth and survival were investigated throughout a spawning season for Mueller's pearlside (*Maurolicus muelleri*) larvae in Herdlefjorden, Norway by daily otolith increment analysis. Three clearly separated larval cohorts each with a narrow window of hatching dates were identified. Cohort 1 hatched in July-August and was characterized by relatively low growth and morphometric condition. Cohort 2 hatched in September and had significantly higher growth and faster development in terms of light organs than cohort 1. Unlike cohort 1, it also succeeded through the larval stages, still being present during the last cruise in November. The last cohort 3 which hatched in October had intermediate growth and condition between cohort 1 and 2 larvae. High resolution drift modelling indicated that the Herdlefjord had a net export of larvae and negligible import for the simulated time period. The advective loss rate of larvae was not considered high enough to

explain the near complete disappearance of the first cohort, which thus partly was considered to be caused by elevated mortality related to temporally within-season sub-optimal growth conditions.

Spatial aspects and drift

Chair: Pierre Petitgas, France

Keynote: Closing the loop: Full life cycle models for pelagic fish stocks

Huse, G.

Hjort's second recruitment hypothesis addressed the fate of offspring that drift out of areas suitable for their survival. This hypothesis has forged the concept of population as a closed life cycle, making adult spawning migration the contra-natant necessary mechanisms balancing larval drift. The classic life cycle of migratory fish stocks thus comprises migrations between spawning, wintering and feeding areas thereby allowing selective exploitation of dynamic environments. The challenge of testing spatial effects on the fate of populations is still linked to the vast limitations in sampling plankton as well as individual fish movements at sufficient spatial and temporal scales. Individual based modelling is valuable for investigating the effects of different spatial distributions on population dynamics. In the talk the different concepts related to spatial dynamics of fish stocks are reviewed in light of recent research. Particular emphasis is put on the Norwegian spring spawning herring. This stock is highly migratory, and has changed its migration pattern several times. A spatially explicit individual based model for the entire life cycle of the Norwegian spring spawning herring is presented and used to investigate effects of different migratory strategies on variation in growth, survival and recruitment.

Exploring decision rules of a migrating exploited population of edible crab using an individual based model

Hart, P., Pearson, E., and Hunter, E.

For thirty years the crab (*Cancer pagurus*) fishery off South Devon, UK has been prosecuted in a designated zone defined by the Inshore Potting Agreement (IPA). This reserves areas for static crab pots protecting them from damage by mobile gear. The fishery in this area is dependent on crabs migrating into the IPA, and recent tagging studies have shown that female crabs tagged in the east all move west. These females are taking part in a cycle of movement that preserves the integrity of the English Channel crab population. Westerly placed females release their eggs into the plankton to be carried east by the prevailing northeasterly current. We have developed an individual based model of crab movements through the IPA to link crab catches to rates of migration into the area. The model is being used to evaluate immigration rates required to sustain catches and to explore hypotheses originating from fishers as to which environmental factors influence the pattern of crab movements through the IPA. This paper describes the model and presents some early results.

The principles of vertical distribution of fish eggs in the world oceans

Sundby, S.

The salinity in the oceans has basic influence on the vertical distribution fish eggs and, hence, the way eggs are dispersed from the spawning sites. Fish populations have adapted accordingly by producing egg specific gravities that tune the egg buoyancy to create specific vertical distributions for each species. A wide variety of buoyancy adaptations is found among the fish populations depending on the physical setting at and around the spawning sites. It results in characteristic vertical distributions like pelagic and mesopelagic eggs in regions where salinity increased with depth. However, in the major part of the world oceans salinity decreases with depth resulting basically different egg distributions. Here, the principles of vertical distributions fish eggs in the world oceans are presented in an overarching framework.

Impact of climate change on larval recruitment of sole in the North Sea

Lacroix, G., Van der Zand, D., Barbut, L., and Volckaert, F.A.M.

The transport of sole (*Solea solea*) larvae from the spawning grounds to the nurseries is driven by hydrodynamic processes but the final dispersal pattern, larval abundance and connectivity may be affected by behavioural and environmental factors. A temperature increase could affect for instance the spawning period, the duration of the pelagic stage, the mortality of eggs and larvae, and the match-mismatch with prey fields. Modifications in the magnitude and direction of the wind regime might affect egg and larval retention and dispersal through changes in the hydrodynamics. We compare scenarios of a particle-tracking transport model (IBM) coupled to a 3D hydrodynamic model to investigate the impact of climate change through hypothetical temperature increase and changes in wind magnitude/direction inspired from IPCC scenarios. The model has been implemented in the area between 48.5°N-4°W and 57°N-10°E over the period 1995 to 2011. A larval mortality parameterization based on match-mismatch between remote sensing algal bloom timing and larval food requirement is tested. The results of projections will be discussed relatively to interannual variability.

Long-term stability in modelled zooplankton influx could uphold major fish spawning grounds on the Norwegian continental shelf

Frugård, Opdal, A., Vikebø, F.B., and Lien, V.

The Norwegian coastline appears to be packed with suitable spawning habitats for fish. Yet, most of the spring-spawning activity seems to concentrate at only a handful spawning grounds. Simultaneously, large abundances of the crustacean zooplankton, Calanus finmarchicus, ascend from their overwintering habitats in the great depths of the Norwegian Sea, to the upper water masses to spawn. The offspring are thought to be a crucial energy source for early life stages of fish spawned on the Norwegian continental shelf, and subsequently rely on calanus being advected onto the shelf. By coupling an individual based model to a numerical ocean model, we are able to model long-term (1960-2011) inter-annual variation in calanus flux from the Norwegian Sea and onto the shelf. Interestingly, we find that cross-shelf transport of calanus is surprisingly stable across years, and that transport is particularly concentrated close to the major fish spawning grounds. We suggest that important fish spawning grounds could be selected for due to stable food supply in the spawning season.

Spatial variations in mortality in pelagic early life stages of a marine fish (*Gadus morhua*)

Langangen, Ø., Stige, L.C., Yaragina, N.A., Ottersen, G., Vikebø, F.B., and Stenseth, N.C.

Mortality of pelagic eggs and larvae of marine fish is often assumed to be constant both in space and time, mainly due to lacking information. This may, however, be a gross oversimplification, as early life stages are likely to experience large variations in mortality both in time and space. We have developed a method for estimating the spatial variability in mortality of pelagic eggs and larvae and apply it to the egg and larval stages of Barents Sea cod (*Gadus morhua*). Using the estimated mortality fields, we show that the spatial variations in mortality might have significant ecological impacts. For example spatial variation in survival may significantly alter the overall survival to later life stages and we show that accounting for the estimated mortality field, improves the correlation between a simulated recruitment index and observation-based indices of juvenile abundance. In addition, other potentially important ecological effects such as e.g. effects of altered location and timing of spawning may be explored.

Growth-dependent spatial distribution and mortality in the anchovy of the Bay of Biscay

Petitgas, P., Grellier, P., and Huret, M.

Growth is a key parameter of population dynamics, linking vital rates with behaviour and spatial occupation. We studied individual fish growth trajectories in the anchovy of the Bay of Biscay. We measured annual growth increments in the otolith of individual fishes collected on the annual fisheries survey Pelgas from 2001 to 2012. The population separates into larger fish at age who occupy off-shore habitats and suffer higher mortality while smaller fish at age have a more coastal distribution and experience lower mortality. Fish length at first winter (growth at age-0) determines life-time growth trajectories. Differences among individu-

als in growth at age 0 can be due to their birth date, as individuals spawned earlier in the season could grow over a longer period than individuals spawned later. Another hypothesis concerns experienced environmental conditions. We used juvenile growth rates and hydrological indices over the year to separate these effects. Results show how spatial distribution and growth are intrinsically linked, which implies modelling the population with individual-based and physiological approaches to fully grasp its spatial dynamics.

Use of otolith microstructure analyses to study the relation between larval hatching time, growth and survival in Norwegian spring spawning herring

Slotte, A., Husebø, Å., Stenevik E.K., Vikebø, F., Folkvord, A., Fossum, P., Mosegaard, H., and Nash, R.D.M.

Sequential sampling within a population at different life stages may provide information on selective mortality patterns. Daily otolith increment widths at selected distances from the core were compared between larvae and 0-group juveniles with the objective to test if survival in Norwegian spring spawning herring (*Clupea harengus L.*) is related to larval growth. In general the daily otolith growth during the first two-three months after hatching was significantly higher in the larvae drifting northwards along the Norwegian coast than in the surviving population of 0-group ending up in the fjords. Spatial analyses demonstrated that the slowest growing larvae, having most in common with the growth observed in 0-group, were the ones originating from early hatching, found close to the coast and far to the north in mid May. Model simulations indicated that this near shore larval drift in general is associated with early hatching and colder ambient temperatures. The results suggest that a selection for the earliest hatched and subsequently slowest growing larvae may take place during the larval phase in this herring stock.

A century of early life history research – the case of the European eel

Munk, P.

In the decade preceding Johan Hjorts famous publication in 1914, leading scientists had much focus on spawning sites and early stages of the more important fishery stocks. At that time the spawning behavior of European eel was completely unknown, but based on findings at a cruise in 1913 the Danish scientist Johannes Schmidt, proposed in January 1914 the Sargasso Sea as the likely spawning area of this species. Due to WW1, the final delimitation of the spawning area was, however, delayed and Schmidt could first publish the renowned findings on eel spawning areas in 1923. Since these findings, the eel spawning areas in the Sargasso Sea have been revisited during a series of dedicated cruises, the latest during March-April 2014. Despite good progress in our understanding of early life processes in eel, there are, however, several unresolved questions. Here I look retrospectively into the historical series of spatial patterns in order to ascertain the earlier observations in the light of recent understanding of physical processes. The physical conditions of the Sargasso Sea have changed markedly during the century, and during the last 40 years the temperature has been steadily increasing. The possible implications to larval distribution and drift are addressed.

Natural mortality and growth

Chair: Richard D.M. Nash, Norway

Keynote: How can understanding variations in egg and larval vital rates enhance our capacity to forecast recruitment variability? Revisiting Hjort's thesis to determine if we have done what was needed.

Pepin, P.

Recruitment is the result of a series of events from spawning to entry to the fishery (or maturation) that are determined by the probabilities of finding food, of being eaten, or of being moved into an environment from which an individual will not return. Hjort stated that "a study of the fluctuations in the population of the sea…and thus the whole organic life existing in the ocean is therefore the soundest possible basis for marine research", essentially implying that an ecosystem perspective of prey-predator relationships was required to understand changes in productivity. Efforts dealing with the study of recruitment variability have demonstrat-

ed a wealth of knowledge dealing with feeding characteristics and variability in growth rates of larval fish with considerably fewer studies that were aimed at measuring mortality rates and understanding the underlying drivers. The question remains, however, as to whether the research conducted in the last 100 years provided researchers with enough knowledge about the effects of prey and predator on early life history survival to allow the prediction of changes in recruitment variability in the absence of in-depth information of the processes that affect a fish population? In this perspective, I consider the extent to which research into the factors that affect growth and mortality can be used to establish a set of simplified principles about how ecosystem elements determine the likelihoods of high/low growth and mortality rates. The purpose is to identify environmental data requirements essential for development of a rudimentary level of recruitment forecasting capacity.

The early life-history dynamics of Northeast Arctic cod: levels of natural mortality and abundance during the first three years of life

Bogstad, B., Yaragina, N.A., and Nash, R.D.M.

Recruitment at age 3 of the Northeast Arctic cod (*Gadus morhua*) is highly variable. It is generally believed that year-class strength for this stock is determined prior to settlement. However, newer observations indicated that year-class strength may change considerably between settlement and recruitment at age 3. Our analyses cover the 1983-2009 year classes because comprehensive surveys started in 1983 which allow the estimation of NEA cod abundance over the first three years of life in the Barents Sea. We have utilised estimates of total egg production (TEP), abundance from pelagic O-group and bottom trawl surveys and VPA estimates of recruitment. We also investigated how these various data sets could be compiled together as relative indices and absolute estimates of abundance to estimate mortalities at various life stages. Generational natural mortality rates vary considerably between years and over parts of the life cycle (TEP to age 0 - 6 to 10; age 0 to 3 - 1.8 to 6). The between-cohort variability in abundance is strongest at the age 0 and 1 stage, and decreases thereafter.

The survival of early life-stages of Atlantic cod (*Gadus morhua*) in the North Sea and the role of changes in predation pressure

Akimova, A., Kreus, M., and Peck, M.A.

We explored the role of predation mortality on early-life stages of the Atlantic cod in the North Sea by using a hydrodynamic drift model coupled to an individual based model including temperature-dependent growth and development of the egg, larval and early juvenile life stages. Multiyear runs explored predation in three schemes. We applied size-dependent predation which 1) did not vary spatially or temporally, suggesting survival depended on climate-driven stage durations and drift, 2) varied only temporally based upon the observed abundances of the main planktivores consuming pelagic life stages and piscivores consuming demersal juveniles, and 3) varied only spatially where the probability of survival was inversely proportional to the overlap with predators experienced along particle drift routes. The results of the simulations are compared with the time series of North Sea cod recruitment, abundance indices of the cod 0-group and spatial distribution of settled juveniles, obtained during North Sea IBTS. This study highlights the gauntlet of potential predators affecting mortality of various early life stages of cod and distribution and abundance of demersal juvenile cod.

Daytime predation refuge for juveniles or night time foraging ground for predators? Two contribution pathways of seagrass beds to production of coastal fishery resources in the western North Pacific

Shoji, J., Kinoshita H., and Tanaka H.

Increase in nocturnal predation risk was demonstrated in seagrass Zostera marina bed which has previously been considered as a predation refuge for small fishes. Seasonal and day-night changes in fish community structures and predation rate on juvenile and small-sized fishes were examined in the seagrass beds in temperate and sub-boreal waters in the western North Pacific. The number of piscivorous fish species collected by a large seine, and their abundance and biomass during night time was significantly higher than those in daytime in all seasons. Occurrence of piscivorous fishes during night time was confirmed by a video camera

with infrared light. Analysis of stomach contents of piscivorous fishes showed predation rate during night time significantly higher than those during daytime. The piscivorous fishes which visited the seagrass bed during night time consist of important fisheries resources. Therefore, the function of seagrass beds as fish habitats should be evaluated considering two possible pathways in which seagrass beds contribute to fishery production: daytime predation refuge for small fishes while as night time foraging ground for large piscivorous fishes.

Assessing natural mortality of anchovy from surveys' population and biomass estimates

Uriarte, A., Abaunza, I.P., Pawlosky, L., Massé, J., Petitgas, P., Santos., M., and Skagen, D.

Natural mortality is a key parameter determining assessments. Parallel egg (DEPM) and acoustic surveys have been applied to assess the anchovy in the Bay of Biscay since 1987. The closure of the fishery between 2005 and 2010 due to low biomass levels gave an opportunity to estimate natural mortality. Under the assumption of no major changes in M occurring between both periods, log linear models on the series of survey population at age estimates and seasonal integrate assessments, assuming constant catchabilities across ages for the two surveys, were used to infer either a constant or a varying pattern of natural mortality at age estimates. The analysis suggest M values around 0.8-09 for a constant natural mortality at age, but there is a firm evidence that natural mortality at ages 2 and older (M2+) is markedly higher than at age 1 (M1) a likely indication of senescent mortality, a possibility suggested since a long time for this type of short living species.

Regulation of fluctuating fish stocks – examples of two kinds of compensation in six depleted groundfish stocks from the Northwest Atlantic

Shelton, P.A., and Morgan, M.J.

Hjort considered environmental factors influencing early life history stages to be of paramount importance in the determinants of fluctuations in year class strength. Despite the large variation in year-class strength caused by environmental factors, fish stocks typically don't decline to extinction or increase indefinitely. This is because regulatory processes, particularly compensation during the pre-recruit stage, result in recruitment rate (recruits per spawner) being negatively related to spawning stock biomass, resulting in depleted stocks tending to have high recruitment rates. Consistent with Hjort's view, year-class strength is determined at the pre-recruit stage, but it is through a combination of environmental and compensatory processes rather than environmental processes alone. What is less commonly documented is post-recruit compensation that contributes to greater production of spawning stock biomass per recruit at low stock size. We evaluate the relative contribution of pre-recruit compensation (recruits per spawner) and post-recruit compensation (spawner per recruit) for six depleted groundfish stocks in the Northwest Atlantic and draw conclusions regarding the importance of compensation in the regulation of fluctuating fish stocks

Strong Norwegian spring spawning herring year classes after 1904 – how have they affected growth of subsequent year classes?

Folkvord, A., Slotte, A., and Stenevik, E.K.

The 1904 year class of herring dominated the Norwegian spring spawning herring (NSSH) stock over a decade in terms of numerical abundance and contributions to the fishery, and density dependent effects have been postulated. We compare the growth of large year classes of NSSH with the two subsequent year classes, starting with the strong 1950, 1959, 1983, 1991, 1998, and 2002 year classes. Back-calculated lengths-at-age were estimated from an extensive historic NSSH scale collection. The two year classes following a strong year class typically exhibited higher growth during the pre-recruit phase than the strong year class. An exception to this pattern is seen for the 2003-2004 year classes following the strong 2002 year class. The 1983 year class which was the first large year class after the stock collapse in the mid-sixties had the highest length-at-age 6 of all strong year classes. The large 1950 and 1959 pre-collapse year classes tended to have smaller lengths-at-age than strong year classes after the collapse. The results are discussed in relation to the regional environmental and climatic conditions.

More predators but lower predation: Effective predator avoidance in a behavioural model for larval cod
Fouzai, N., Opdal, A.F., Jørgensen, C., and Fiksen, Ø.

Predation is believed to be the major cause of death in early life stages, and understanding how larval traits and behavioural responses influence their risk of being eaten remains key to better predict year-class strength. We use a state-dependent optimality model for the behaviour of larval Atlantic cod *Gadus morhua* to study how larvae respond behaviourally to shifting predator communities. We let the relative dominance of ambush, cruising invertebrates, and fish predators vary, and analyze effects on vulnerability and distribution patterns within the water column. The model includes mechanistic descriptions of encounter rate with each predator type, and finds optimal state-dependent vertical migration and foraging activity, from which detailed predictions of predation, growth and survival emerge. The model shows that larval behavioural responses and vulnerability to each type of predator depends on the dominance of others predators. It highlights the ability of fish larvae to assess and behaviourally control their predation risk from each type of predator by adjusting their foraging activity and habitat choice, and is radically different from traditional models with fixed-behavioural responses.

Environmental effects on anchovy *(Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) early growth in the North Aegean Sea (eastern Mediterranean)
Schismenou, E., Giannoulaki, M., Tsiaras, K., Triantafyllou, G., and Somarakis, S.

There is an optimal temperature for anchovy and sardine early growth in the eastern Mediterranean. Post-larvae and juveniles were collected from a coastal area of the North Aegean Sea in July 2007, December 2007 and February 2009 and used for otolith microstructure analysis. The potential environment that fish experienced during their development was reconstructed using a coupled 3D hydrodynamic-biogeochemical model implemented in the North Aegean (POM-ERSEM), which provided daily (from January 2007 to February 2009) values of oceanographic parameters averaged over the broader sampling area. To comprehend the environmental effects on daily growth, these model averages were used as explanatory variables in generalized additive models of otolith increment widths for each species/life stage combination. In the models we incorporated the effect of 'inherent otolith growth' (associated with the potential uncoupling between somatic and otolith growth rates) by including the explanatory variables 'previous increment width' and 'age'. Both species' early daily growth was influenced by temperature, exhibiting an optimum at ~24.5oC; anchovy juvenile daily growth rate also increased with increasing food availability (mesozooplankton biomass).

Consumption and growth in a seasonally varying environment
Johannesen, E., Johansen, G.O., and Korsbrekke, K.

The interaction between cod and capelin in the Barents Sea has been extensively studied. The proportion of capelin in diet and total consumption of cod varies with capelin abundance. Since the 1970's there have been three severe capelin stock declines. During the first capelin collapse in the 1980's the growth of cod was severely reduced, the starving episode influenced the affected year classes throughout their life. The next collapse impeded the growth but less severely so. The collapse in the recent decade had no effect on cod growth. The last decade has been characterized by ocean warming and increasing cod abundance. In the very recent years, there are indications of food limitation. Growth of immature cod has been stable, while growth and maturation of older cod has declined. Here we use ten years of survey data including stomach samples from winter and late summer. We analyze seasonal variation in diet (total consumption and proportion capelin) and relate changes in cod feeding to seasonal variation in growth.

Proposal of a general solution to the recruitment puzzle in marine organisms
Johannessen, T.

It is generally assumed that "bigger is better" for fish during critical recruitment stages. However, extensive studies of Atlantic cod on the south coast of Norway suggested there is an optimal size between cod and available prey that maximize survival, and that young-of-the-year cod depend on energy-rich planktonic prey until they are quite large (<8-9 cm). Early shifts to less energy-rich prey (e.g., fish and prawns) resulted in low

condition and poor survival. It is proposed that variability in the plankton community generates variable energy flow patterns to higher trophic levels and thereby induces recruitment fluctuations in cod, other fishes and invertebrates that depend on pelagic prey during early life stages. After this period of food-limited survival, abundant organisms will attract opportunistic predators, which will then act to reduce differences between year-classes at older stages. It is suggested that, as general phenomena, physical and chemical bottom-up processes generate variability in marine pelagic food webs, whereas predation, parasitism, and diseases act to dampen variability. Fisheries targeting larger fishes will thus enhance variability in marine ecosystems.

Environmental drivers - fluctuations and change

Chair: Coleen Moloney, South Africa

Keynote: Global vulnerability of fish recruitment to climate change: insights from Hjort's legacy

Cheung, W.W.L., Asch, R., Jones, M., Rykaczewski, R., Sarmiento, J.L., and Stock, C.

Johan Hjort is considered the 'father' of fish recruitment studies as he established a compelling set of hypotheses explaining recruitment variability in the early 20th century. His "Critical-period" hypothesis and "Aberrant Drift" hypothesis have fuelled a century of research and debate about the unsolved mystery of fish recruitment, inspiring the development of modified and new arguments to explain recruitment variability. The study of recruitment variability is now particularly important given the demand for understanding the effects of climate change (CC) and ocean acidification (OA) on fish population dynamics and fisheries. However, the scientific consensus is that there is no single dominant hypothesis; instead mechanisms determining recruitment are context-dependent, varying according to species, space, time, interactions with other organisms and human activities. Recognizing the difficulties in predicting recruitment, we use a vulnerability assessment approach to understand the potential risk of CC and OA impact on recruitment of exploited marine species. We review existing hypotheses explaining recruitment variability and highlight some of the environmental and ecological drivers affecting recruitment. We then look at available projections of changes in these variables and examine the potential sensitivity and adaptive capacity of exploited populations to the projected environmental and ecological changes. We discuss the potential vulnerability of different species and ocean basins to recruitment disturbance from CC and OA. Finally, we highlight the uncertainty and gaps in existing projections and knowledge, and suggest some possible ways to address them. In summary, this study underscores the importance and knowledge gaps in understanding the risk of CC and OA impacts on global fisheries and ecosystem structure through recruitment.

Local adaptation of behaviour and life history across North Atlantic cod stocks – a model for current and future climates

Holt, R.E., and Jørgensen, C.

At the individual level, increasing temperature influences bioenergetics and numerous physiological and life history processes, which have consequences for the population level and beyond. We provide a bioenergetics model that predicts temperature-induced adaptations for life histories and behaviour of Atlantic cod (*Gadus morhua*). The key constraint is temperature-dependent respiration. The only stock-specific input data are a seasonal temperature cycle, the distance of the spawning migration, and a fishing level to which the stock presumably has adapted. Dynamic programming is used to find evolutionarily optimal state-dependent strategies of foraging and energy allocation, from which survival, growth and reproduction emerge.
Using current forcing, the model reproduces stock-specific patterns of growth, size-at-age, and maturation for each of the nine different cod stocks tested. The predicted climate responses vary, with cold-water stocks generally expected to do better while warm-water stocks may exhibit failing recruitment, reduced growth, and higher natural mortality. The model illustrates how climate warming may influence the behaviour and life history strategies of cod in diverse ways, and how stocks may differ in their response.

Cod and climate changes: Performance of previous projections

Drinkwater, K., Christiansen J.T., Friedland, K., Hatun, H., Kristiansen, T., Mills, K., Myksvoll, M.S., Sundby, S., and Valdimarsson, H.

Under climate change, the temperature in North Atlantic is expected to rise by 1 to several degrees C. There have been numerous studies showing relationships of the recruitment and distribution of Atlantic cod (*Gadus morhua*) with ocean temperatures. Several authors have gone on to use such relations to make predictions on the impact of future climate change on cod. In this paper we review such predictions for many of the important cod stocks throughout its geographic range from Georges Bank and the North Sea in the south to West Greenland and the Barents Sea in the north. We then examine recent changes in the ocean temperatures for these stocks and explore the subsequent response of the cod stocks in terms of their recruitment and distribution. These changes will then be compared to the future predictions to determine if the observed and predicted responses are consistent. We conclude with a discussion of how reliable such future predictions may be.

Do modeled zooplankton abundances increase the hindcast and prediction strength of fish recruitment models?

Skern-Mauritzen, M., Sigler, M., Hjøllo, S., Hansen, C., Holsman, K., Jacobsen, J.A., Oskarsson, G., Samuelsen, A., Svendsen, E., Utne K.R., Hermann, A., Aydin, K., and Hollowed, A.

The recruitment of many fish stocks is highly variable because of large interannual fluctuations in survival during early life stages. Prediction of year-class strength is a critical challenge for fisheries managers, and may improve if the effects of environmental factors that influence pre-recruit mortality are accounted for. However, recruitment predictions are often challenged by non-stationary recruitment-environment correlations, indicating that the environmental correlates used only partially reflect the causal mechanisms involved. Typically, environmental correlates tested in recruitment models reflect ocean climate, primary production and/or predator abundances, whereas information on food availability is rarely available due to the challenge of sampling zooplankton at relevant locations, at relevant spatio-temporal scales. Here we examine if zooplankton fields from coupled ROMS-NPZ models are positively associated with the recruitment of 9 stocks in the Bering, Norwegian and the Barents Seas, and if such zooplankton fields increase the hindcast and prediction strength of the fish recruitment models. Preliminary results support positive associations between modeled, seasonal zooplankton abundances and fish recruitment.

Climate and abundance affects distribution of a sub-arctic fish stock – a case study on Northeast Arctic haddock

Landa, C.S., Ottersen, G., Sundby, S.R., Dingsør, G.E., and Stiansen, J.E.

Climate variability and change may have strong effects on the abundance and distribution of marine fish stocks, not least in high-latitude ecosystems. This general issue is here exemplified by the Northeast Arctic haddock (NEAH) in the Barents Sea. We investigate the effect of "ecosystem temperature" from a fixed transect on distribution boundaries and abundance between 1981 and 2008, a period with increasing temperatures. The ecosystem temperature is compared with the NEAH's species habitat temperature (i.e., age specific abundance-weighted ambient temperatures) – two temperature approaches representing the indirect and direct environmental impacts on fish, respectively. Variability in the two temperature representations is shown to have very different implications for a fish population in a thermal-gradient ecosystem. In addition to temperature, density-dependent effects on distribution boundaries are considered. We find positive relationships between ecosystem temperatures and abundance-at-age. There was a trend towards the distribution boundaries shifting further towards northeast, likely due to increased food availability. There was also an increase in the range of NEAH's species habitat temperatures, lower limits decreased and upper limits increased.

Spatial dynamics of the bearded goby and its key fish predators off Namibia vary with climate and oxygen availability

Salvanes, A.G.V., Bartholomae, C., Yemane, D., Gibbons, M.J., Kainge, P., Krakstad, J.-O., Rouault, M., Staby, A., and Sundby, S.

Hypoxia [O2 < 2.0 mL L-1 (87 lmol kg-1)] and severely hypoxic water masses [O2 < 0.5 mL L-1 (21.8 lmol kg -1)] are increasing in coastal marine ecosystems due to eutrophication and warming. Here, we investigate the response of the suboxic-tolerant endemic fish, *Sufflogobius bibarbatus*, to variations in the thermal and oxygen environment, as well as to predation pressure, using 22 yr worth of satellite and in situ data. We show that environmental variation and predation pressure affect the goby population, which has expanded over the last decade while that of horse mackerel has contracted. These changes co-occurred with a general warming in the north and central shelf areas (north of 24.5°S). Spring warming positively affected both goby and hake abundances, but not the horse mackerel, suggesting different responses to surface temperature. The goby habitat contracted when predators were abundant, particularly in the north, which is the fringe of its distributional area. The implications of the differential tolerance of gobies and their predators for climate variations are discussed.

How can we distinguish between competing explanations of year class strength?

Sofia, A. Ferreira. A., MacKenzie, B.R., and Payne, M.R.

Johan Hjort's groundbreaking work was inspired in part by the observation of a set of exceptional year classes in Norwegian spring spawning herring. In the intervening century fisheries science has generated a long list of environmental drivers that can generate such anomalous year classes but distinguishing between them in specific instances has proved challenging. We demonstrate here how modern statistical, computational and observational advances can be leveraged to perform such attribution. We illustrate the approach using a modern example, namely blue whiting (*Micromesistius poutassou*), which during the late 1990s and early 2000s generated year classes an order of magnitude higher than those seen before or after. We catalogue a range of environmentally driven hypotheses and apply the information theoretic approach to assess the evidence supporting each of these mechanisms. We then expand this analysis to consider the possibility of multiple competing mechanisms. We conclude that the scientific advances made since Hjort's time have taken us to a point where identifying the causes of large year classes is now feasible.

Co-incident recruitment patterns of southern hemisphere fisheries

Castillo-Jordán, C., Klaer, N.L., Tuck, G.N., Cubillos, L.A., Frusher, S.D., Tracey, S.R., and Salinger M.J.

Two dominant recruitment patterns were identified across 12 stocks from the Southern and Eastern Scalefish and Shark Fishery in Australia using data from 1980 to 2005. Principal components, cluster and dynamic factor analysis produced consistent groupings. Stocks exhibited a detectable degree of synchrony according to the distribution area (East or West of Tasmania). The species in the first group were eastern ling, blue grenadier, redfish and eastern gemfish, and the second blue warehou and jackass morwong. We tested three oceanographic indices, (Inter-decadal Pacific Oscillation (IPO), Southern Annular Mode (SAM), Southern Oscillation Index (SOI), to see their relationship with the stocks analysed. The time-series of IPO and SOI were clearly related to recruitment patterns observed for school whiting, jackass morwong and blue grenadier (r= 0.45) and SAM was negatively related to eastern ling (r=-0.42). These results indicate that broad-scale changes in oceanographic conditions play an important role in the variability in recruitment of several key species in south eastern Australia.

Modeling habitat selection of European anchovy (*Engraulis encrasicolus*) at different life stages in a highly productive ecosystem (Adriatic Sea)

Campanella, F., De Felice, A., Russo, A., Biagiotti, I., Canduci, G., Malavolti, S., Vasapollo, C., Costantini, I., De Marco, R., and Leonori, I.

The Adriatic Sea is one of the most productive basins of the Mediterranean Sea, characterized by a wide continental shelf, strong river inputs and complex circulation patterns. In this ecosystem, small pelagic species

play a fundamental role for both economical and ecological reasons. A better understanding of how environment can affect the habitat selection dynamics of these species is crucial for an effective management of the resource. Within this work, modeling techniques were applied in order to describe the potential habitat of European anchovy (*Engraulis encrasicolus*) addressing different life stages (adults and juveniles). In particular, Generalized Additive Models (GAMs) were applied to presence-absence data derived from acoustic surveys, along with satellite environmental data and Regional Oceanic Modelling System (ROMS) outputs. Selected models were used to construct habitat suitability maps and to explore the possible relationships between anchovy distribution and environmental forcing. The models highlighted the importance of productivity and hydrodynamics in explaining the distribution of this species. Moreover, according to the obtained results, a mechanism that could explain recruitment dynamics of anchovy was identified.

Temporal and spatial variability in environmental controls of three small pelagic species in the southern Benguela

Twatwa, N.M.

Environmental factors operating on different time and space scales that govern habitat preference and impact on fisheries resources can be assessed by linking prevailing environmental conditions to the abundance and distribution of individual species. Spatially-explicit estimates of recruitment and abundance of anchovy (*Engraulis encrasicolus*), sardine (*Sardinops sagax*) and round herring (*Etrumeus whiteheadi*) were combined with environmental data bases to reveal the habitats utilized by these three species during juvenile and adult life stages in the southern Benguela upwelling ecosystem. Populations of these species are of great socio-economic and ecological importance to the region and are vulnerable to change in response to environmental fluctuations. Upwelling intensity has been associated with growth and development of early stages, and temperature has been shown to influence survival and reproduction, affecting patterns of recruitment and spawning variability in this region. To understand the preferred environmental envelopes, a single parameter quotient (SPQ) method with randomization and a non-linear model, and a combination of variables within a regression modelling framework were used. Based on the preferred habitats, as defined from SPQ ranges, the environmental data were used to generate maps of suitable habitats, linking their spatial location and size to the time series of recruitment and spawner biomass. Understanding how, where and when environmental variability affects fish distribution, physiological development, survival and reproduction is important for understanding recruitment, which drives most of the interannual fluctuations in abundance of the populations.

Long term variations in the population dynamics of Iberian sardine (*Sardina pilchardus*) and its relation to environmental conditions and exploitation history

Malta, T., Santos, A.M.P., Santos, P., and Silva, A.

A historical recruitment index (HRI) was developed for sardine in the Portuguese west coast, the main recruitment area of the Iberian stock. HRI was calculated as the number of individuals per kg landed using length and weight distribution samples from purse-seine fleet landings between 1947 and 2012. HRI has a correlation of 90% with recruitment series from acoustic surveys (1995-2010). In the past 66 years, recruitment varied considerably between years, with peaks every 4-5 years and oscillated with a periodicity of 20-25 years. Exceptionally high recruitments were seen in the mid 1950's and were never seen afterwards. Generalized Additive Models were used to examine the relationship between recruitment and environmental variability, both at local and large scale. The model explained 39% of the recruitment variability but was unable to reproduce the high recruitment values of the 1950's. The fishery history suggests a period of overexploitation between late 1950's and mid 1960's which seems to have led the stock to lower abundance levels, not capable of producing recruitment values as the one's in mid XX century.

Exploratory analyses, uncertainty and predictions

Chair: Mark Dickey-Collas, Denmark

Keynote: Can we and should we reunite recruitment and stock assessment science?

Minto, C.

Elucidating the origins of year-class variability has been a central component of fisheries science. Despite a century of fruitful investigation, considerable uncertainty still surrounds our understanding; correlative relationships appear ephemeral and observation errors may mask relationships where they exist. In the face of these uncertainties there appears to have arisen a divergence between stock assessment and recruitment science. In management-oriented stock assessment, recruitment estimates are derived from catch-at-age and survey indices coupled to a population dynamics model. Fitted relationships can then be used to project the population forward - annually according to an average of recent recruitments or over longer time periods in Monte Carlo-type simulations. Uncertainty surrounding projections can thus be quantified and harvest strategies derived to mitigate risks. Further, recent developments in state space estimation of time-varying parameters may allow for the separation of observation error from process error in recruitment and associated projections, allowing management advice to be adjusted to present levels of productivity. Arguably these will suffice present management goals. But where does this leave a mechanistic understanding of the origins of recruitment variability that should be a goal of recruitment science? I suggest that a reunification could lie in coupling the same developments in time-varying recruitment dynamics to mechanistic hypotheses that go beyond interesting but often auxiliary (to the management process) correlative relationships. Scientific impetus in the pursuit of mechanism ever abounds but whether a necessarily utilitarian management justifies the pursuit appears less certain.

A parsimonious approach to modeling temporal scales and patterns of fish population variability

Subbey, S., Planque, B., and Lindstrøm, U.

A major challenge in modeling of fish stock dynamics is the inability to adequately capture the scale of variability seen in field observations. This paper investigates the potential use of a discrete-time, stage-structured stochastic population model to study the temporal variability of fish stock dynamics. The framework is based on a parsimonious description of complex biological (e.g. investment in somatic growth versus reproduction) and ecological processes (e.g. inter-cohort predation, environmental and demographic stochasticity). We present numerical experiments to demonstrate the capability of such a model to replicate the patterns and scale of variability observed in many fish populations.

Identifying and explaining time trends in recruitment

Skagen, D.

The study addresses whether recruitment time series have systematic trends in addition to random independent variation, and if so, to what extent such trends can be attributed to exploitation. The fifty-one stocks in the North-East Atlantic where ICES accepts an analytic stock assessment as basis for its advice, were examined. A baseline time series of recruitment was constructed by low pass filtering the original recruitment series. As a trend function, a cosine function was fitted to the baseline. The ratio between high and low in that function exceeded 1.5 in all and was above 2 in more than half the stocks. There was no clear consistency in the trends between stocks. Time series of model recruitments, according to stock-recruit functions applied to SSBs from the model recruitments and historic fishing mortalities, failed to reproduce the baseline series in most cases. In conclusion, time series of recruitments have substantial trends that are poorly explained by exploitation and stock-recruitment functions. The lack of consistency in trends between stocks suggests complex effects of environmental signals.

Unquantifiable uncertainty in projecting stock response to climate

Howell, D., Filin, A.A., Bogstad, B., and Stiansen, J.E.

Data suggest that for some years there has been a positive relationship between the recruitment of cod in the Barents Sea and the sea temperature at the Kola section during the year of spawning. However, analysis of the most recent data indicates that this relationship no longer holds. This change in the recruitment dynamics will clearly have an impact on projections of future stock dynamics. This also highlights the impacts arising from possible future changes in similar relationships in other species and ecosystems on our ability to predict biological responses to climate change. This presentation uses a 'STOCOBAR' forward simulation model to evaluate North East Arctic cod dynamics under a variety of climate scenarios and temperature-dependent and -independent recruitment hypotheses. The divergence between the modeled populations (and hence yields) under the different recruitment hypotheses indicates the high difficulty of predicting the future development of a stock with any degree of certainty, or even with any quantifiable degree of uncertainty. These results highlight the importance of working towards process-based, rather than regression-based, models for recruitment variability.

Correlations, causalities, and the prediction of fisheries time series

Frank, A., Subbey, S., Planque, B., and Solvang, H.K.

Most biological time series models used in fisheries science are based on correlations between the dependent biological variable and other covariates. It is well known, however, that strong correlations do not necessarily imply the existence of causal links between the covariates and the biological variable. Further, even in the absence of correlations, true causal relationships can still exist. This is particularly true for nonlinear causal relationships. As an alternative to conventional fisheries models, this paper investigates two modeling approaches which quantify nonlinear causal links in time series data. It discusses how time series models with high predictive ability can be developed for several types of causal links (biotic and abiotic) and for different time and data resolution scales. Numerical examples are presented based on real and simulated data sets. We discuss the significance of our results in the context of predicting fisheries time series in a changing climatic environment.

Propagation of uncertainties in fisheries science for advice: the case for confidence interval harvest control rules (CI-HCRs)

Dankel, D.J., Aanes, S., and Vølstad, J.H.

Strategic Norwegian funding to support the Ocean Resource Act *(Havressursloven)* paired expertise from the Institute of Marine Research in Bergen and the University of Oslo's Center for Ecological and Evolutionary Synthesis together in the Adaptive management of living marine resources by integrating different data sources and key ecological processes (ADMAR) project. The overall goal of ADMAR is to create a framework that streamlines the route from improved survey design and data collection to parsimonious ecosystem models, and finally to operational harvest control rules. We designed a new way to formulate harvest control rules (HCRs) based on inherent underlying uncertainties. The current harvest control rule (HCR) for Northeast Arctic cod depends on point estimates of the size of the spawning stock biomass (SSB) and fishing mortality (F). The 2013 ICES advice for cod was based on, among other factors, a SSB estimated at 1,986,000 metric tons, where the relative standard error is likely to be >10% of that estimate. When the TAC advice is based on a point estimate for SSB, the propagation of uncertainties (assessment models of varying complexity, variable data sources and variable degrees and structures of uncertainty) and subjective expert decisions, is contained, at best, in the "Stock Annex". We outline an alternative formulation of the HCR that reflects the knowledge base with confidence intervals (CIs) dictated by the quality of data from catch sampling, scientific surveys and model uncertainties. The advantage of CI-HCR is that the advised quota will depend on the quality of the assessments. Also, the adequate level of monitoring for advice support can be determined based on what science can actually provide.

Modelling the uncertain stock dynamics and noisy catch and survey data for northern cod, with emphasis on short-term projections for catch advice

Cadigan, N.

Fisheries and Oceans Canada (DFO) does not currently use a catch-based stock assessment model for northern cod because of uncertain fishery landings statistics. A model of survey catch rates is used to estimate trends in stock size and total mortality rates. However, providing advice on future fishing quotas has been a drawback of the approach. The survey-only model is also deficient because it does not utilize fishery age-sampling information which may be reliable even if reported landings are not. Another important assessment uncertainty is the value of the natural mortality rate (M). There are reasons to suspect that M increased substantially around 1992 and this higher M persisted for some years, although the level and duration is uncertain.

We present a state-space assessment model for northern cod that utilizes survey indices, catch age-composition information, under-reported landings, and tagging information to provide short-term (3-5 years) catch projections. The model incorporates uncertainty about M in the projections.

Fig. 54. Spawning region of the cod *(Gadus callarias)*. The broken line gives the extreme western limits of the area in which pelagic fry have been found off the coast of Norway. L = Littoral Bottom Stages. B = Bottom Stage of the 0-group.

Hjort J. (1914) *Fluctuations in the great fisheries of Northern Europe.*
Rapports et procès-verbaux - Volume XX. Copenhagen: Andr. Fred. Høst & Fils.

Abstracts - Poster presentations

Spawning dynamics and parental effects

P01: Oocyte development and early life history of saithe, *Pollachius virens* – experimental studies

Godiksen, J.A., Otterå, H., and Kjesbu, O.S.

Saithe is one of the most important commercial species in the Northeast Atlantic fisheries. Despite this, the biology of this gadoid is little documented in the primary literature. In this study wild saithe (n = 36) were collected from the North Sea during summer 2013 and kept in captivity at Parisvatnet (IMR). During the spawning season spring 2014 the saithe were allowed to spawn naturally in the tank and egg batches were collected and incubated. Gonad biopsy after the season has ended, confirmed that five females had spawned. Their size ranged between 51 and 69 cm, while the size range of immatures was 41 to 63 cm. Early stage larvae were transferred to a 50 m3 mesocosm and fed natural plankton, and the subsequently produced juveniles placed into tanks for growth studies. Gonad biopsy were taken bimonthly from adult females in order to track the rate of degeneration of post-ovulatory follicles (POFs), which is a useful tool to validate the presence of spawning zones in otoliths, a topic of conflicting views.

P02: Temporal and individual variability in reproductive success for two Skagerrak Norwegian coastal cod populations

Roney, N.E., and Hutchings J.A.

Reproductive success is a fundamental parameter that largely determines a population's growth rate, resilience to fishing pressures and ability to recover following severe depletion. All things considered, there is a surprisingly there is a shallow depth of knowledge with regards to how it varies both temporally and individually. The purpose of this study was to investigate the individual and temporal variability of reproductive success in two Skagerrak Norwegian cod populations. Wild adult cod were collected from two genetically distinct populations on the Skagerrak coast: (1) inner and (2) outer Risør fjord; and subsequently placed in a semi-natural environment where they were allowed to spawn uninterrupted. During the entire spawning season, egg samples were collected daily and incubated until 50% hatch, at which point 50 larvae were genotyped for the final parentage analysis. Results indicate considerable and interesting variability, both temporally and individually, in the reproductive success of both cod populations, highlighting the need for a more thorough understanding of this important parameter in developing effective fisheries management practices.

P03: Energy allocation patterns associated with reproduction in Northeast Arctic gadoids

Skjæraasen, J.E., Devine J.A., Frugård Opdal A., Korsbrekke K., and Jørgensen C.

Throughout life, energy is allocated towards competing needs, such as growth, maintenance and reproduction. The latter typically represent a huge energetic oocyte investment for females, especially in highly fecund broadcast spawners, whereas for males, sperm may be comparatively cheap, but there may be substantial investments associated with the mating act itself. What patterns of allocation and storage exist within and between the sexes is therefore not obvious and can give considerable insights into species' mating systems. We therefore investigated energy storage and allocation patterns in males and females in two Northwest Arctic gadoids cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*. These closely related gadoids share several common traits; amongst them that i) reproduction is associated with a long-distance energetically costly spawning migration, ii) complex reproductive behavior involves both visual and auditory signals, and iii) frequent skipped spawning has been documented in females. We look for indications of the latter in both sexes by looking at size distributions of fish not undertaking the spawning migration and remaining at the Barents Sea feedings grounds.

P04: Spawning zones in cod otoliths: Do they really reflect spawning?
Irgens, C., Folkvord, A., and Kjesbu, O.S.

Knowledge of growth, age and size at the onset of maturation is important for fish stock assessment. So-called spawning checks or "spawning zones" in cod otoliths, first described by Rollefsen (1933), have subsequently been used to determine age at maturation and to construct maturity ogives for individual cohorts of Northeast Arctic cod (NEAC). Spawning checks in otoliths may be especially useful in studies of change in age-at-maturation in relation to climate change and exploitation due to the access to large historical otolith archives (e.g. at the Institute of Marine Research, Norway). However, spawning checks in gadoid otoliths have not yet rigorously been validated, and it also remains to be documented the exact timing of spawning check formation relative to the actual time of spawning. This poster will present the results from an experimental pilot study of multiple marked NEAC to validate potential spawning checks in relation to the actual observed spawning behaviour. A more exact timing of spawning related otolith growth could be determined since the otoliths were stained prior and post spawning.

P05: Predicting the reproductive potential of Atlantic sardine using Dynamic Energy Budget theory
Nunes, C., Marques, G.M., Pecquerie, L., Silva, A., Meneses, I., Ganias, K., and Sousa T.

Atlantic Iberian sardine (*Sardina pilchardus*) stock presents significant interannual fluctuations of population biomass and recruitment levels. Recruitment is mainly driven by environmental factors, but population dynamics depends also on its reproductive potential. However, the interaction between these factors is not completely understood. A Dynamic Energy Budget (DEB) model was built to describe the growth and reproduction dynamics of sardine individuals throughout their life time, and particularly the duration of each spawning period and the number of eggs produced (reproductive potential) off the Portuguese coast. The model obtained is able to predict and explain the main stylized facts (life-cycle, assimilation, growth, reproduction, seasonal and geographical variations) that were collected for sardine. For example, the fact that sardine grows mainly in spring/summer while it reproduces mainly in autumn/winter is related, according to DEB, with allocation to reproduction not competing directly with allocation to growth, and maintenance having priority over growth. Simulations were performed for varying environmental conditions and using different initial conditions for the individual (birthdate, size and body condition). Changes in "reproduction rules" were also tested.

P06: Reproduction and growth of the suboxia tolerant bearded goby on the Namibian shelf
Salvanes, A.G.V., Seivåg, M.L., Taha, Y., Christiansen, H., Kjesbu, O.S., Folkvord, A., Utne-Palm, A.C., Ekau, W., van der Plas, A., and Henchler, C.

The bearded goby, *Sufflogobius bibarbatus*, is only found on the hypoxic coastal shelf outside Namibia and South-Africa. Since the collapse of the sardine fisheries, late 1970s, this goby has increasingly become the predominant prey species of larger commercial fish, birds and mammals in the region. Its main distribution coincides with that area of the Namibian shelf where sea-bed oxygen levels are <1 ml O2 L-1 [43.5 µmol kg-1]. Unlike their predators, these fish can remain alert in complete suboxia and as well as with sulphide shocks. Despite its importance to the northern Benguela ecosystem, very little is known of its recruitment biology. Here we present empirical data on variation in maturation, growth and male reproductive tactics. The later differed in age, size and growth, where sneakers are smaller and younger than territorials. Both sexes mature and reproduce at oxygen levels < 0.5 ml/L, but oxygen stands out as a limiting factor for growth and reproduction. Females are smaller and grow slower than males, with an average relative fecundity, including recruiting oocytes, of 1600 g-1. Findings are discussed in view of environmental variation.

Early life stages and 'the critical period'

P07: Habitat change in early life stages of Pacific herring *Clupea pallasii*

Shirafuji, N., Nakagawa, T., Murakami, N., Morioka, T., and Watanabe, Y.

Larval and juvenile habitats of Pacific herring were investigated around brackish lake in northern Japan. Eggs were attached to seagrass and seaweed in the lake area with dense vegetation. Larvae (10.0-32.8 mm TL) were distributed during April and June in the eastern part of the lake with less dense vegetation. Juveniles (35.0-89.6 mm) were collected in the whole lake area from June to August, when water temperature was lower than 20°C. Young herring around 160 mm were collected in autumn in neighbouring Akkeshi Bay connected with the lake by a narrow canal. Yearlings around 180 mm were caught in the bay in May next year. Juveniles seemed to move from the lake area to the bay area with a seasonal temperature rise to 20 °C and stayed there until next spring. Distribution density of larvae in May was similar between 2012 and 2013, but the number of juveniles collected was quite different between the 2 years, indicating that survival in the lake habitat determines recruitment of this local herring population.

P08: Survival processes of young-of-the-year Japanese anchovy (*Engraulis japonicus*) in the Kuroshio-Oyashio transition region

Zhang, K., Kawabata, A., Kawamura, T., and Watanabe, Y.

Young-of-the-year (YOY) Japanese anchovy *Engraulis japonicus* have been observed to occur in the Oyashio region (OR) in fall. They are assumed to be survivors of larvae and juveniles distributed in the southern Kuroshio-Oyashio transition region (TR) in spring and summer. The survival processes of larval and juvenile stages in TR impact on the recruitment to YOY population in OR. To understand the survival processes, we compared the daily otolith increment width (IW) among larvae (L, 24-63 d), early juvenile (Jearly, 35-70 d), late juvenile (Jlate, 76-98 d) and YOY (141-187 d). L, Jearly and Jlate were collected in TR from May to July, and YOY were collected in OR from September to October in 2010-2012. YOY had significantly larger IW-at-ages than L after 40 d. However, no significant differences were found among Jearly, Jlate, and YOY from hatch to 90 d. Since 40 d of age corresponds to the metamorphosis stage of Japanese anchovy, our results suggest that those with higher growth rates during metamorphosis stages have higher possibility of survival to the recruitment.

P09: Latitudinal difference in condition at the initiation of metamorphosis in Japanese anchovy *Engraulis japonicus*

Hayashi, A., Fukamichi, K., Yamane1, K., Ebisawa, Y., Kawamura, T., and Watanabe, Y.

In the extensive distribution range of Japanese anchovy in the western North Pacific, larval condition factor at the initiation of metamorphosis (Cm) was low in the subarctic Oyashio area (6.0 at 40°N), high in the subtropical Kuroshio area (7.3 at 35°N), and intermediate in the Kuroshio-Oyashio transition area (6.4 at 36.4°N). Since Cm was almost constant at 7.3 through seasons in spite of the temperature changes from 13 to 28 °C in the southern Kuroshio area, the latitudinal gradient in Cm does not seem to be explained by the difference in the ambient temperature. Increase in body weight relative to body length was large in high latitudinal waters where the zooplankton density is higher (17.3 g•m-2) than in the Kuroshio area (5.8 g•m-2). Higher growth rate in body weight relative to body length may induce metamorphosis at lower condition factor in the northern waters with high food availability.

P10: Specific gravity and Vertical Distribution of Chub Mackerel *Scomber japonicas* Eggs in Korean Waters

Kang, S., Jung, K.M., Lee, H.H., Kim S. and Myksvoll, M.S.

Chub mackerel *Scomber japonicus* is commercially important species in Korean waters, but spawning grounds are not clearly identified. Naturally spawned eggs in circular raceways were used for egg specific gravity measurement in 2013 and 2014, and environmental data (temperature and salinity) were collected using

CTD. Based on this information, egg vertical distribution of chub mackerel in Korean waters was simulated using general numerical models to figure out transport process during early life stages. The egg specific gravity during the early stages ranged from 1.0203-1.0211. In general, the fertilized eggs showed a gradual decline in egg specific gravity until full development of the main organs, with a sudden increase just before hatching. Modeled egg vertical distributions were influenced more by wind speed than by egg buoyancy and vertical structure of the sea water. During calm and normal wind speeds, the eggs were distributed from the surface to 25-m depths. Under strong wind conditions (three times higher than the normal speed), the egg concentration on the surface decreased, and the egg distributional depth was deeper (~50 m).

P11: Withdrawn

P12: Generation of recruitment variability during early life history stages in western Irish Sea cod and haddock
Beggs, S.E., Schon, P-J., and McCurdy, W.

Recruitment variability remains central to population dynamics in understanding the future productivity of managed fish stocks under various exploitation and climate scenarios. Scientists use historical data to try and understand the "relationship" between stock and recruitment so that short term forecasts can be made. For many stocks, processes occurring during the early life history stages (eggs, larvae and juveniles) are important in generating recruitment variability. Surveys targeting multiple life history stages of cod and haddock have been carried out in the Irish Sea. We compare the trends from these surveys targeting the egg, pelagic juvenile and demersal stages in the western Irish Sea. The western Irish Sea is characterised by a seasonal stratified gyre, which is thought to be linked to the distribution of juvenile cod and haddock in the area. The results suggest that processes operating during the early life history stages generate recruitment variability in cod and haddock. Trends in annual mean lengths at age provide further insights into these processes.

P13: Acoustic characterization of gadoid larvae aggregations in Galician waters (NW Spain)
García-Seoane, E., Álvarez-Colombo, G., Miquel, J., Rodríguez, J.M., Fletcher, C., Álvarez, P., and Saborido-Rey, F.

Based on previous knowledge on the use of acoustics to assess hake larvae, a study was conducted in the Galician shelf (NW Spain) during winter (February-March 2012). An echosounder operating with 18, 38, 70, 120 and 200 kHz split-beam, hull-mounted transducers was employed. We analyzed the acoustic records in order to describe vertical and horizontal distribution patterns of fish larvae aggregations (mainly of the gadoid species blue whiting *Micromesisitius poutassou* and European hake *Merluccius merluccius*). Net sampling revealed that acoustic back-scattered energy at 38 and 70 kHz was roughly proportional to the density of *Micromesistius poutassou* larvae of 3.5mm and larger, while scattering due to zooplankton appear to be negligible at those frequencies. The results described herein suggest that echo-sounding data may provide a viable methodology for the study of spatial and temporal changes and trends in abundance of gadoid larvae, in particular blue whiting. In addition, the characterization of fish larvae aggregation will allow the mapping of their distribution by the analysis of previous acoustic databases.

P14: Simulation of larval dispersion of *Mullus surmuletus* based on larval competency periods
Muntoni, M, Rocklin, D., Cheoma, F., Lambiase, E., and Murenu, M.

Intra-specific variability in fish pelagic larval duration (PLD) is a known phenomena but its implications on the larval dispersal processes and thus the connectivity, are still difficult to predict, since several behavioral factors can act during this "temporal window". Extending their competency period, post-larvae (i.e. pre-settlers) can determine different spatial scenarios of the settlement patterns. By the use of the post-larval otolith sclerochronology, it is possible to obtain detailed information on early-life fish traits like the PLD or spawning and settlement dates. Such information is highly useful when implementing dispersal models and allow to develop various dispersal scenarios. In this study we acquired local information on PLD and spawning date for the red

striped mullet *Mullus surmuletus*, to estimate the intra-specific temporal range of the competency phase of the pre-settlers. Then, we run a Lagrangian simulation model of larval dispersion based on the larval pre-competency/competency temporal range previously calculated, to obtain different predictions of the settlement patterns at regional scale.

Spatial aspects and drift

P15: Models and sensitivity: How reliable are they?
Rocklin, D., Muntoni, M., Beuvier, J., and Charton, J.A.G.

The larval dispersal processes, leading to the connectivity of many fish populations, depend, among others, on the highly variable winds and marine currents. However, the fish early-life migrations knowledge is essential for proposing a coherent management of the resources. We studied the striped red mullet (*Mullus surmuletus*) population connectivity in the Western Mediterranean Sea, coupling modeling and empirical genetic studies, and evaluated the sensitivity of the models to the uncertainty of some parameters related to the larval phase. We combined the NemoMed12 hydrodynamic models based on daily data of currents, temperature and wind directions with biological data using the Ichthyop Lagrangian tool to evaluate the larval dispersal according to various scenarios. The outputs of the dynamic model were processed using GIS and the highest connectivity probabilities were mapped and dispersal kernels were derived. Such consideration is necessary to evaluate the reliability of the models outputs and these limitations must be taken into account when discussing. Moreover, it will help to point out the weaknesses of our expertise to reinforce in the future research effort.

P16: Modeling advection of herring larvae and assessing selective grazing by seabirds
Myksvoll, M.S., Vikebø, F.B., and Anker-Nilssen, T.

Early papers claimed that slow transport and retention on coastal banks along the Norwegian coast was beneficial to recruitment of Norwegian spring spawning herring, however other results have shown that years with rapid transport coincide with years of good recruitment. The main spawning area for NSSH is at the Mørebank, and the larvae passes by several large seabird colonies on their way northwards to the nursery areas in the Barents Sea. The breeding period for puffins at Røst starts in May and the eggs hatch towards the end of June. Herring larvae that are transported quickly northwards in the Norwegian Coastal Current avoid the heavy predation pressure by puffins and other seabirds along the route. Retention of herring larvae at coastal banks causes accumulation of biomass which will then be suitable feeding areas for seabirds. We investigate grazing of puffins on herring larvae by using an individual-based model coupled to an ocean model archive of the Nordic seas. The model has shown to realistically reproduce the larval temperature exposure for the period 1970 to 2011.

P17: Catch me if you can – how whales follow herring
Volkenandt, M., Berrow, S., O'Connor, I., and Guarini, J-M.

Atlantic herring (*Clupea harengus* L.) are highly clustered and randomly, patchy distributed within the Celtic Sea during spawning migration. Large, dense shoals of pre-spawning, protein rich herring constitute a high energy resource for cetaceans. Foraging on pelagic shoals has been observed for several baleen whale species within Irish waters. After spawning, herring contain significantly less energy and shoals break up, making foraging for cetaceans challenging – with a fluctuating energy gain. This study used a dynamic model to investigate the co-occurrence of whales and herring. Whale movement, including behaviour changes has been simulated, using an oriented random walk process with energy provided by herring for setting up the foraging strategy. Predation is governed by processes derived from dynamic energy budgets in a framework of optimal foraging, although the loss of energy during foraging was seen as a deterministic feature and energy gain remained a stochastic component. The model represents a theoretical distribution of a top predator and its prey, including predation interactions.

P18: Spatial linkages in the early life history of north eastern Atlantic herring populations: Can early signals in the otoliths move us closer towards the origin?

Geffen, A.J., Chang, M-Y., Johannessen, A., Maneja, R.H., Clemmesen, C., and Nash, R.D.M.

Natal signatures in otoliths can provide crucial information to link individuals to areas, and reveal population connectivity. However, these signals are not always straightforward to interpret. As geotags, the otolith chemical composition should track spatial processes, such as dispersal from spawning areas, residence in nursery areas, and mixing at feeding grounds. In herring larvae, there is some evidence of maternal effects on otolith composition. We have combined laboratory and experiments with field studies of herring larvae to help to distinguish between maternal and geographic influences. Herring larvae from different females were reared in common-garden conditions and their otolith composition analysed. Individual families of larvae can have a strong signal of presumably maternal origin. We then analysed otoliths from field sampled larvae, representing different scenarios: 1) dispersal of larvae from the west coast of Scotland into the North Sea, and 2) mixing of local and migratory population components along the west coast and fjords of Norway. The spatial differences in larval otolith chemistry were consistent with what is known about drift patterns.

P19: Identifying essential juvenile habitat for sardine along the Portuguese coast and Gulf of Cádiz

Rodríguez-Climent, S., Marques, V., Angélico, M.M., and Silva, A.

Understanding fish distribution, including juvenile fish distribution, is essential for sustainable fisheries management, where the protection of the juveniles (i.e. assuring first spawn) is required. The distribution of juvenile sardine (*Sardina pilchardus*; Walbaum, 1972) was mapped along the Portuguese coast and Gulf of Cádiz for the springs of the years 2005-2010 using data obtained during the acoustic surveys. The abundance of juveniles was then related with six environmental variables: sea surface temperature, salinity, fluorescence, zooplankton volume and depth, using Generalized Additive Models. Our results highlighted three key locations for the residence of juveniles: the Northern Portuguese shelf (centred off Aveiro), the coastal region in the vicinity of the Tagus Estuary and the Eastern Gulf of Cádiz. Enriched by the river runoff during the winter months, these areas are characterized by higher productivity in spring and lower salinities, factors cited to be crucial for the presence of juvenile stages. Moreover the combination of mesoscale and submesoscale physical processes and features occurring in these waters, have been reported to promote retention mechanisms for early life stages.

P20: Integrating field data to parameterize a larval transport model of sole and improve knowledge on recruitment in the North Sea

Barbut, L., Delerue-Ricard, S., Vanden Bavière, A., Robbens, J., Volckaert, F.A.M., and Lacroix, G.

Inter-annual recruitment variability of sole (*Solea solea*) in the North Sea is high. Among many fish taxa, the early life stages are critical in determining recruitment. With a Lagrangian larval transport model, coupling a physical model with an Individual-Based Model (IBM), it has been shown that hydrodynamics explains part of this variability in sole (Lacroix *et al*., 2013). IBMs require a good knowledge of the biological processes governing larval dispersal. However, it is difficult to obtain observations of life history traits; their estimates may strongly influence larval connectivity / retention and successful migration as predicted by the model. Various assumptions about these traits can be tested by comparing simulation results with field data. Several datasets, from the literature and from a 2-year-long monthly sampling at 13 stations in the southern North Sea, will be used to identify the most plausible model parameterisation. It represents a first step towards the calibration and improvement of a larval dispersal model of sole in the North Sea and the development of a tool for fisheries management.

P21: Aspects of the European hake ecology in the North Sea and Norwegian waters

Staby, A., and Skjæraasen, J.E.

The distribution of the European hake (*Merluccius merluccius*) extends from northern African waters into the North Sea and off the coast of Norway. In the latter area commercial catches have in recent years increased and the same trend is observed in scientific research surveys of the North Sea. This has prompted the need

for a more in-depth understanding of the biology and ecology of hake in Norwegian waters. Here we investigate temporal and spatial variation in the distribution of Norwegian hake catches and the length and weight of fish in said catches in relation to habitat descriptors such as temperature and depth. We further tentatively examine the hypothesis that hake come into Norwegian waters and fjords to spawn by looking at the limited available information on gonad size of hake in these areas and finally point to areas where future research could be directed

P22: Spawning dynamics of the Balsfjord herring, an outpost of Pacific herring in the Atlantic
Mikkelsen, N., Pedersen, T., and Falk-Petersen, I-B. (Spawning dynamics and parental effects)

The Balsfjord herring stock spawns repeatedly in the intertidal zone in Balsfjord (69oN), northern Norway and show a spawning dynamics that is very different from the adjacent Norwegian spring spawning herring. Herring eggs that were deposited mainly on macroalgae substratum in the upper shore are exposed to air, direct sunlight and fluctuating temperature and experience high mortality. Spawning dynamics of Balsfjord herring was investigated in two surveys in April 2014. Spawning had taken place in the intertidal zone at four locations in the inner part of the fjord. Survey one was conducted by boat using aqua scope and underwater-video and survey two was conducted by walking at low tide. The eggs were adhered to each other and substratum, mainly *Ascophyllum nodusum*, *Fucus vesiculosus* and *Fucus serratus*. No eggs were found at the sea bottom. That the collected eggs were in two different stages of development and gillnet catches during the first survey contained both spent and mature herring, show that spawning had taken place twice with about one month between the two spawning waves.

P23: Strong vertical stratification of larval European eel linked to water column characteristics
Munk, P.

During an expedition to the Sargasso Sea in 2014, the vertical stratification of plankton organisms was investigated at a station showing high densities of European eel. The water column characteristics were monitored by CTD casts, and series of hauls at constant depth was carried out, for eel larvae by a large 3.5 diameter ring net. At the selected site the water column showed characteristic patterns, with high saline water in the depth range 80-140 m, and up to 90 % of all eel larvae were found in a stratum just below this salinity maximum. At night-time most of the larvae were found at shallow depth – in the 40 m depth stratum. The implications of the vertical stratification for the understanding of larval biology and drift are addressed.

P24: Feeding strategy of Downs herring larvae in the English Channel and North Sea
Denis, J., Valet, C., Vincent, D., Courcot, L., Marchal, P., and Loots, C.

The larval phase is a crucial step in fish life cycle due to its determining role in population renewal. The aim of this study was to characterize the feeding strategy of Downs herring larvae at "critical period" during winter in the English Channel and North Sea. Data collected during the French part of the International Bottom Trawl Survey from 2008 to 2014 were used to analyse fish larvae diet by direct observation using Scanning Electron Microscope (SEM). There were completed by fluorimetry measurements in order to quantitatively assess grazing pressure of larvae on phytoplankton. The relative importance of small preys observed in gut contents proved that the use of the SEM was essential to better appreciate Downs herring diet. Gut contents analysis revealed that these Downs herring larvae from 6 to 20 mm were omnivorous, specialized on invertebrate eggs and more rarely consumed a variety of phytoplankton and zooplankton prey types. They seemed to positively select some phytoplankton prey types that were poorly abundant in the water whereas they negatively select several zooplankton prey types.

Natural mortality and growth

P25: Species-specific growth rate responses to seasonal temperature variations in clupeoid larvae
Watanabe, Y.

As the metabolic rate is a function of temperature, it is generally true that the larval growth rate is dependent on ambient temperature. A question arises if the degree of growth dependence on temperature is similar among species. I examined larval growth rates of three clupeoids, *Etrumeus teres, Engraulis japonicus*, and *Sardinops melanostictus*. They were simultaneously captured by towing seining net on the Pacific coast off central Japan. Correlations between otolith growth increment widths, as a proxy of daily growth rate, and ambient temperatures were examined at 5 body sizes ranging from 15–24 mm notochord length. *Et. teres* showed strong positive correlations at all the 5 body sizes, indicating that the growth rate is strongly dependent on temperature in the larval stage. *En. japonicus* showed significant but weaker correlations than *Et. teres*. In *S. melanostictus*, on the other hand, none of the correlations at any of the 5 sizes was significant. Larval responses in somatic growth rates to seasonal temperature variations were species-specific among closely related species sharing a coastal habitat.

P26: Small-scale dynamics of vital rates of herring *Clupea harengus membras* and goby *Pomatoschistus* spp. larvae in a shallow temperate bay
Laur, K., Arula, T., and Ojaveer, H.

Vital rates during the early life history stages have a great influence on recruitment success of marine fish populations: higher larval survival is generally linked to elevated growth rates which should result in a more abundant recruitment. In this study, we have investigated daily growth rate and instantaneous mortality of the two dominating marine fish, herring *Clupea harengus membras* and gobies *Pomatoschistus* spp., larvae in the Gulf of Riga, Baltic Sea. The current study provides first-ever estimates on daily growth rates and mortality on larval goby. Despite of high growth rates (variability range 0.41-0.82 mm day-1), larval herring mortality was around one order of magnitude higher than reported elsewhere, but similar to that of larval goby. High growth rates and elevated mortality may result from rapid increase in water temperature occurred during the investigation period, but may also involve other environmental factors not quantified within this study, e.g. predation or temperature influence on embryonic development. We suggest that the study area might act as a predation trap for fish larvae under high temperature conditions.

P27: Energy allocation in relation to salinity conditions - trade-off between somatic and gonad growth in different turbot, *Scophthalmus maximus*, populations
Wallin, I., and Nissling, A.

In fish, energetic costs of osmoregulation are expected to be low at isosmotic conditions (9-12 psu) and therefore result in lower metabolism and potentially higher growth. However, marine fishes in the Baltic Sea (6-18 psu) display smaller sizes compared to their conspecifics inhabiting marine conditions.
Energy investment in somatic and gonad growth was studied using data of size and fecundity at age in turbot from the Baltic Sea, the Black Sea and the North Sea, three ecosystems with different salinity conditions. Additionally, specific growth rate (SGR) of newly settled 0-group turbot was assessed at different salinities. No effect of salinity on SGR in 0-gr fish occurred. No effect of population on annual total energy investment (somatic and gonad growth) occurred, but a difference in investment in gonad tissue (in average 7-9% in the North and Black Seas vs 14-19% in the Baltic Sea). Thus, the trade-off between somatic and gonad growth involve lower somatic growth and thus smaller sized fish at low salinity conditions; probably an adaptation to less favourable conditions affecting egg survival.

Environmental drivers - fluctuations and change

P28: From an antagonistic to a synergistic predator prey perspective: Bifurcations in marine ecosystems
Johannessen, T.

"From an antagonistic to a synergistic predator prey perspective: Bifurcations in marine ecosystems" is the tile of a book that was published by Elsevier in 2014. The book presents predator-prey synergism as a novel perspective in ecology, defined as predator-prey relationships enhancing abundances of both predator and prey. The idea emerged during analyses of near-century long time series of observations of marine coastal ecosystems, but it is suggested that synergism may be important in some terrestrial systems too. Predator-prey synergism has wide-ranging implications for management of marine ecosystems and for theories in ecology and evolution. Resilience in marine ecosystems may be explained mechanistically by synergism, as may repeated incidents of bifurcations observed in the long time series. Bifurcations are sudden and persistent regime shifts as a result of gradually changing environmental conditions. It is suggested that global warming may induce bifurcations which in turn may result in recruitment failures in fishes and substantially reduced fish abundances.

P29: M&Ms – Mortality and megafauna or how to share resources with whales and sea birds
Volkenandt, M., Berrow, S., O'Connor, I., and Guarini, J-M.

For implementing an ecosystem-based approach to sustainable fisheries (EBFM), the ecological impacts of top predators on the resources should be integrated. The importance of small pelagic fish in the diet of cetaceans and sea birds is difficult to assess. Cetacean stomach content data are only collected by whaling countries. Sea bird information is limited to the breeding season and breeding grounds. Can this field information be adapted to other ecosystems and for the full cycle of the organisms? Ecosystem specific EBFMs are needed to encompass regional challenges i.e. climate change consequences. Referring to a ten years data set of Atlantic herring (*Clupea harengus* L.) distribution and simultaneously collected sea bird densities and cetacean sightings, is a non-invasive approach leading to a better understanding of trophic interactions within the Celtic Sea ecosystem. This study uses generalized additive models, spatial analysis and movement patterns of Atlantic herring *(Clupea harengus* L.), sea birds and cetaceans in the Celtic Sea to highlight the ecological impact of charismatic megafauna on a forage fish stock.

P30: Fishing-induced life-history changes cause increased resilience in an evolutionary model
Enberg, K., and Jørgensen, C.

Fishing changes the abundance, biomass, population structure, life-history and behavioural traits of the targeted species, potentially on decadal time-scales. This study focuses on how these adaptive changes may influence population dynamics and resilience. We use an evolving individual-based model of energy allocation and life history evolution to predict adaptations to environmental fluctuations and fishing. The model predicts that a pristine population adapted only to natural mortality has slow dynamics and suffers longer from changes in stock size, thereby showing low resilience in a fished world. However, individuals gradually adapt to the fished environment by earlier maturation and by reproducing more intensely, and this leads to quicker population dynamics and faster responses to environmental fluctuations. Fishing-induced evolutionary adaptations may thus increase the resilience of the fished population. The link between environmental variables and population measures such as recruitment or spawning stock biomass is strengthened when the population age and size structure changes towards younger and smaller. However, as a consequence of the fastened life cycle the stock recovers faster from periods of negative environmental exposure.

P31: From aerobic scope to fitness: Incorporating physiology with life history and behaviour in a model for climate change effects in fish
Jørgensen, C., and Holt, R.E.

Oxygen availability has been suggested to constitute a key limiting process prescribing how fish may cope with climate warming. While the relationship between environment and oxygen uptake is relatively well-studied, less is known about how oxygen availability constrains performance and fitness. To study this, we extend an evolutionary model for life history and behaviour of Atlantic cod by incorporating explicit oxygen budgets. Central to the model is a set of trade-offs where natural mortality increases with foraging intensity and reproductive investment and decreases with body size. In addition we incorporate increasing mortality as oxygen consumption gets close to aerobic scope. The model then finds optimal strategies for foraging, growth, and reproduction given temperature and environmental characteristics. We predict optimal temperatures for growth and fitness that lie well below that for aerobic scope. This happens because the increasing metabolic demand at higher temperatures puts extra requirements on foraging activity, digestion, and standard metabolic rate, thus progressively eating up aerobic scope. The model illustrates how physiological adaptations are part of a suite of traits that have coevolved.

P32: Factors affecting the stock recruitment of North-east Arctic haddock
Russkikh, A.

This paper considers the important issue of various abiotic factors and spawning biomass size variability to Northeast Arctic haddock (*Melanogrammus aeglefinus*, Linne, 1758) recruitment in the Barents Sea and adjacent waters. Comparison of fluctuations of abiotic factors, mainly water temperature, spawning biomass and recruitment indicates a coherent character between their values and allows to build a model of the relationship of the NEA haddock stock recruitment and the most significant factors. These relationships were amply investigated in the past. However, an unexpectedly high abundant NEA haddock stock recruitment was observed in 2006-2008 resulted in the significantly changed stock structure and fishery. In this regard, updated environmental data and haddock population biological data should be considered for their application in predicting recruitment dynamics. Possible biotic and abiotic predictors were tested and the most important ones for predicting recruitment dynamics for this species were selected. Equations with statistical analysis describing the relationship various factors on NEA haddock stock recruitment were set and recommendations on modeling population dynamics were made.

P33: Predicting recruitment variability in toothfish around South Georgia
Brigden, K.

The Patagonian toothfish *Dissostichus eleginoides* is a deep-water nototheniid fish, endemic to the Southern hemisphere. It supports a valuable fishery within the waters of the UK overseas territory of South Georgia. Relatively little is known about ideal breeding conditions although there are indications that environmental factors play a key role. Variability in recruitment has been linked to local environmental conditions and wider oceanographic phenomena such as El Nino Southern Oscillation. This PhD project, now in its first year, aims to generate knowledge essential to predicting variability in the recruitment of toothfish in South Georgia. A long-term dataset, combining observations both from the fishery (years 1996 to present) and scientific surveys (mid-1980s to present), was developed to describe toothfish reproductive dynamics. The dataset is used to describe spatial and temporal variation in abundance and distribution of mature fish and inter-annual variation in the timing of spawning. The impact of environmental data – including sea surface temperature - on timing of spawning is examined.

P34: Standardizing trends in abundance of a *Pollachius pollachius* stock harvested along the Galician coast (NE Atlantic)

Otero, J., Alonso-Fernández, A., Villegas-Ríos, D., and Bañón, R.

We developed a multimodel approach to standardize onboard observers data on *Pollachius pollachius* catch rates harvested by the artisanal fleet along the Galician (NE Atlantic) coast. Small-scale fisheries are usually ignored despite being one of the biggest contributors to worldwide fishing figures so as to local economies, society and culture. Consequently, the lack and paucity of appropriate information prevent the assessment and management of key species. By means of fitting a set of generalized linear models allowing the high fraction of zero catches we estimated trends in relative abundance of the by-catch species *P. pollachius* and related its variability with operational, temporal, spatial and environmental variables. Results of the best-fitting zero-inflated negative binomial model showed that abundance peaked in summer and decreased during the last 15 years. Moreover, warmer waters favored catches and excess zeroes were related to deeper fishing. This study aims to shed light on the stock status and dynamics of pollack off the Galician coast to provide valuable information for future assessment and management policies under the current context of ecosystem changes.

P35: What caused the collapse of walleye pollock population in Korean waters?

Kim, S., and Kang, S

Walleye pollock (*Theragra chalcogramma*, pollock hereafter) appeared in history book in 1652, and are one of the most important fishery species culturally and economically. The majority of the population is located in North Korean waters because of its coldwater preference. The catch records have been changed dramatically since the commercial fisheries begun in the early 20th century: the highest catch in 1930s, sudden decrease during 1940s~1960s due to low fishing activity, another boom in 1970s~1980s, and a continuous decrease in 1990s before they collapsed completely in 2000s. Three plausible hypotheses were introduced for such collapse: overfishing on pollock including juveniles in high biomass period, warming of seawater, and changes in ecosystem structure and function. Those hypotheses reviewed could be the basis for addressing how Korean pollock populations survive in ecosystem and how they interact with other species when they return to Korean waters again in the future. Intensive collaboration between South and North Korea with interdisciplinary concept is recommended to predict their re-visiting under changing environment and to apply proper conservation measures for better management.

P36: Spawning, and distributions of anchovy and sardinella eggs and larvae off Senegal, Gambia and Guinea: A biological response to physical forcing

Bagøien, E., Stenevik, E.K., Ostrowski, M., Sow, F.N., Ensrud, T., and Krakstad, J-O.

Vertical and horizontal distributions of anchovy (*Engraulis encrasicolus*) and sardinella (*Sardinella aurita*) eggs and larvae were studied during two survey-coverages between Cape Vert (Senegal) and Guinea. Biological sampling was accompanied by physical investigations to characterize water-masses. We detected a strong biological response of the coastal ocean to an upwelling event caused by a combination of physical forcing factors including; a local wind event and remotely controlled large-scale tilt of the thermocline surfacing near the Senegalese coast. The biological response was time-lagged, consisting of an algal bloom followed a week later by a spawning event of small pelagic fish. Their spawning distributions reflected their ecologies. The pocket of cold water in the lee of Cape Vert sustained spawning of the anchovy, which is known to have a low tolerance of warm conditions. In contrast, Sardinella proved more tolerant to higher water temperatures. Its spawning may have benefited from the shelf edge upwelling during Coverage 1, but the larvae were still surviving when the region was affected by the warm water intrusion during Coverage 2.

P37: Establishing a baseline for evaluating changes in body condition and population dynamics of sardine (*Sardinops sagax*) in the southern Benguela ecosystem
Ndjaula, H.O.N., Gerow, K.G., van der Lingen, C.D., Moloney, C.L., and Jarre, A.

Standard weight (Ws) equations were developed for sardine (*Sardinops sagax*) in the southern Benguela ecosystem and used to provide fixed baselines for calculating relative weight (Wr) indices. The method was applied to a database of sardine length and weight measurements collected from South African coastal waters from 1953 to 2010. Statistical properties of the standard weight equations were investigated. Four quadratic standard-weight equations were established, using medians, means and first and third quartiles weight measurements (Y) per caudal length class (X). A Ws model using medians ($Y = -1.825 + 2.679X + 0.224X2$) is used to calculate Wr values over time and space. The Wr indices showed periods and areas of varied fish condition, with Wr ranging from 50 to 150 for individual fish and 97 to 106 for annual averages. Possible causes of these dynamics include environmental and ecological factors. Using sardine as an exploited fish species in a changing ecosystem example, we indicated the status of the population's body condition, and a proxy for habitat quality in an ecosystem with the Wr index.

P38: The seasonal oceanographic regimes and interannual variability in the Angolan Tropical Upwelling region (6-12°30 S)
Ostrowski, M., Tchipalanga, P., Sangolay, B.B., and Fide, Q.

Indices of sardinella abundance by fish census surveys carried out in the Angolan Tropical Upwelling region (ATU) exhibit large year-to-year fluctuations. Those are routinely interpreted as responses to anomalous environmental variability. Here we combine satellite imagery with a survey derived historic time-series in order to: (i) identify the seasonal oceanographic regimes, (ii) evaluate their variability and (iii) compare the characteristics of this variability to other eastern boundary upwelling systems (EBUS). We confirm the two seasonal regimes in ATU: upwelling (Jun-Aug) and stratified regime (Feb-Mar and Oct-Nov); both controlled by large scale forcing of coastal Kelvin waves (KW) induced in the Equatorial Atlantic. We find that compared to other EBUS, environmental variability within ATU is noticeably less exposed to anomalous conditions on the interannual and inter-seasonal time-scales, except for the intra-seasonal variability dominated by acute events in Feb-Mar (termed Benguela Niños). We conclude that ATU is a climatologically stable region and that the environmental variability cannot be singled out as the main factor responsible for the observed fluctuations in the acoustic biomass indices.

P39: Coupling an oceanographic model to a fishery observing system through mixed models: the importance of fronts for anchovy in the Adriatic Sea
Carpi, P., Martinelli, M., Belardinelli, A., Russo, A., Arneri, E., and Santojanni, A.

Generalized Additive Mixed Models (GAMM) were used to couple a dataset obtained by means of a Fishery Observing System (FOS) to outputs of an oceanographic model (ROMS) implemented in the Adriatic Sea. Weekly geo-referenced catch data of *Engraulis encrasicolus* were referred to a 0.2 × 0.2 degrees grid and associated to environmental parameters weekly and spatially averaged for each cell. To identify a relationship between abundance in the catch and oceanographic conditions, GAMM without and with random effects were used. The outcome of models was examined. The GAMM incorporating two random effects had the smallest AIC and was chosen as the best model. The oceanographic variables included in this model suggested that catch abundance of anchovy in the Adriatic Sea is positively related to lower temperature, local upwelling and salinity fronts. Moreover, the outcomes demonstrated that GAMM are useful tools to combine geo-referenced catch data with oceanographic variables and that use of a mixed model approach with a spatial and temporal random effect is an appealing way to better understand the dynamics of marine species.

P40: Linking shrimp recruitment and environmental variability in French Guiana
Magraoui, A., Baulier, L., and Blanchard, F.

The shrimp fishery (*Farfantepenaeus subtilis* and *F. brasiliensis*) was the first fishery in value in French Guiana during the 1990s. However, two successive drops in recruitment in 1999 and 2006 led to decreases in stock

and hence landings of shrimp. Recruitment levels are today at their lowest. Prior analyses suggest a minor influence of harvesting and fish predation on the failure in stock rebuilding. Environment instead appears to play a pivotal role here.
In a region where few oceanographic surveys have been carried out, remote sensing has proven a powerful tool to track variations in the environment. Series of water temperature, turbidity, suspended matters and chlorophyll a concentrations were analysed and compared to the series of shrimp recruitment in order to: 1) Detect the occurrence of temporal trends or potential regime shifts in waters off French Guiana, 2) Assess the relationships between these environmental factors and recruitment success of *F. subtilis*.
While trends can be observed in some environmental factors, no clear link can be established between a single variable and the recent decline in shrimp recruitment.

Exploratory analyses, uncertainty and predictions

P41: Stock recovery for the hoki (*Macruronus magellanicus*) according to favorable decadal changes scenarios for recruitment

Curin-Osorio, S., and Cubillos, L.A.

Hoki is an important fish resource for a trawl fishery operating on the continental shelf off central Chile and Patagonian waters. At present, Hoki is depleted due to both the overexploitation and negative change in average recruitment level since 2000. Because a future change for a favorable recruitment is uncertain, feasible hoki stock recovery was studied by considering favorable scenarios of decadal changes in recruitment. An age-structured stock assessment model allowed to simulate projections of 40 years (2011-2050) under a constant exploitation rate as a proxy of MSY. Simulations (n=100) of random occurrences of favorable decadal recruitment shifts within a period of 10 years (±5 years) showed recovery of the spawning stock biomass (S) after 2025, and fully recovered by 2030. However, the probability of recovery was low (Pr[S/So>0.4]=41%). Therefore, the hoki recovery is uncertain in the near future. The target exploitation rate must be adjusted to lower levels, and actions oriented to recover the age composition are necessary during the current unfavorable recruitment regime.

P42: The impact of recruitment projection methods on recovery of alsonsino (*Beryx splendens*)

Licandeo, R.

Alfonsino (*Beryx splendens*) is a demersal fish which is caught in the Juan Fernandez Archipelago (Chile) since 1989, but in 2011 the fishery was closed and declared as overfished. Stock assessment showed that the spawning biomass was driven to less than 10% of the estimated unexploited biomass and high uncertainty in recruitment estimates. Under the Chilean fishing law, this fishery requires a rebuilding plan. The objective of this study is develop a rebuilding analysis for alfonsino in order to estimate minimum and maximum times of recovery, while taking into account uncertainty in recruitment estimates. An age-structured population model was used to conduct projections. As recruitments have a profound impact on the dynamics, three methods were used to generate future recruitment: random recruitment, random recruits per-spawner, and a Beverton-Holt relationship. Time of recovery, future catch and spawning biomass showed differences depending on the method used to generate recruitment. This study shows the importance of assessing the uncertainty in future recruitment in recovery plans, especially with highly depleted stocks and long-lived species.

P43: Implications of the potential loss of recruits and exogenous recruitment on the fishery of Patagonian toothfish *Dissostichus eleginoides* in southern Chile

Henriquez, V., Cubillos, L., and Licandeo, R.

Patagonian toothfish supports important fisheries throughout South America. In Chile, it is managed as a discrete stock (47°S – 57°S). However, two spawning areas have been identified: Burdwood Bank in South Atlantic (SA) and Cape Horn in the South Pacific Ocean (SP). Simulation studies based on oceanographic circulation and otolith microchemical showed that there is a connectivity between fish from SA and SP.

Therefore, the Chilean population is constituted by residents and migrants. A proportion of fish, in their early stages, are drifted by currents from SP to SA, contributing to the fishery in SA. There is evidence that a percentage of migrants could come back years later to recruit into the Chilean fishery. An age-structured simulation model with spatial structure was developed to evaluate the consequences of input and output of individuals to the Chilean fishery and to examine the importance of recruitment from SA. The proportion of residents supports the Chilean fishery, however, the input of recruits from SA are more important to the population productivity than individuals lost toward SA.

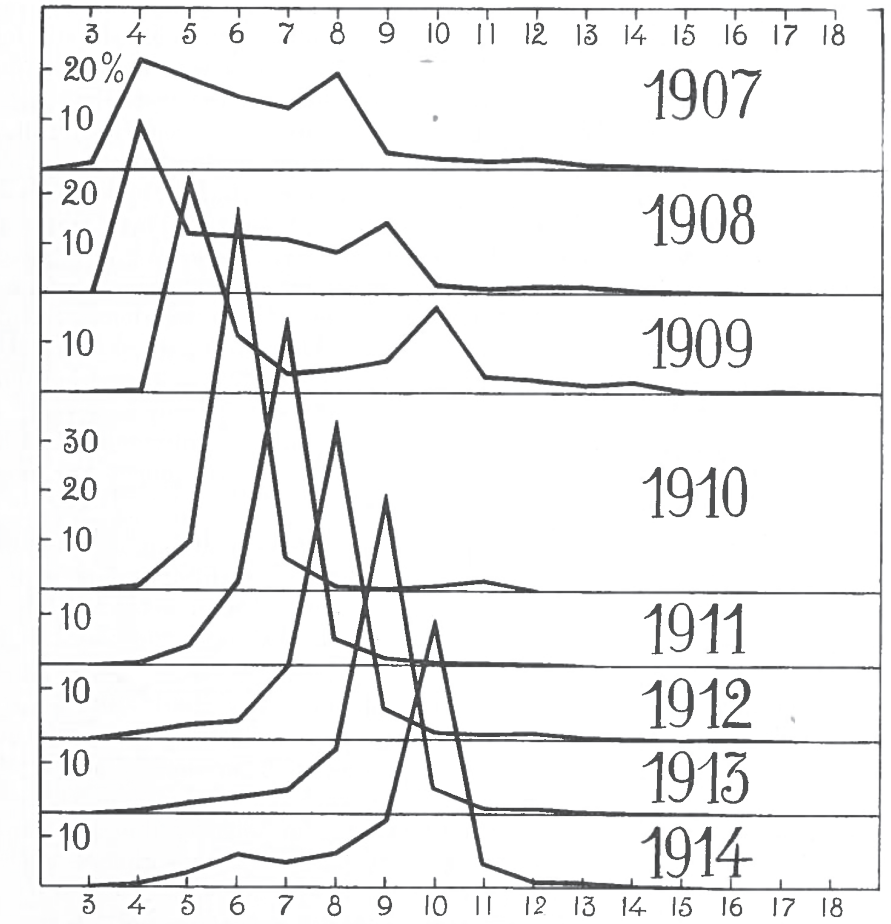

Fig. 133. Composition in point of age of spring herring for the years 1907—1914; average of all samples examined in each year. For 1914 only samples from February included.

Hjort J. (1914) *Fluctuations in the great fisheries of Northern Europe.*
Rapports et procès-verbaux - Volume XX. Copenhagen: Andr. Fred. Høst & Fils.

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Notes

According to his son, Ering F. Hjort. This was Johan Hjort's favorite image of himself.
Picture: Institute of marine research, Norway