Growth and food consumption of whiting Merlangius merlangus

In the western Baltic Sea (WBS), whiting Merlangius merlangus is the main piscivorous fish together with cod Gadus morhua. In the present study, we investigate the growth and food consumption rates of WBS M. merlangus and compare the growth rates of males and females with those of M. merlangus in the North Sea (NS). Food consumption rates are estimated directly from sampled stomach contents in the WBS using a gastric evacuation rate model and indirectly by using a static energy-budget model together with the growth rates. The results indicate that male and female M. merlangus in the WBS have similar feeding and growth strategies, while in the NS M. merlangus show more pronounced differences in food consumption and growth dynamics between the sexes. Female WBS M. merlangus grow significantly slower than their conspecifics in the NS, but there is no significant difference for males. Sexual size dimorphism is seen in both areas, but for M. merlangus in the WBS the difference is less pronounced. Food consumption rates in the WBS differ between seasons, with the lowest food intake in the first 2 quarters of the year and the highest in the 3rd quarter. No differences in consumption rates were seen between males and females, which could be related to the more similar growth pattern seen for M. merlangus in the WBS.
Diet composition and food consumption rate of harbor porpoises (Phocoena phocoena) in the western Baltic Sea

Stomach content composition and prey-specific consumption rates of juvenile and adult harbor porpoises (Phocoena phocoena) were estimated from a data set including 339 stomachs collected over a 32 yr period (1980–2011) in the western Baltic Sea. The stomach contents were mainly hard parts of fish prey and in particular otoliths. The bias originating from differential residence time of otoliths in the stomachs was addressed by use of a recently developed approach. Atlantic cod and herring were the main prey of adults, constituting on average 70% of the diet mass. Juvenile porpoises also frequently consumed gobies. Here, the mass contribution by gobies was on aver-age 25%, which was as much as cod. Other species such as whiting, sprat, eelpout, and sandeels were of minor importance for both juveniles and adults. The diet composition differed between years, quarters, and porpoise acquisition method. Yearly consumption rates for porpoises in the western Baltic Sea were obtained in three scenarios on the daily energy requirements of a porpoise in combination with an estimate including the 95% CLs of the porpoise population size. Cod of age groups 1 and 2 and intermediate-sized herring suffered the highest predation from porpoises.

General information
Publication status: Published
Organisations: Section for Marine Ecology and Oceanography, National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, University of Veterinary Medicine Hannover, Foundation
Contributors: Andreasen, H., Ross, S. D., Siebert, U., Andersen, N. G., Ronnenberg, K., Gilles, A.
Pages: 1053-1079
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: Marine Mammal Science
Volume: 33
Issue number: 4
ISSN (Print): 0824-0469
Ratings:
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 1.79 SJR 1.016 SNIP 1.066
Web of Science (2017): Impact factor 1.909
Web of Science (2017): Indexed yes
Original language: English
DOIs: 10.1111/mms.12421
Source: FindIt
Source-ID: 2370891684
Research output: Contribution to journal › Journal article – Annual report year: 2017 › Research › peer-review

An important step towards accurate estimation of diet composition and consumption rates for the harbor porpoise (Phocoena phocoena)

General information
Publication status: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Living Resources, Section for Marine Ecology and Oceanography, University of Veterinary Medicine Hannover, Foundation
Contributors: Ross, S. D., Andreasen, H., Andersen, N. G.
Pages: 1491–1500
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: Marine Mammal Science
Volume: 32
Issue number: 4
ISSN (Print): 0824-0469
Ratings:
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.87 SJR 1.123 SNIP 0.98
Web of Science (2016): Impact factor 1.66
Species interactions in the western Baltic Sea: With focus on the ecological role of whiting

The food web of the upper trophic levels in marine ecosystems is often complex, encompassing multiple biological interactions. One species may serve as prey, predator and competitor at the same time, and the interactions are likely to change with the ontogenetic development from juvenile to adult. Disentangling food web dynamics is important for both ecologists and conservationists involved with management. Multispecies assessment models and ecosystem-based trophic models are becoming increasingly used as tools to investigate and assess biological interactions and predation impacts of key species in the food web. Furthermore, the models can be used to evaluate effects of anthropogenic activities such as fishing, eutrophication and pollution from land-based activities and shipping. Despite the growing awareness of the strength of these models to describe food web dynamics and ecosystem functioning, implementation of the models in strategic management advice for commercially important fish stocks and protected marine mammals is not common practice. This is due to the lack of sufficient information about species interactions including knowledge about the diet, food intake and growth dynamics. This thesis investigates the ecological role of whiting in the western Baltic Sea. The ecosystem is more brackish than for example the North Sea and the species diversity of the upper trophic levels is lower and the food web simpler. The main piscivorous fish species are whiting and cod, while herring and sprat are the predominant forage fishes. The growth dynamics and feeding ecology of whiting in the western Baltic Sea has not previously been investigated, despite the fact that it is an important species both in the commercial fishery and in the food web of the North Sea. Due to differences in hydrography, species diversity and fishing pressure, the ecological role of whiting in the Baltic Sea is likely to differ considerably from that of its conspecific in the North Sea. The western Baltic Sea also provides a habitat for protected marine mammals, including the harbour porpoise, the grey seal and the harbour seal, which potentially prey on and compete for food with whiting. Here, the growth dynamics and feeding ecology of whiting in the western Baltic Sea is investigated and discussed in an ecosystem context. Furthermore, the diet of the harbour porpoise is examined and the interactions between whiting, cod and porpoises are discussed. Describing the fish population dynamics and biological interactions of the main species at the higher trophic levels in the western Baltic Sea is an important step towards a broader regional understanding of the ecosystem dynamics. The information can be used to inform single species and multispecies assessment models for fish and ecosystem-based trophic models, and, thus, potentially improve management advice for fish stocks and protected marine mammals in the western Baltic Sea.
Management of fishery: Importance of fish food web dynamics in coupling of multispecies and bio-economic fisheries management evaluation models

How does prey quality affect life-history traits under different temperature regimes?

Importance of food web dynamics in coupling of multispecies models and bio-economic fisheries management evaluation models

A reliable method for ageing of whiting (Merlangius merlangus) for use in stock assessment and management
top predator in the western Baltic Sea, where it is fished commercially although less extensively compared to the North Sea. Although the species is considered one of the most difficult gadoids to age, few efforts have been made to shed light on the ageing problems. The aim of the present study was to identify and validate the 1st winter ring and to examine the visibility of the subsequent winter rings. Microstructure analysis was used to confirm the 1st winter ring. Additionally, otolith growth trajectories were obtained, confirming the allometric growth as seen in many fish species. The method for ageing of whole otoliths presented in this study can be directly implemented in future ageing of whiting otoliths from the Baltic Sea – and potentially also adjacent areas where the conspecifics have similar growth rates.

**General information**
Publication status: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Ecology and Oceanography
Contributors: Ross, S. D., Hüssy, K.
Pages: 825-832
Publication date: 2013
Peer-reviewed: Yes

**Publication information**
Journal: Journal of Applied Ichthyology
Volume: 29
ISSN (Print): 0175-8659
Ratings:
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 0.99
Web of Science (2013): Impact factor 0.903
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Original language: English
Electronic versions:
Ross_jai.pdf
DOIs:
10.1111/jai.12204
URLs:

**Does whiting play a central role in the food web of the western Baltic Sea?**

**General information**
Publication status: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Ecology and Oceanography
Contributors: Ross, S. D., Nielsen, J. R., Gislason, H., Andersen, N. G.
Publication date: 2013
Peer-reviewed: No
Event: Abstract from ICES Annual Science Conference 2013, Reykjavik, Iceland.
Research output: Contribution to conference → Conference abstract for conference – Annual report year: 2013 → Research

**Haemoglobin genotypes in cod (Gadus morhua L): their geographic distribution and physiological significance**

**General information**
Publication status: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Ecology and Oceanography, Centre for Ocean Life, Norwegian University of Science and Technology, University of Copenhagen
Contributors: Ross, S. D., Behrens, J. W., Brander, K., Methling, C., Mork, J.
Pages: 158-168
Publication date: 2013
Peer-reviewed: Yes

**Publication information**
Journal: Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology
Volume: 166
How important is whiting in the western Baltic Sea ecosystem?

General information
Publication status: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Ecology and Oceanography
Contributors: Ross, S. D., Nielsen, J. R., Gislason, H., Andersen, N. G.
Publication date: 2013
Peer-reviewed: Yes
Event: Abstract from Baltic Sea Science Congress, Klaipeda, Lithuania.

Recruitment decline in North Sea herring is accompanied by reduced larval growth rates
The stock of North Sea autumn spawning herring (Clupea harengus L.) has shown an unprecedented sequence of ten years of sharply reduced recruitment, in spite of a high spawning biomass. Recent work has identified this below-expected recruitment as being determined during the larval phase: however, the underlying mechanism remains elusive. In this study we analysed archived larval samples captured before and after the onset of the reduced survival to test the hypothesis of a concurrent change in the larval growth rate. Individual larval growth rates, averaged over the 21 days prior to capture, were estimated for two hundred larvae from four different years using a model-based analysis of the otolith ring-widths. Hydrographic-backtracking models complemented the otolith analysis by reconstructing the environmental history and spawning origin of each larva. A significant reduction in net larval growth rate of 8%, concurrent with the reduced larval survival and recruitment, was identified: after correcting for the effect of other explanatory variables (e.g. temperature changes), the gross reduction was found to be 12%. This reduction is most probably due to changes in either the amount or quality of available food. The study demonstrates the potential in coupling of two different techniques, the otolith microstructure analysis and the hydrographic modelling, for affording new insights into fish early-life history. Finally, the study provides a novel indication of the association between reduced growth and larvae survival, thereby narrowing the range of potential mechanisms underlying the observed reduction in the recruitment of North Sea autumn spawning herring.
Coupling otolith microstructure analysis and hydrographic backtracking suggests a mechanism for the 2000s North Sea herring recruitment failure

The North Sea autumn spawning herring (Clupea harengus) has, since the 2002 year class, shown an unprecedented sequence of ten years of sharply reduced recruitment, in spite of a high spawning biomass and low fishing mortality. Recent work has identified this reduction in recruitment level (or stock productivity) as taking place during the larval overwintering phase: however, the underlying mechanism remains elusive. In this study we analysed archived larval samples captured both before and after the onset of the reduced survival to test the hypothesis of a reduction in the larval growth rate. Individual larval growth rates, averaged over the 30 days prior to capture, were estimated for 200 larval otoliths from four different years using a model-based analysis of the ring widths. The otolith measurements were complemented with additional information derived from hydrographic backtracking models (e.g. average temperature experienced, time available for feeding and spawning origin) to reconstruct the recent history of the larvae. A mixed-modelling approach was then employed to analyse the combined data: after correcting for the effect of the other variables, a significant reduction in larval growth rate, associated with the onset of the reduced recruitment, was identified. These results suggest that the reduced recruitment is associated with a reduction in the growth rate of the larval survivors, most probably through changes in either the amount or quality of the available food. Furthermore, this study demonstrates how coupling two different techniques (otolith microstructure analysis and hydrographic modelling) can yield unique insights into fish ecology.
for implementing the directives has been limited by insufficient models, deficiencies in terms of uncertainties, local and regional aspects and lack of knowledge on the interplay between agriculture, fishery, environmental qualities in all surface waters, and economy. The project aimed to establish an interdisciplinary and international approach designed to establish a body of knowledge to develop tools, models, scenarios and predictions in order to integrate science and management from agriculture, fishery, aquatic environments and economy into a common platform. The main aims were to link the complex interplay between land use in the drainage basins, the transport of nutrients to water bodies, biogeo-chemistry of freshwater and marine water, marine ecosystem dynamics and the removal of biomass and nutrients in marine fisheries all integrated into a management strategy evaluation (MSE) framework consisting of linked catchment area and river-run-off models, marine bio-geo-chemical models, end-to-end marine ecosystem models, fishery models, economic and cost-minimization models, and ecosystem services assessments models. Such a complex model and MSE framework could be used to assess effects of changing market conditions, changed agricultural and fishery support policies, as well as fulfillments of water related directives.

Tasks and Deliverables
The Danish Strategic Research Council financed project IMAGE was a strategic research alliance between central Danish and international fisheries and marine environment based university institutes. The project integrated, educated, and trained new researchers and private and public end-users to develop and work with a number of empirical and dynamic models and management tools, further developed into cross traditional media and science-based decision support systems, to strengthen national and international environmental management. The results published in a high number of scientific peer reviewed articles have provided major scientific progress. The results and research quality included analyses of novel processes and development of new and improved models, integrated prognoses and scenarios for the interplay between changes in the drainage basins and the ecological and economic consequences, and a number of science-based decision support tools. The work involved (i) identification of key elements and reduction of uncertainties in using complex models, (ii) designing, developing and integrating important new concepts in the models, (iii) linking models and evaluating their ability to detect and follow changes in terrestrial environments into ecological and economic consequences, and (iv) strengthened Danish research in linking science, modeling and management of the environment and economics and thereby consolidating a strong international position. The DTU Aqua has focused on further development, implementation and validation of advanced models and fisheries and ecosystem management evaluation tools. Development, calibration and implementation of the Baltic ATLANTIS end-to-end ecosystem and tropho-dynamic model linked to the HBM-ERGOM physical and bio-geo-chemical models and the FISHRENT fishery economic model; Further development and implementation of the bio-economic and individual vessel based multi-stock-multi-fleet DISPLACE simulation model; Dynamic coupling of the Baltic FLR multi-stock-multi-fleet bio-economic model to the SMS-Multi-Species model. The focus has been on biological interactions and integrated fisheries interactions.

Partners
The project had 12 project partners mainly from Danish universities (AU, DTU, KU, SDU) and national fisheries economics and fisheries research institutes (SMHI Sweden), but also from American, Swedish and Finnish universities as well as SMEs (e.g. DHI). The project was coordinated by Aarhus University. DTU Aqua was main project developer, WP4 leader and member of the Project Steering Group.

This project was funded by the Danish Council for Strategic Research.
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Palacz, A., Project Participant, National Institute of Aquatic Resources
Andersen, B. S., Project Participant, National Institute of Aquatic Resources
01/01/2010 → 31/12/2015
Keywords: Research areas: Fisheries Management & Ecosystem based Marine Management
Project: Research

Activities:

International Council for the Exploration of the Sea (External organisation)
Period: 2012 → …
Stine Dalmann Ross (Participant)
National Institute of Aquatic Resources
Section for Management Systems

Description
ICES Working Group on Multispecies Assessment Methods (WGSAM)
Degree of recognition: International

Related external organisation
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar