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## Report of the Workshop on Growth–increment Chronologies in Marine Fish: climate–ecosystem interactions in the North Atlantic (WKGIC)

2–3 December 2014

Hamburg, Germany



**ICES**

International Council for  
the Exploration of the Sea

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l'Exploration de la Mer

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## Executive summary

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Over the past several decades, thousands of otoliths, bivalve shells, and scales have been collected for the purposes of age determination and remain archived in European and North American fisheries laboratories. Advances in digital imaging and computer software combined with techniques developed by tree-ring scientists provide a means by which to extract additional levels of information in these calcified structures and generate annually-resolved (one value per year), multidecadal time series of population-level growth anomalies. Chemical and isotopic properties may also be extracted to provide additional information regarding the environmental conditions these organisms experienced. Given that they are exactly placed in time, chronologies can be directly compared to instrumental climate records, chronologies from other regions or species, or time series of other biological phenomena. In this way, chronologies may be used to reconstruct historical ranges of environmental variability, identify climatic drivers of growth, establish linkages within and among species, and generate ecosystem-level indicators.

The first workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC) met at the Johann Heinrich von Thünen Institute in Hamburg, Germany, 2–3 December 2014, chaired by Bryan Black (USA) and Christoph Stransky (Germany). Twenty-three participants from eleven different countries attended. Objectives were to i) review the fundamentals of crossdating and chronology development, ii) review the application of growth-increment widths in marine fish and bivalve species to biochronologies, iii) discuss assumptions and limitations, iv) identify the most promising species and collections for chronology development, and v) initiate cooperative projects or training exercises to commence after the workshop.

The workshop began with an overview of tree-ring techniques of chronology development, including a hands-on exercise in crossdating. Next we discussed the applications of fish and bivalve biochronologies and the range of issues that could be addressed with talks from several workshop participants. We then reviewed key assumptions and limitations after which we developed a preliminary inventory of archival holdings that would be most suitable for chronology development, specific to species and regions. In several cases, there is the potential to generate continuous centennial-length time series of fish growth anomalies. Finally, we agreed that the next step is to hold a hands-on training workshop in 2015. The objective would be to develop a biochronology as a group and in so doing, provide participants the skills with which to apply tree-ring techniques to their otolith collections. Overall, we hope to increase the use of these techniques, and over the long-term, develop networks of biochronologies for integrative analyses of ecosystem functioning and relationships to long-term climate variability and fishing pressure.

## 1 Background

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Over the past decade, a growing network of chronologies in the North Pacific has been developed from annual growth-increment widths in marine fish and bivalves using tree-ring techniques. These chronologies have been integrated across species, marine regions, and other biological time series to reconstruct growth and environmental variability and identify climate drivers of productivity and functioning at the ecosystem level. For example, chronologies of rockfish (*Sebastes* spp.) and salmon (*Oncorhynchus* spp.) have been combined with indices of seabird reproductive success to demonstrate that winter upwelling is critical to ecosystem functioning in the California Current. This winter upwelling pattern is driven by broad-scale atmospheric pressure systems that facilitate or block onshore flows of precipitation. Due to their drought sensitivity, tree-ring chronologies can be used to hind-cast this biologically important winter pattern over the past six centuries, documenting that variance in the system has risen to unusually high levels over the past 100 years that has been driven by a series of winters with anomalously low upwelling. Moreover, these California Current chronologies have been compared to those developed in the Gulf of Alaska, showing that the two ocean domains co-vary out of phase. Robust growth in the north is associated with poor growth in the south and vice versa, a pattern largely driven by winter El Niño Southern Oscillation activity. Beyond the Pacific, such approaches have resulted in fish chronologies off New Zealand and along the Australia west coast.

Tree-ring techniques have also been used to develop exactly dated chronologies for the extremely long-lived bivalve species *Arctica islandica* and *Glycymeris glycymeris* in the North Sea and North Atlantic for the purposes of reconstructing ocean circulation and climate over the past several centuries. This work suggests that such approaches for chronology development may be broadened to include fish in these regions. Perhaps the greatest impediment to expanding this work remains a lack of knowledge as to suitable species and collections available for chronology development in the Atlantic, North Sea, and Baltic region. Thus, the proposed workshop would assemble those most familiar with otolith (and bivalve) collections to identify species and locations that would be most suitable, and to identify the most promising research directions for the eastern Atlantic region. The ultimate goal is to initiate biochronology projects and / or training course(s) on chronology development to commence after the workshop.

## 2 Fulfilment of Objectives

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**Objective 1. Review the applications of chronologies developed from growth-increment widths in the hard parts (otoliths, shells, scales) of marine fish and bivalve species.**

Applications of biochronologies to issues of marine climate and ecology were addressed in a series of four talks, abstracts for which are provided below.

1. **Bryan Black, University of Texas Marine Science Institute, United States: From the trees to the seas: multi-species perspectives on long-term climatic and ecological variability**

Climate variability and change substantially impact the structure and functioning of marine ecosystems, yet establishing these relationships is complicated by the relatively short timespans covered by existing instrumental records and observational bio-

logical time series. One way to address this issue is through the analysis of annual growth increments in the hard parts of long-lived fish, mollusk, and coral species. Growth-increment chronologies are exactly placed in time, extend over multiple decades, and can be used to quantify impacts of climate on growth and hind-cast climate prior to the start of instrumental records. Moreover, chronologies can be integrated with observational records of phenology, growth, community composition, and reproduction to yield ecosystem-level perspectives on climate impacts and generate ecosystem indicators. For example, a Pacific rockfish and salmon chronologies have been combined with records of seabird reproductive success and tree-ring chronologies to document the importance of winter climate in the California Current and adjacent terrestrial systems. On broader spatial scales, chronologies from the California Current inversely covary with chronologies from the southern Gulf of Alaska, highlighting an inverse productivity regime between these two systems and the potential to compare across ocean domains. Finally, crossdating can be used to improve accuracy of age estimates, better resolving episodic recruitment events than simple ring counts in the long-lived Pacific geoduck (*Panopea generosa*). A network of growth-increment chronologies in the northeast Pacific (20+) is rapidly expanding and represents a tool to identify key climatic variables and their effects within and among species, trophic levels, and ecosystems.

## 2. Paul Butler, School of Ocean Sciences, Bangor University, United Kingdom: The state of the science: bivalve sclerochronology

The development of long bivalve chronologies began with work on *Arctica islandica* from the northern North Sea. In a paper published in 1997, Rob Witbaard developed three centennial scale chronologies using live collected specimens from different sites in the Fladen Ground. In subsequent work, chronologies were developed using dead collected (subfossil) shells, either to extend live chronologies, or to form standalone 'floating' chronologies. In 2009 the first near-500 year chronology (492 years) was constructed, for *A. islandica* from Irish Sea waters close to the Isle of Man. Determinations of the longevity of *A. islandica* have rapidly increased from 149 years in 1980 to 500 years in 2013. Its actual maximum lifespan is unknown. The most long-lived animals have been found off the north coast of Iceland, and a 1300-year crossdated chronology includes several that lived for more than 300 years.

There are now a number of distinct applications of bivalve sclerochronology. Using multicentennial time series, it is possible to calibrate the marine radio-carbon reservoir in time through radiocarbon analysis of absolutely dated shell material; these dated analyses can then be compared to the modelled global marine reservoir allowing the reservoir correction ( $\Delta R$ ) to be determined. Changes in  $\Delta R$  through time can be interpreted in terms of the age of the dominant water mass in the area, allowing the historical oceanography to be inferred.

Long-lived bivalves found in shell middens can be crossdated, enabling the construction of an extended and precisely constrained archive of the history of site occupation.

The first 1000-year absolutely dated marine temperature record (using stable oxygen isotope analysis of shell material from the Iceland chronology) has been carried out, and this work is in review at Science (D.J. Reynolds *et al.*).

It is also possible to use bivalve chronologies to validate model outputs. A proposed bidecadal response of the North Atlantic meridional overturning circulation to volcanic activity is supported by changes in bivalve growth in the Iceland chronology.

Finally, a new project (ArcheoSHELL) proposes using ancient DNA from subfossil shells to monitor changes through time in the environmental meta-genome associated with *A. islandica*.

Important new work is now being carried out as part of the ARAMACC project (Annually Resolved Archives of MARine Climate Change). In this project, a suite of new multicentennial chronologies for the northeast Atlantic is being constructed, together with research into the environmental drivers of shell growth, new geochemical proxies, the response of crystalline structures in the shell top environmental change, and proxy-model comparisons.

**3. Peter Grønkjær, Department of Biological Sciences, Aarhus University, Denmark: Changes in growth and trophic position of Atlantic cod**

Data that can be used to substantiate links between climate variability, ecosystem changes and fish population productivity is generally limited to data collected during the last 30–40 year or compromised by frequent data gaps. As a consequence, decadal or multi-decadal patterns in fish growth are difficult to resolve and assign to specific environmental drivers. In order to improve our ability to link Atlantic cod growth to environmental variability, the CODLOG project has created continuous otolith based growth chronologies of Atlantic cod from the Nuuk fjord from 1926 to 2009 and from the Faroe Shelf from 1947 to 2009. In addition, we have developed a methodology to extract stable nitrogen and carbon isotopes from the protein matrix of the otoliths. This technique has enabled us to create corresponding chronologies of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ , - proxies for cod trophic position and carbon source, respectively. The analyses of these data have revealed interesting growth patterns and a wide array of relationships with environmental variables. These include significant cycles of growth with periods from 5 to 26 years, a strong relationship between the Atlantic Multi-decadal Oscillation (AMO) and the growth of Faroese shelf cod, and a relationship between  $\delta^{13}\text{C}$  and the growth of Nuuk fjord cod. The data also suggest that there exist transition points in the chronology, where the relationship between a specific environmental driver and a measured variable breaks down (e.g. AMO and Faroese cod growth around 1990) and the environmental impact on growth is mediated through another driver (NAO, 1990–2009). In this talk I will give an overview of the CODLOG project, the derived understanding of the links between environmental variability, ecosystem change and cod growth, and how these links influence the productivity and resilience of North Atlantic cod populations.

**4. Audrey Geffen, Department of Biological Sciences, University of Bergen, Norway: Imprints of recent climate variations: coastal cod fisheries in the middle ages**

Biochronology approaches can be coupled with many other chemical and biological analyses to merge archeological and live collected otoliths for climate related studies. These combined analyses are the only way to access the historic and recent seasonal and annual patterns, enabling an extension of modern chronologies and instrument records.

Otoliths from archaeological collections are a valuable source of samples for historical data on fish growth, since the structures are so well preserved and the sources well dated. We have an informal “Hard Rock” group of researchers in Norway and Denmark, with collaborations in Iceland, the Faroes Islands, and the USA/Sweden, interested in long-term changes in marine productivity and fish populations. We’ve connected otolith archives, archaeological samples, and bivalve samples, measuring growth chronologies, stable isotopes (for temperature, metabolism, and trophic ecol-

ogy) and microchemistry (for migration and population discrimination). In addition, DNA extracted from the otoliths and otolith shape analysis allow for more detailed studies of population shifts and patterns of human exploitation over centuries and millennia.

This presentation showcases the results of our study of Viking age cod otoliths (published as Geffen, A. J., Hoie, H., Folkvord, A., Hufthammer, A. K., Andersson, C., Ninnemann, U., Pedersen, R. B., *et al.* 2011. High-latitude climate variability and its effect on fisheries resources as revealed by fossil cod otoliths. *ICES Journal of Marine Science*, 68: 1081-1089). With this collection we showed the effects of the Little Ice Age which slowed individual growth of cod during this period. We showed that human settlements in northern Norway exploited two different cod populations, and that these populations exhibited different growth and movement patterns during their life history.

Many studies have combined archeological and current archived otolith material to analyse growth patterns in areas such as the North Sea and the Baltic, as well as in the Mediterranean Sea. By adding chemical and genetic analyses to this approach, we have built up a powerful “biochronology toolbox” – and we are currently raising awareness of our activities through proposals and presentations.

**Objective 2. Review the fundamentals of chronology development. Topics to be covered include visual crossdating, increment measurement, and relevant statistical approaches.**

Bryan Black provided a talk on basic chronology development technique with particular emphasis on the dendrochronology technique of crossdating, which is employed to ensure that all increments are assigned the correct calendar year of formation. Crossdating, is based on the assumption that some aspect of the environment influences growth, and that as the environment fluctuates over time, it induces a synchronous growth pattern among individuals of a given site and location. For living samples, crossdating is the process of cross-matching this synchronous ‘bar code’ among all individuals, working backward through time from the partial increment formed at the known year of collection. If an increment has been missed or falsely identified, the growth pattern in that individual will be offset by a year, beginning where the error occurred. The error is then confirmed by re-examining the wood for a micro or false ring. Samples with unknown death dates may also be crossdated among one another or with live-collected samples, assuming there is sufficient temporal overlap. In this way, highly accurate recruitment histories and growth-increment chronologies may be generated. Crossdating has proven effective on a wide range of long-lived freshwater and marine bivalve and fish species.

Following this introduction, the group completed a crossdating exercise using images of freshwater drum (*Aplodinotus grunniens*) otolith thin sections from samples collected in 2010 and 2009. Experienced crossdaters were paired with inexperienced participants and each group was charged with describing synchronous growth patterns among fish by listing those calendar years in which conspicuously narrow or wide increments occurred. In this way, participants were able to see the synchronous growth ‘bar code’ shared among fish, and that all groups arrived at the same dates and conclusions.

This exercise concluded with a description of how otolith growth-increment widths are measured and how crossdating is statistically verified using dendrochronology software such as COFECHA. Basic techniques of chronology development were cov-



ered, including the statistical approaches used to remove age-related growth declines from measurement time series and how to generate a master chronology for the given species and site.

**Objective 3. Discuss the assumptions and limitations of chronology development as well as the characteristics of species and collections for which these approaches would be ideally suited.**

Bryan Black led a discussion on the underlying assumptions and limitations of tree-ring approaches for developing biochronologies and ensuring that all increments are exactly placed in time. The first of these assumptions is that growth increments must clearly be visible and easily delineated. If growth-increment boundaries are unclear, then increment widths cannot be seen for crossdating or measuring. There must also be interannual (year-to-year) variability in increment width for crossdate to be possible. If beyond the typical age-related growth decline, increments are too regular in width, then there is no pattern with which to use for crossdating. The second assumption is that individuals are sufficiently long-lived to crossdate (greater than 20 years). This is necessary to have the confidence that pattern matches among individuals are not spurious. Moreover, it is unlikely to find distinctive growth signatures in very short intervals of time, greatly limiting the use of crossdating.

In comparison to tree-ring chronologies, there are additional considerations for otolith chronologies. The first of these is that fish are mobile, and caution must therefore be used when attempting to apply crossdating to migratory species. There are also issues of differences between sexes and diversion of energy from growth to reproduction, especially for females. Finally, juvenile and adult life stages must be considered as there may be contrasting ecologies and climate-growth relationships. As a group, we agree that there are no rules for identifying ideal species for crossdating. Indeed, some migratory species such as hake (*Merluccius*) may be suitable. Testing whether crossdating applies to a collection of otoliths is the ultimate test for identifying whether synchronous growth patterns occur, and the spatial extents across which they are coherent. Finally, there is the assumption that increments are indeed annual. If a collection crossdates and the resulting chronology relates to annually-resolved climate records in ways that make sense ecologically, then there is strong evidence of annual periodicity. Ideally, however, the annual periodicity should be confirmed independently with for example radiometric dating, bomb-carbon dating, mark recapture, or marginal increment analysis. Note that crossdating has not been attempted on subannual increments (e.g. daily rings), but this may be a possibility.

**Objective 4. Identify species and collections that are most promising for chronology development based on participants' expertise on otolith interpretation and institutional collections. Also discuss potential research projects and funding sources.**

After discussing assumptions, limitations, and the attributes of suitable collections for crossdating, the workshop divided into subgroups to list those species and sites that might have a high probability of success. Ideally, these are species that are long-lived, have clearly-defined increments, and an archival collection that dates back over several years or decades.

Upon reconvening as a full group to compile a master list (see Annex 6), we found that few long-lived species met chronology development requirements. Instead, we identified a number of short-lived species with extraordinarily long archives (70 to

100 years; Annex 6). In his talk earlier in the workshop, Peter Grønkjær provided examples of 100 year cod growth-increment chronologies developed using archival otolith collections. Increment boundaries are well defined and errors are likely to be quite low such that measurement data are exactly placed in time even though these individuals are too short-lived for crossdating. Should an error occur, its effects would be very limited in time, unlike long-lived species in which decades of measurements could be frame-shifted by a year in the event of a false or missed ring.

Ultimately, the greatest potential for centennial-length chronologies may be for short-lived species with archival collections. The group identified the need to modify tree-ring techniques of estimating minimum sample sizes and related techniques to accommodate chronology development for these shorter-lived species. Indeed, chronologies can be developed with the same quality as those generated from long-lived crossdated datasets. It would be ideal to provide quantitative evidence of such using modified tree-ring techniques.

Ultimately, width is only one of many otolith growth-increment properties that could be used to address fish life history. Combining width with microchemical, isotopic, and genetic properties could open new possibilities for describing population response to climate and / or fishing pressure. Moreover, these other approaches could broaden the temporal scope of analysis to include subannual (seasonal) timescales. Where appropriate (especially for long-lived species), dendrochronology approaches provide excellent temporal controls, but the power of the analysis could be greatly expanded by including a range of increment properties beyond width.

**Objective 5. Based on the results, conclusions, and recommendations from this workshop, initiate an international cooperative project or training program on chronology development to commence after the workshop.**

The group identified the need for additional training in biochronology techniques, which could facilitate the generation of new dataset for the region. Thus, we propose a hands-on training workshop in which participants will learn all aspects of crossdating and chronology development by generating a biochronology using samples from the North Atlantic region. Ideally, this workshop would be held in fall of 2015 at an otolith laboratory; Palma, Mallorca, Spain, and Split, Croatia, were suggested as possible locations. The workshop would be a week in length and modelled after the North American Dendroecological Fieldweek (NADEF) <http://dendrolab.indstate.edu/nadef/>. NADEF 2015 will be held in June 1-10 in Maine, USA, and a sclerochronology section will be offered. However, the participants agreed that a European sclerochronology workshop would be easier to attend.

The group also agreed that there are too few biochronologies to pursue integrative projects; datasets must first be built and a training workshop would help achieve this goal in the long term. There may be funding sources available with which to fund biochronology research, including the European Commission's Horizon 2020 programme. The specific goals of the research would be guided at least in part by the requirements in the call for proposals. Another important issue to pursue is investigating the existing literature for studies related to biochronologies, but use different terminology such as "back calculation." Indeed, there is a number of studies in which long-term time series of fish growth have been quantified using otolith data, but for different purposes than those proposed for this next generation of biochronology work. These earlier studies will no doubt provide guidance on suitable species and collections for biochronology development and proof of concept to increase

chances of funding. A review paper on these studies and their relevance to bio-cronology work would be an important contribution.



**WKGIC group picture, Thünen Institute, Hamburg, Germany, 3 December 2014.**

## Annex 1: List of participants

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Bryan Black (Co-Chair)	USA	University of Texas at Austin	bryan.black@utexas.edu

## Annex 2: WKGIC terms of reference

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### **Workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC)**

**2013/2/SSGEF09** A Workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC), chaired by Bryan Black, USA, and Christoph Stransky, Germany, will meet in Hamburg, Germany, 2–3 December 2014 to:

- a) Review the applications of chronologies developed from growth-increment widths in the hard parts (otoliths, shells, scales) of marine fish and bivalve species, including: age verification, generation of multi-decadal time series of population-wide growth anomalies, establishing climate-growth relationships, disentangling human and climate impacts, comparisons of growth among diverse taxa or across marine regions, and development of ecosystem-level indicators;
- b) Train participants on the fundamentals of chronology development. Topics to be covered include visual crossdating, increment measurement, and statistical approaches to chronology development;
- c) Discuss the assumptions and limitations of chronology development as well as the characteristics of species and collections for which these approaches would be ideally suited, including issues of longevity, archival history, use of specimens with unknown dates of death, and growth-increment clarity;
- d) Identify species and collections that are most promising for chronology development based on participants' expertise on otolith interpretation and institutional collections;
- e) Consider other physical and biological time series (indices of fish somatic growth or size, recruitment histories, lower-trophic productivity) that could be integrated with fish or bivalve chronologies;
- f) Identify the most promising research questions that may be addressed using these techniques in the North Atlantic, North Sea and Baltic Sea.
- g) Based on the results, conclusions, and recommendations from this workshop, initiate an international cooperative project on chronology development to commence after the workshop;
- h) Propose a future training workshop approximately one week in duration for those interested in learning chronology-development techniques in depth. The workshop will involve a hands-on research project and be based on previous workshops taught in North America, Australia, and once in the UK (examples: International Sclerochronology Fieldweek, May 2013, University of Wales, Bangor; North American Dendroecology Fieldweek sclerochronology group 2006, 2009, 2011 <http://dendrolab.indstate.edu/nadef/>).

WKGIC will report by 15 January 2015 (via SSGEF) for the attention of SCICOM.

## Supporting information

Priority	<p>Millions of otoliths, bivalve shells, and scales collected for routine ageing in support of stock assessment are archived in European and North American fisheries laboratories. Yet these structures are chronometers of the environmental conditions the organism experienced over the course of its lifespan and thus contain far more information than age. Advances in digital imaging and computing power combined with techniques developed by tree-ring scientists provide a means by which to generate exactly dated, multidecadal time series of population-level growth anomalies (i.e. chronologies). Given that they are exactly placed in time, chronologies can be directly compared to instrumental climate records, chronologies from other regions or species, or time series of other biological phenomena such as primary productivity or recruitment history. In this way, chronologies may be used to understand long-term ranges of growth variability, associated climatic drivers of growth, linkages within and among species, and generation of ecosystem-level indicators. Such information will be particularly relevant to the desired transition from single stock assessments to ecosystem based management strategies, especially with respect to establishing historical ranges of variability, influence of climate, and ecosystem indicators and their thresholds.</p> <p>Here, we propose to assemble representatives of major fisheries labs to learn basic fundamentals chronology-development techniques, and most importantly, identify the most promising species and collections that would be suitable for such an approach. We would then propose the most suitable and immediate projects that could be pursued, initiating international cooperative projects to commence after the workshop. Overall, this workshop would be the first step in generating chronology networks in the region.</p>
Scientific justification	<p>Over the past decade, a large and growing network of chronologies has been developed from annual growth-increment widths in marine fish and bivalve in the North Pacific. These chronologies have been integrated across species, marine regions, and other biological time series to develop indicators and identify climate drivers of productivity and functioning at the ecosystem level. For example, chronologies of rockfish (<i>Sebastes</i> spp.) and salmon (<i>Oncorhynchus</i>) have been integrated with indices of seabird reproductive success to demonstrate that winter upwelling is critical to ecosystem functioning in the California Current. This winter upwelling pattern is driven by broad-scale atmospheric pressure systems that facilitate or block onshore flows of precipitation. Due to their drought sensitivity, tree-ring chronologies can be used to hind-cast this biologically important winter pattern over the past six centuries, documenting that variance in the system has risen to unusually high levels over the past 100 years that has been driven by a series of winters with anomalously low upwelling. Moreover, these California Current chronologies have been compared to those developed in the Gulf of Alaska, showing that the two ocean domains co-vary out of phase. Robust growth in the north is associated with poor growth in the south and vice versa, a pattern largely driven by winter El Niño Southern Oscillation activity. Such approaches have also resulted in fish chronologies off New Zealand and along the Australia west coast.</p> <p>Over the past decade, a number of exactly dated chronologies have been developed for the extremely long-lived bivalve species <i>Arctica islandica</i> and <i>Glycymeris glycymeris</i> in the North Sea and North Atlantic for the purposes of ocean climate reconstruction. Thus, the “tree-ring” approach for chronology development works in these regions, but has not yet been applied to fish or to address ecological or management issues. In pilot studies, Black Straneky, and Norway’s Akvaplan-NIVA have generated strong preliminary chronologies for Atlantic cod, plaice, and the greater Argentine for the North</p>

	Atlantic region. However, the greatest impediment to expanding this work remains a lack of knowledge as to suitable species and collections available for chronology development in the Atlantic, North Sea, and Baltic region. The proposed workshop would assemble those most familiar with otolith (and bivalve) collections to identify species and locations that would be most suitable, and to identify the most promising research directions for the eastern Atlantic region. The goal would be to initiate an international cooperative project on chronology development to commence after the workshop.
Resource requirements	This workshop will be held at the Johann Heinrich von Thünen Institute in Hamburg, Germany. All necessary background, practice images, and meeting space will be provided by the instructors.
Participants	10-15 otolith specialists from leading age labs (IMR, IFREMER, CEFAS, DTU Aqua, IMARES, TI, etc...)
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no obvious direct linkages with the advisory committees.
Linkages to other committees or groups	WGBIOP
Linkages to other organizations	None.

### Annex 3: Draft terms of reference for a new workshop

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A Workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic 2 (WKGIC2) will be chaired by Bryan Black, USA, and Christoph Stransky, Germany, will meet in Palma, Mallorca, Spain or Split, Croatia in October 2015.

This will be a hands-on training exercise in which participants will work as a group to develop an otolith growth-increment chronology, including all phases of data collection, analysis, and interpretation. The chronology will be developed from one of the North Atlantic collections identified during WKGIC in December 2014. The 2015 workshop will involve learning:

- a) Fundamental dendrochronology (tree-ring analysis) technique, with particular emphasis on visual crossdating followed by statistical verification using such programs as COFECHA.
- b) How to prepare and photograph otolith samples, then measure growth-increment widths using image analysis software.
- c) Statistical techniques for generating biochronologies from growth-increment width measurements. Topics will include the removal of age effects, issues of minimum sample size, and maximizing signal-to-noise ratio. Special consideration will be given to datasets for chronologies developed using archival collections of short-lived individuals.
- d) Techniques for relating the biochronology to instrumental climate records, principally through the use of the KNMI Climate Explorer.

A new otolith chronology and its relationships to climate will be established over the course of the workshop.

WKGIC will report by 1 December 2015 (via SSGEPD) for the attention of SCICOM.

### Supporting Information

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Priority	<p>Over the past several decades, thousands of otoliths, bivalve shells, and scales have been collected for the purposes of age determination and remain archived in European and North American fisheries laboratories. Advances in digital imaging and computer software combined with techniques developed by tree-ring scientists provide a means by which to extract additional levels of information in these calcified structures and generate annually-resolved (one value per year), multidecadal time series of population-level growth anomalies. Given that they are exactly placed in time, chronologies can be directly compared to instrumental climate records, chronologies from other regions or species, or time series of other biological phenomena. In this way, chronologies may be used to reconstruct historical ranges of environmental variability, identify climatic drivers of growth, establish linkages within and among species, and generate ecosystem-level indicators.</p> <p>The first workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC) met at the Johann Heinrich von Thünen Institute in Hamburg, Germany, from Dec 2-3, 2014, chaired by Bryan Black (USA) and Christoph Stransky (Germany). Twenty-three participants from eleven different countries attended. During this meeting, we identified that the greatest limitation to developing biochronologies in the North Atlantic region is lack of training in the specialized crossdating and statistical approaches involved. To this end, we propose a longer training workshop (WKGIC2) in which participants will learn these techniques by</p>
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	developing a biochronology using otoliths from the North Atlantic region.
Scientific justification	<p>A large and growing network of chronologies has been developed from annual growth-increment widths in marine fish and bivalves in the North Pacific. These chronologies have been integrated across species, marine regions, and other biological time series to develop indicators and identify climate drivers of productivity and functioning at the ecosystem level. For example, chronologies of rockfish (<i>Sebastes</i> spp.) and salmon (<i>Oncorhynchus</i>) have been integrated with indices of seabird reproductive success to demonstrate that winter upwelling is critical to ecosystem functioning in the California Current. This winter upwelling pattern is driven by broad-scale atmospheric pressure systems that facilitate or block onshore flows of precipitation. Due to their drought sensitivity, tree-ring chronologies can be used to hind-cast this biologically important winter pattern over the past six centuries, documenting that variance in the system has risen to unusually high levels over the past 100 years that has been driven by a series of winters with anomalously low upwelling. Moreover, these California Current chronologies have been compared to those developed in the Gulf of Alaska, showing that the two ocean domains co-vary out of phase. Robust growth in the north is associated with poor growth in the south and vice versa, a pattern largely driven by winter El Niño Southern Oscillation activity. Such approaches have also resulted in fish chronologies off New Zealand and along the Australia west coast.</p> <p>A number of exactly dated chronologies has also been developed for the extremely long-lived bivalve species <i>Arctica islandica</i> and <i>Glycymeris glycymeris</i> in the North Sea and North Atlantic for the purposes of reconstructing ocean circulation and climate. However, these “tree-ring” approaches for chronology development has not yet been applied to fish or to address ecological or management issues. The first workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC) met at the Johann Heinrich von Thünen Institute in Hamburg, Germany, from Dec 2-3, 2014, chaired by Bryan Black (USA) and Christoph Stransky (Germany). During this meeting, we identified several pilot studies have generated strong preliminary chronologies for Atlantic cod, plaice, and the greater Argentine. However, the greatest impediment to expanding this work remains a lack of knowledge as to suitable species and collections available for chronology development in the Atlantic, North Sea, and Baltic region. To this end, we propose a training workshop (WKGIC2) in which participants will learn these techniques and foster new collaborations by developing an otolith biochronology.</p>
Resource requirements	This workshop will be held at IMEDEA in Plana, Mallorca, Spain, or at the Institute of Oceanography and Fisheries, Split, Croatia. All necessary background, samples, images, and meeting space will be provided by the instructors and participants.
Participants	We anticipate 10-20 participants from leading age labs and universities.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	SCICOM
Linkages to other committees or groups	.
Linkages to other organizations	

## Annex 4: Agenda

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### Day 1: December 2, 2014 (Tuesday)

- 09:00 Introductions: participant backgrounds, organizations  
Hamburg logistics (where to eat, what to see)
- 09:20 Purpose of the meeting and objectives
- 09:40 Introduction to crossdating and chronology development basics
- 10:45 Break
- 11:00 Crossdating exercises
- 12:00 Lunch
- 13:30 Crossdating exercises
- 15:00 Break
- 15:20 The range of possibilities for biochronologies  
Bryan Black: Applications of otolith ring-width chronologies  
Paul Butler: State of the science-bivalve sclerochronology  
Peter Grønkjær: Regime shifts and stable isotopes  
Audrey Geffen: Archaeological cod otoliths
- 17:30 Adjourn

### Day 2: December 3, 2014 (Wednesday)

- 09:00 Discuss attributes of the ideal sample sets, also limitations to the techniques
- 09:30 Break into subgroups; discuss candidate species and collections
- 10:15 Each subgroup reports to full group
- 10:45 Break
- 11:00 Full group discussion of research priorities that could be addressed by these sample sets
- 12:00 Lunch

- 13:30 Continue discussion, also of possible funding opportunities
- 15:30 Final wrap-up: do we want future training workshops?
- 16:00 Adjourn

## Annex 5: Recommendations

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During the first workshop on Growth-increment Chronologies in Marine Fish: climate-ecosystem interactions in the North Atlantic (WKGIC; 2–3 December 2014), we found that the greatest impediment to expanding otolith biochronology work is lack of training in the specialized crossdating and statistical approaches involved. To this end, we propose a training workshop (WKGIC2) in which participants will learn these techniques by developing a biochronology using otoliths from the North Atlantic region. The workshop is tentatively planned for early October 2015 to be held at either IMEDEA in Palma, Mallorca, Spain, or at the Institute of Oceanography and Fisheries, Split, Croatia. Please see Annex 3 in this report for draft terms of reference.

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<b>Recommendation</b>	<b>Adressed to</b>
1.WKGIC2	SCICOM

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Species Scientific Name	Species Common Name	Location / Region	Range (depth / spatial extent)	Mean / max fish age	Time period of archive	Archive size (general numbers)	Age / annual periodicity validated	Increment clarity	Institute(s)	Contact person	Condition (thin sections, whole otoliths, in resin...)
<b>Bivalves</b>											
<i>Arctica</i>		North Sea; Irish Sea; Iceland; NW Scotland	20-140m	50-500 years	Holocene (10,000 yrs)	12000	yes			Paul Butler	
<i>Arctica</i>		North Sea; Norwegian Sea	80-120m	50-500 years	Holocene (10,000 yrs)	5000-10000	yes		Uhi Research NIOZ	Carin Anderson	
<i>Glycymeris</i> , <i>Arctica</i>		North Sea					yes			Roy Wibaux	
<i>Arctica</i>		Iceland; North Sea					yes			Bernd Schöne	
<i>Glycymeris</i>		Britanny; Bay of Biscay	20-50 m				yes			Julian Thebaud	
<i>Glycymeris</i>		Adriatic	2-15m	1-30; 70 yr	2008 onwards	1000	yes	yes	IOF	Milica Petardica	shells
<i>Serpis</i>	Hairy cockle	Barents Sea; Polar front; high Arctic; Atlantic					yes			Mike Carroll	
<b>Fish</b>											
<i>Aphanopus carbo</i>	Black scabbardfish	North Atlantic		max. 30-35	1970s onwards			dubious	IPMA(P)		
<i>Argentina silus</i>	Greater argentine	North Atlantic (North Sea)		Sep-40	1990 onwards	7500	(yes)	good	IMARES	Loes Bolle	
<i>Arnoglossus laterna</i>	Scadfish	North Sea		2,7 / 9	1993-2000 irregularly, 2002 onwards	4000		medium	IMARES	Loes Bolle	
<i>Buglossidium luteum</i>	Solenette	North Sea		14-May	1993-2000 irregularly, 2002 onwards	2500		good	IMARES	Loes Bolle	whole, drv, in resin (on plates)
<i>Callionymus lyra</i>	Draxonet	North Sea		1,7 / 21	2002 onwards	2000		medium	IMARES	Loes Bolle	scales
<i>Caspius asper</i>	Boarfish	North Atlantic		max. 25	2009 onwards?			dubious	MI, DTU		
<i>Clupea harengus</i>	Herring	North Atlantic, North Sea, Baltic		max. 25	1960s onwards (otoliths), 1910 onwards (scales)			good	IMARES, MSS, CEFAS, TI, IMR...		scales
<i>Clupea harengus</i>	Herring	Baltic		max. 25	1961 onwards	>100000		good	NMFI	Z. Mimy	
<i>Clupea harengus</i>	Herring	North Atlantic, North Sea		4,6 / 20	1960 onwards	239500	(yes)	good	IMARES	Loes Bolle	
<i>Dentex dentex</i>	Common dentax	Adriatic Sea	200m	>25 years	from 1985 sporadically	>500	yes	yes	IOF	S.Matic Skoko	whole, drv
<i>Dicentrarchus labrax</i>	European seabass	North Atlantic, North Sea, Mediterranean		max. 25 / 19 (Mediterranean)	1970 onwards	1000		good (scales)	CEFAS, IFREMER		whole, drv
<i>Dicentrarchus labrax</i>	European seabass	North Sea		6,2 / 21	2000 onwards irregularly	1000		good	IOF	Loes Bolle	whole drv and in glycerin
<i>Diplodus sargus</i>	Sargo	Adriatic Sea	200m	>25 years	from 1985 sporadically	>500	yes	yes	IOF	S.Matic Skoko	whole drv and in glycerin
<i>Disostichus eleginoides</i>	Patagonian toothfish	Antarctic		max. 40-50	2009 onwards			OK	CEFAS		
<i>Echichthys vipera</i>	Lesser Weeвер	North Sea		6,7 / 19	2002 onwards	1500		good	IMARES	Loes Bolle	whole drv and in glycerin
<i>Eteopterus angustirostris</i>	Snake eelfish	North Sea		2005-2007	2005-2007	500		good	IMARES	Loes Bolle	whole and drv
<i>Eutrigla gurnardus</i>	Grey gurnard	North Sea		14-Aug	2004-2013 irregularly	1000		good	IMARES	Loes Bolle	whole and drv
<i>Gadus morhua</i>	Cod	North Atlantic		max. 25	1910 onwards	good		good	IMARES, MSS, CEFAS, TI, IMR...		whole and drv
<i>Gadus morhua</i>	Cod	Baltic		max. 25	1960 onwards	>40000		good	NMFI	Z. Mimy	
<i>Gadus morhua</i>	Cod	North Atlantic, Sea of Okhotsk		max. 25	1960-1988	>25000		good	NMFI	Z. Mimy	whole drv and in glycerin the old samples
<i>Gadus morhua</i>	Cod	North Sea		2,9 / 38	1968 onwards	87000	(yes)	good	IMARES	Loes Bolle	
<i>Glyptocephalus cynoglossus</i>	Witch	North Sea	>200m	-	2003-2006	1000		bad	IMARES	Loes Bolle	whole drv
<i>Halsaleneus mediterraneus</i>	Ionian Sea			2,7	1992;1996-1999; and after 2000 sporadically	>27	no	yes	HCMR	K. Anastasopoulou & Ch. Mytilineou	whole drv and in glycerin
<i>Hippoglossoides platessoides</i>	Long rough dab	North Sea		4,1 / 17	2003 onwards	3500		medium	IMARES	Loes Bolle	whole drv
<i>Hoplostethus mediterraneus</i>	Mediterranean silimthead	Ionian Sea	>200m	15-20	1996-1999; and after 2000 sporadically			yes	HCMR	K. Anastasopoulou & Ch. Mytilineou	whole drv and in glycerin
<i>Lepidotrombus whitigiensis</i>	Magrim	North Atlantic		max. 17	1970s onwards			good	IEO, CEFAS		whole drv
<i>Limanda limanda</i>	Dab	North Sea		5,3 / 19	1978 onwards	89000	(yes)	bad	IMARES	Loes Bolle	
<i>Melanogrammus aeglefinus</i>	Haddock	North Sea		3,2 / 12	1968-1988, 1991 onwards	26500	(yes)	good	IMARES	Loes Bolle	whole, drv, thin slices - in resin
<i>Merlangius merlangus</i>	Whiting	North Sea		3,2 / 14	1968 onwards	72500	(yes)	bad	IMARES	Loes Bolle	
<i>Merluccius merluccius</i>	Hake	Aegean and Ionian Sea	200-800m	10 years	1982, 1990-1999, 2003-2008, 2013-now	500	yes (daily rins)	yes	HCMR	K. Anastasopoulou & Ch. Mytilineou	whole, drv
<i>Merluccius merluccius</i>	Hake	Balearic Isls	200-800m	10 years	1979-1991	500	no	yes	IMEDEA	B. Morales	
<i>Merluccius merluccius</i>	Hake	Adriatic Sea	200-800	10 years	from 1965 sporadically collected and from 1990-now annually	>500	yes	yes	IOF	N.Vrgoc	whole, drv
<i>Merluccius merluccius</i>	Hake	Namibian/Senegaliese Coast		10 years	1987-1995	>4000	no	good, but not ne	NMFI	Z. Mimy	whole, drv, thin slices - in resin
<i>Merluccius merluccius</i>	Hake	Atlantic		max. 20	1970s onwards			good, but not ne	IEO, CEFAS		
<i>Merluccius merluccius</i>	Hake	North Sea		3,7 / 11	2005 onwards	500		bad	IMARES	Loes Bolle	
<i>Microchirus variegatus</i>	Thickback sole	North Sea		Oct-38	2003 onwards	500		medium	IMARES	Loes Bolle	
<i>Micromesistius poulassou</i>	Blue whiting	North Atlantic		4,3 / 13	2001 onwards	30000	(yes)	medium	IMARES	Loes Bolle	whole, drv, in resin (on plates)
<i>Microstomus kitt</i>	Lemon sole	North Sea (North Atlantic)		5,5 / 20	2002 onwards	10500	(yes)	bad	IMARES	Loes Bolle	1 whole & (since ~2000) 1 sectioned
<i>Mullus barbatus</i>	Red mullet	Aegean and Ionian Sea	>50	8 years	1990-1999; 2004-2008; 2013-now	>500		medium	HCMR	K. Anastasopoulou & Ch. Mytilineou	1 whole & 1 broken or (since ~2000) sectioned + stained
<i>Mullus barbatus</i>	Red mullet	Balearic Isls		8 years	sporadically			good	IMEDEA		1 whole & 1 broken-polished-burnt or (since ~2000) sectioned + stained
<i>Mullus barbatus</i>	Red mullet	Adriatic Sea	200-800	8 years	from 1965 sporadically collected and from 1990-now annually	>500	yes	yes	IOF	N.Vrgoc	1 whole & 1 broken-polished-burnt or (since ~2000) sectioned + stained
<i>Mullus surmuletus</i>	Striped red mullet	Aegean and Ionian Sea	>50	8 years	1982; 1987; 1993; 2004-2008; 2013-now	500		medium	HCMR	K. Anastasopoulou & Ch. Mytilineou	1 whole & 1 sectioned
<i>Mullus surmuletus</i>	Striped red mullet	Adriatic Sea		>8 years	from 2005 -now annually	>500	yes	medium	IOF	S.Matic Skoko	1 whole & (since ~2000) 1 sectioned
<i>Mullus surmuletus</i>	Striped red mullet	North Sea (North Atlantic)		2,5 / 17	2002-2010 irregularly	500		medium	IMARES	Loes Bolle	1 whole & 1 sectioned (+ sometimes stained)
<i>Pageulus bogoraveo</i>	Red seabream	Ionian Sea	>200m	15-20	1996-1999; and after 2000 sporadically			yes	HCMR	K. Anastasopoulou & Ch. Mytilineou	1 whole & 1 sectioned
<i>Pageulus bogoraveo</i>	Red seabream	Adriatic Sea	200m	>22 years	form 2000 sporadically	>500	yes	yes	IOF	S.Matic Skoko	1 whole & 1 sectioned
<i>Pleuronectes aeglefinus</i>	Flounder	North Sea		3,1 / 12	1969, 2002 onwards	12000	(yes)	good	IMARES	Loes Bolle	whole embedded in resin
<i>Pleuronectes platessa</i>	Plaice	North Atlantic, North Sea, Baltic		max. 45 (regularly up to 20)	1949s onwards			good	IMARES, CEFAS, TI, ...		whole embedded in resin
<i>Pleuronectes platessa</i>	Plaice	Baltic		max. 25 (regularly up to 15)	1994 onwards	>2000		good	NMFI	Z. Mimy	1 whole & (since ~2000) 1 sectioned
<i>Pleuronectes platessa</i>	Plaice	North Sea (North Atlantic)		5,8 / 38	1957 onwards	481000	yes	good	IMARES	Loes Bolle	whole embedded in resin
<i>Pollachius virens</i>	Saith	North Sea		6,9 / 13	1970-1979, 1992-2012 irregularly	6000	(yes)	good	IMARES	Loes Bolle	whole
<i>Pomatoschistus sp.</i>	Gobies	North Sea		-	2005-2013 irregularly	1000		?	IMARES	Loes Bolle	whole
<i>Sardina pilchardus</i>	Sardine	Iberian Peninsula, Morocco		max. 10-15	1980 onwards	4000		good	IEO, IPMA, IFREMER	Z. Mimy	1 whole & 1 broken or (since ~2000) sectioned
<i>Sardina pilchardus</i>	Sardine	Iberian Peninsula, Morocco		max. 10-15	1976			good	NMFI		1 whole & 1 broken or (since ~2000) sectioned
<i>Scomber scombrus</i>	Mackerel	North Atlantic		max. 20	1950s onwards			good	IMARES, MSS, CEFAS, TI, IMR		1 whole & 1 broken or (since ~2000) sectioned
<i>Scomber scombrus</i>	Mackerel	North Atlantic		max. 20	1969-1991	>28000		good	NMFI	Z. Mimy	1 whole & 1 broken
<i>Scomber scombrus</i>	Mackerel	North Atlantic, North Sea		4,8 / 33	1959, 1968 onwards	92000	(yes)	good	IMARES	Loes Bolle	1 whole & 1 broken or (since ~2000) sectioned
<i>Scophthalmus maximus</i>	Turbot	North Sea (North Atlantic)		Age-35	1981 onwards	29000	(yes)	good	IMARES	Loes Bolle	1 whole & 1 broken or (since ~2000) sectioned
<i>Scophthalmus rhombus</i>	Brill	North Sea (North Atlantic)		2,6 / 22	1981 onwards	22500	(yes)	good	IMARES	Loes Bolle	scales & whole otoliths
<i>Sebastes spp.</i>	Redfish	North Atlantic		max. 60	1990s onwards			medium	IEO, TI, MFI, IMR		1 whole & 1 sectioned
<i>Sebastes spp.</i>	Redfish	North Atlantic (Greenland)		max. 60	1960-1972; 2004-2006	14000		medium	NMFI	Z. Mimy	1 whole & 1 sectioned
<i>Solea solea</i>	Sole	North Atlantic, North Sea		max. 40 (regularly 20)	1950s onwards			good	IMARES, CEFAS, TI, ...		1 whole & 1 sectioned + stained
<i>Solea solea</i>	Sole	North Sea (North Atlantic)		5,3 / 42	1957 onwards	280000	yes	good	IMARES	Loes Bolle	1 whole & 1 sectioned + stained
<i>Sprattus sprattus</i>	Sprat	North Sea		1,9 / 4	1966-1988, 1991 onwards	12000		medium	IMARES	Loes Bolle	1 whole & 1 sectioned + stained
<i>Trachurus trachurus</i>	Horse mackerel	North Atlantic, North Sea		max. 25-30	1970s onwards			medium	IMARES, IEO, TI, CEFAS...		1 whole & 1 sectioned
<i>Trachurus trachurus</i>	Horse mackerel	North Atlantic, North Sea		max. 25-30	1967-1984	>9000		medium	NMFI	Z. Mimy	1 whole & 1 sectioned + stained
<i>Trachurus trachurus</i>	Horse mackerel	North Atlantic, North Sea		7,2 / 38	1982 onwards	71500	(yes)	medium	IMARES	Loes Bolle	1 whole & 1 sectioned + stained
<i>Trigla lucerna</i>	Tub gurnard	North Sea		2,9 / 6	2008-2012 irregularly	500		medium	IMARES	Loes Bolle	whole
<i>Trisopterus esmarki</i>	Norway pout	North Sea		1,5 / 6	1991 onwards	3000	(yes)	good	IMARES	Loes Bolle	whole