STOCK IDENTIFICATION METHODS WORKING GROUP (SIMWG; outputs from 2019 meeting)

VOLUME 2 | ISSUE 7

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371 I

ICES Scientific Reports

Volume 2 | Issue 7

STOCK IDENTIFICATION METHODS WORKING GROUP (SIMWG; outputs from 2019 meeting)

Recommended format for purpose of citation:

ICES. 2020. Stock Identification Methods Working Group (SIMWG; outputs from 2019 meeting). ICES Scientific Reports. 2:7. 93 pp. http://doi.org/10.17895/ices.pub.5960

Editor

Lisa Kerr

Authors

Steve Cadrin • Helene De Pontual • Karin Hüssy • Lisa Kerr • Ken Mackenzie • Kelig Mahe • Stefano Mariani • Richard McBride • David Secor • Christoph Stransky • Zachary Whitener

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

The Stock Identification Methods Working Group (SIMWG) reviews new methods for the definition and investigation of stock structure and provides guidance to other ICES expert groups on how to interpret patterns of population structure.

Over the past three years, there has been a proliferation of applications of stock identification methods to ICES stocks, as well as several notable advances in stock identification methods with many results relevant to ICES science and advice. SIMWG provided annual updates on recent applications and advances in stock identification methods. Over the past three years, SIMWG received requests for guidance on stock structure of (1) European sardine (*Sardina pilchardus*), (2) Beaked redfish (*Sebastes mentella*) stock affiliation on the East Greenland slope, (3) Atlantic cod in ICES area 6a, and (4) red gurnard (*Aspitrigla cuculus*) stock structure in ICES subareas 3-8. These requests came from a range of ICES working groups including North Western Working Group (NWWG), the Workshop on Atlantic Sardine (WKSAR) and the Working Group on Widely Distributed Stocks (WGWIDE). SIMWG did not find sufficient evidence to support the recent change in stock structure of European sardine adopted in the 2017 benchmark and recommended review of new genetics research prior to the next benchmark. SIMWG did not recommend a combined assessment of beaked redfish along the east Greenland slope with the Icelandic slope. SIMWG reviewed and provided feedback on a proposed cod genetics study in ICES area 6a which promises to resolve some critical questions of stock identity of cod in ICES area 6a. SIMWG did not find strong evidence for splitting the red gurnard stock into two stock areas (North Sea/west of Scotland and Celtic Seas/Biscay). Over the past three years, SIMWG also made progress on reviewing and reporting on advances in mixed stock analysis. This work will continue through our next three year to and is relevant to resolving mixed stock composition issues in assessment and management. Understanding stock structure is a fundamental requirement before any assessment or modelling on a stock can be contemplated and SIMWG will continue to work with ICES expert groups to address pressing stock identification issues.

ii Expert group information

Expert group name	Stock Identification Methods Working Group (SIMWG)
Expert group cycle	Multiannual
Year cycle started	2017
Reporting year in cycle	3/3
Chair	Lisa Kerr, USA
Meeting venue(s) and dates	By correspondence in 2017
	7-8 August 2018, Portland, USA
	By correspondence in 2019

1 Review recent advances in stock identification methods

Over the past three years, there has been a proliferation of applications of stock identification methods to ICES stocks, as well as several notable advances in stock identification methods with many results relevant to ICES science and advice. SIMWG has committed to providing annual updates on recent applications of stock identification methods to ICES species and on advances in stock identification methods. The group has focused on summarizing research in the focal areas listed below:

- Genetics
- Growth marks in calcified structures
- Life history parameters
- Morphometrics/meristics
- Tagging
- Otolith shape
- Otolith chemistry
- Parasites
- Simulation approaches
- Interdisciplinary approaches
- Published Theme Sets

SIMWG's annual reviews on advances in stock identification methods keeps ICES members abreast of best practices in this field of study. This review activity has served as a valuable contribution to the field and has formed the foundational material for 2 editions of the book Stock Identification Methods: Applications in Fishery Science. This book was published first in 2005 and again in 2014. SIMWG members S. Cadrin, L. Kerr and S. Mariani edited the 2nd edition and several SIMWG members contributed chapters to this book.

The details of annuals reviews of advances in stock identification methods are summarized in Annex 4.

2 Technical reviews and expert opinion on matters of stock identification

SIMWG provides ICES expert groups and working groups expert feedback on questions of stock structure for ICES stocks. Over the past three years, SIMWG has contributed to ICES advisory needs by providing expert feedback on the status of stock structure of several species. These requests came from the North Western Working Group (NWWG), the Workshop on Atlantic Sardine (WKSAR), Working Group on Widely Distributed Stocks (WGWIDE), and in previous years we have connected with many more ICES groups to fulfill such requests.

Over the past three years SIMWG provided expert recommendations on the following species:

1. European sardine (*Sardina pilchardus*);
2. Beaked redfish (*Sebastes mentella*) stock affiliation on the East Greenland slope;
3. Atlantic cod in ICES area 6a;
4. Red gurnard (*Aspitrigla cuculus*) stock structure in ICES subareas 3-8.

The details of the reviews are summarized in Annex 4.

SIMWG expert reviews on questions of stock structure for ICES stocks are directly relevant to the appropriate definition of stock and contribute to the accuracy of stock assessment and effectiveness of management actions. Understanding stock structure is a fundamental requirement before any assessment or modelling on a stock can be contemplated and SIMWG will continue to work with ICES expert groups to address pressing stock identification issues. We see an important role for SIMWG in the future as ICES copes with the shifting distributions of fishery resources and questions regarding the appropriate definition of fish stocks.

SIMWG's advice has been well received by the requesting groups and there are a growing number of requests from different groups which speaks to the service that SIMWG provides to the ICES community. SIMWG's expertise should be continued to be used to address on specific questions of stock structure and should be considered in the advisory process in the context of whether the stock units are appropriate for accurate assessment and sustainable management of ICES fishery resources.

3 Review and report on advances in mixed stock analysis, and assess their potential role in improving precision of stock assessment

There have been notable advances in stock identification methods and a proliferation of applications in recent decades, with many results relevant to fisheries assessment and management. In many cases, the application of stock identification methods has revealed inconsistencies between the spatial structure of biological populations and the definition of management units. Despite the increasing number of applications, there are few examples where this information has been integrated into the assessment and management of stocks. Mixed stock analysis using an established stock identification technique can enable quantification of the origin of fish across broad spatial and temporal scales. There are a range of approaches for integrating mixed stock information into the assessment and management process, including: 1) revising data to inform assessment, 2) integrating information into assessment, and 3) changing the scale of the stock assessment and/or management. Alignment of biological and management units requires continual monitoring through the application of stock identification methods in conjunction with responsive management to preserve biocomplexity and the natural stability and resilience of fish species.

Over the past three years, this issue has been area of focus for several meetings and meeting symposia that are described in further detail below:

- Center for the Advancement of Population Assessment Methodology (CAPAM) meeting, October 2018
- ICES Annual Science Meeting 2019 Theme Session E: Integrating information on population structure and migration into fisheries stock assessment and management

CAPAM Mini-Workshop Announcement: Development of spatial stock assessment models

The Center for the Advancement of Population Assessment Methodology (CAPAM) hosted a technical mini-workshop on the development of spatial stock assessment models at the Southwest Fisheries Science Center, La Jolla, CA, USA, October 1-5, 2018.

Most, if not all, fish populations exhibit spatial structure to some extent. The spatial structure could simply be in abundance, but often involves other characteristics such as life stage, size, or gender, or it could be factors such as fisheries processes (e.g., catchability) or population processes (e.g., growth, recruitment, natural mortality). The spatial structure will often be a consequence of movement processes (even if it is through larval dispersal e.g., in sessile organisms), habitat (e.g., bottom substrate or environmental conditions), or spatial distribution of fishing effort, and may change over time. Properly accounting for the spatio-temporal distribution of both fishing effort and fish abundance has been one of the largest sources of uncertainty ignored in most stock assessments, which typically assume a closed, well-mixed population. Of particular concern are changes in spatial distribution over time due to movement of the stock, recruitment dynamics, and/or local depletion. Substantial progress has been made in both the statistical methodology and the practical implementation (e.g., software) of spatial stock assessment models. However, there has not been a comprehensive evaluation of the methodology. Coordinated research and focused discussions among experienced researchers are needed to make the most of this modelling technique. The objective of the workshop was to bring together researchers to present and discuss the development and application of spatial stock assessments. The format of the workshop will follow that of the successful CAPAM series (http://www.capamresearch.org/workshops) with a specialized technical focus and allowing ample time for presentations, questions, and discussion.

The presentations and discussions took place over three and a half days, with half a day tutorial on implementing spatial structure in Stock Synthesis (taught by Juan Valero, IATTC),one day dedicated to applying the methods to bigeye tuna in the eastern Pacific Ocean and one or more other stocks, and/or preparing recommendations and research plans. Topics (and keynote speakers) included: defining spatial structure (Steve Cadrin, University of Massachusetts Dartmouth, USA), movement: data (Chi (Tim) Lam, University of Massachusetts Boston, USA) and theory (Andrew Hein, NMFS and University of California, Santa Cruz, USA), spatial stock assessment models (Andre Punt, University of Washington, USA), integrating tagging data (Dan Goethel, NMFS, USA), application of natural markers (Lisa Kerr, Gulf of Maine Research Institute, USA; Patrick Lehodey, Collecte Localisation Satellites, France), management implications (Aaron Berger, NMFS, USA), and applications (John Hampton, SPC, New Caledonia; Alistair Dunn, Ministry for Primary Industries, New Zealand; Adam Langley, Trophia, New Zealand).

ICES Annual Science Conference 2019: Theme session E: Integrating information on population structure and migration into fisheries stock assessment and management

Michael Frisk (USA), Lisa Kerr (USA), Daniel Duplisea (Canada)

Theme session E addressed the following topics:

- methods of integrating biological population structure and migration ecology into fishery stock assessment models and management strategies
- challenges encountered when implementing new ecological findings into assessment and management
- quantitative evaluations of alternative assessment and management options which incorporate novel information on population structure, migration ecology, and connectivity

Developments in innovative electronic tagging technologies, otolith chemistry analyses, and genetic methods have all allowed ecologists to address long-standing questions on migration ecology, population structure, and connectivity of marine and diadromous fish populations. In many cases, these findings have contradicted unit stock assumptions underlying fisheries stock assessments and management frameworks. The effective integration of this information has been slow, however, largely due to challenges in characterizing dynamic processes (e.g., spatio-temporal stock structuring, migration ecology). In many cases, the novel information on migration and population structure is not directly suitable for incorporation into stock assessment models, due to the spatial and temporal resolution of sampling. When considering the effects of climate change, the incorporation of changing patterns of movement, connectivity, and subsequent mixed-stock composition can also present serious challenges.

There are multiple approaches to integrating these dynamic processes into stock assessment modelling and management; however, it is still rare that assessments address the wealth of emerging information on migration, connectivity, and stock structure. Mixed-stock composition information derived from otoliths, genetics, and tagging can be used to revise data inputs to stock assessment (e.g., assign catch to its natal origin), potentially resulting in more accurate estimates of abundance, fishing mortality, and vulnerability to fishing. Information from data storage and satellite tags can provide information on fish movements between regions, which can be directly integrated into assessment models to account for stock mixing and connectivity. Synthesis of interdisciplinary stock structure information can also be used to inform spatial and temporal management strategies aimed at conserving unique populations, or can be used to redefine harvest stock units.

Despite the benefits of proactively restructuring assessment and management strategies to incorporate the best available science, further work is needed to ensure that biological, economic, and social trade-offs are fully considered in the context of adaptive assessment and management. The objective of this theme session, therefore, is to review recent work which applies novel information on migration ecology, connectivity, and population structure – information coming from an array of stock identification methods to inform fisheries stock assessment and management strategies.

Annex 1: List of participants

Name	Institute	Country (of institute)	Email
Lisa Kerr (Chair)	Gulf of Maine Research Institute	USA	lkerr@gmri.org
Steve Cadrin	School for Marine Science & Technology	USA	scadrin@umassd.edu
Stefano Mariani	Ecosystems & Environment Research Centre – University of Salford	UK	s.mariani@salford.ac.uk
Zachary Whitener	Gulf of Maine Research Institute	USA	zwhitener@gmri.org
David Secor	University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory	USA	secor@umces.edu
Richard McBride	Northeast Fisheries Science Center National Marine Fisheries Service	USA	Richard.McBride@noaa.gov
Kelig Mahe	IFREMER, Sclero-chronology centre	France	Kelig.Mahe@ifremer.fr
Ken Mackenzie	School of Biological Sciences, University of Aberdeen	UK	k.mackenzie@abdn.ac.uk
Christoph Stransky	Thünen Institute of Sea Fisherieries	Germany	christoph.stransky@thuenen.de

Annex 2: Resolutions

The **Stock Identification Methods Working Group** (SIMWG), chaired by Lisa Kerr, USA, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2017	By correspondence	By correspondence	Interim report by 1 August	
Year 2018	7-8 August	Portland, USA	Interim report by 27 August	
Year 2019	By correspondence	By correspondence	Final report by 1 December	

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Review recent advances in stock identification methods	a) Tracks best practices in stock ID b) Promotes new technologies c) Relevant to all ICES species	1.4; 1.7; 5.2	3 years (and continued)	EG report
b	Provide technical reviews and expert opinions on matters of stock identification, as requested by specific Working Groups and SCICOM	a) Contributes to understanding of structure and connectivity of fish populations/stocks b) Highly relevant to assessment and management	5.1; 5.2; 5.4	3 years (and continued)	EG report and updated table of species reviews
c	Review and report on advances in mixed stock analysis, and assess their potential role in improving precision of stock assessment	a) Relevant to resolving mixed stock composition issues in assessment and management	5.1; 5.2; 5.4	3 years	EG report and contribution to ICES ASC; manuscript submitted to a peer-reviewed scientific journal'

Summary of the Work Plan

Year 1	Address terms of reference through work by correspondence in 2017
Year 2	Organise a physical meeting for summer 2018
Year 3	Address terms of reference through work at an in-person meeting for SIMWG for summer 2019

Supporting information

Priority	Understanding stock structure is a fundamental requirement before any assessment or modelling on a stock level can be contemplated. SIMWG liaises with ICES expert groups and working groups on stock identification issues and continues to review new methods as they develop
Resource requirements	SharePoint website and clear feedback from expert groups, SCICOM and SSGEPI is pivotal for the efficacy of SIMWG.
Participants	The Group is normally attended by some 10–15 members and guests.
Secretariat facilities	Access to SharePoint to all members and Chair-nominated guests.
Financial	None
Linkages to ACOM and groups under ACOM	ACOM
Linkages to other committees or groups	SIMWG has recently worked closely with a range of ICES working groups including WGWIDE, WGBIE, WGHANSA, and NWWG; benchmark workshops including WKPLE and WKHAD, and advice drafting groups such as ADGDEEP, and in previous years SIWMG connected with many more ICES groups to fulfill requests.
Linkages to other organizations	There are no obvious direct linkages, beyond the SIMWG members' affiliation and commitment to their own employers.

Annex 3: Responses to requests from ICES working groups

1. SIMWG does not find sufficient evidence to support the recent change in stock structure of European sardine adopted in the 2017 benchmark. Furthermore, SIMWG is not certain that the previous stock structure (north, south) is well supported. Ongoing genetics may help to resolve this issue and SIMWG recommends the review of this new research prior to the next benchmark for a decision on this topic (WGHANSA).
2. SIMWG does not recommend a combined assessment of beaked redfish along the east Greenland slope with the Icelandic slope. Furthermore, more precautionary management should be considered in managing the mixed fishery (NWWG).
3. SIMWG's review of a proposed cod genetics study in ICES area 6a is well developed, with a strong problem statement, a concise but relatively comprehensive literature review, clearly stated objectives, a technically sound approach, a well-qualified team of scientists, and a promising partnership with the fishing industry. SIMWG offers some recommendations for consideration by the principal investigators.
4. SIMWG does not find strong evidence for splitting the red gurnard stock into two stock areas (North Sea/west of Scotland and Celtic Seas/Biscay). Although there are different trends in abundance between the areas across surveys, it is challenging to interpret these trends without additional information. Additional understanding of seasonal and ontogenetic movements of this species is needed to more fully interpret these trends. Furthermore, there is no biological information that might allow for more in-depth assessment of stock identity between areas (e.g., genetic or phenotypic markers). We recommend further biological data collection and application of stock identification methods before any spatial management changes should be considered (WGWIDE).

Annex 4: ToR a) Review recent advances in stock identification methods

Advances in Stock Identification Methods in 2017

In 2017, there were several notable advances in stock identification methods and a proliferation of applications, with many results relevant to ICES science and advice. Here, we summarize advances and results accounting for research in genetics, life history parameters, growth marks in calcified structures, morphometrics, tagging, otoliths, parasites, simulation approaches, and interdisciplinary approaches.

- Genetic Analysis (Contributor: Stefano Mariani)
- Life history parameters (Contributor: Richard McBride)
- Body Morphometrics (Contributor: Zachary Whitener)
- Tagging (conventional, acoustic, satellite) (Contributors: Helene De Pontual (lead), Steve Cadrin)
- Otolith Shape (Contributors: Kelig Mahe, Christoph Stransky, Helene De Pontual
- Otolith Chemistry (Contributors: Lisa Kerr and David Secor)
- Parasites (Contributor: Ken Mackenzie)
- Simulation approaches (Contributor: Lisa Kerr
- Interdisciplinary analysis (Contributor: All participants)
- Published Theme Set Update (Contributor: Lisa Kerr)

Genetic Analysis (Contributor: Stefano Mariani)

Since the analysis carried out in Mariani and Bekkevold (2014), we are continuing to monitor changes in the usage of genetic methods in fisheries stock identification on an annual basis. Here we report data on the most recent ten years of scientific output (Figure 1). Through 2015 microsatellites continued to be the most widely applied genetic method, however in 2016 the relative importance of SNPs appears to become more substantial. SNP studies now account for approximately one third of the total applications for fish pop structure identification. SIMWG will continue to track and summarize trends in genetic methods, in order to monitor the short-term changes in molecular marker usage in fisheries science.

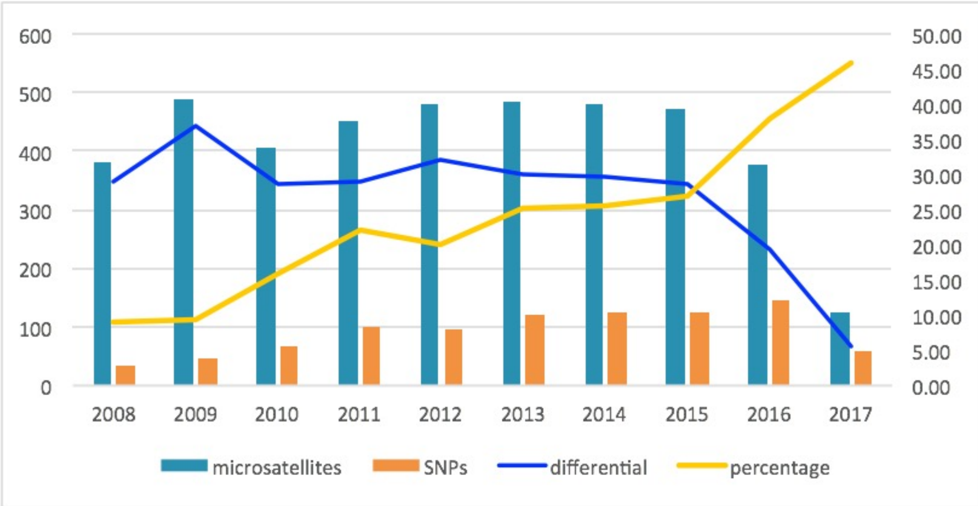


Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (blue bars) and SNPs (orange bars), as listed in the ISI Thompson-Reuters Web-of-Science. The search criteria were: "fish* AND gene* AND (population OR stock) AND 'molecular marker*'," where 'molecular marker*' means "Microsatellite*" or "SNP*". Only papers in the following disciplinary areas were considered: 'Fisheries', 'Environmental Sciences & Ecology', 'Biodiversity Conservation', 'Marine & Freshwater Biology' and 'Oceanography'.

Below we summarize a few notable papers published in the past year:

Kennington *et al.* (2017) exemplifies the fact that many species that are commercially exploited and traded must still be assessed for structure, and that microsatellites are still useful and practical in many situations. Alfonso *et al.* (2017) shows that some related tasks, such as monitoring changes in effective population size, can be still be performed with low-coverage hypervariable markers. Martinez *et al.* (2017) and Jasonowicz *et al.* (2017) show that in many cases SNPs will not necessarily unveil new strong structure, compared to microsatellites. These papers demonstrate examples of species for which the application of genomic SNPs simply does not detect any meaningful structure.

References

Jasonowicz, Andrew J.; Goetz, Frederick W.; Goetz, Giles W.; *et al.* 2017. Love the one you're with: genomic evidence of panmixia in the sablefish (Anoplopoma fimbria). Canadian Journal of Fisheries and Aquatic Sciences. 74(3): 377-387

Kennington, W. Jason; Keron, Peter W.; Harvey, Euan S.; *et al.* 2017High intra-ocean, but limited inter-ocean genetic connectivity in populations of the deep-water oblique-banded snapper Pristipomoides zonatus (Pisces: Lutjanidae). Fisheries Research. 193:242-249

Martinez, Edith; Buonaccorsi, Vincent; Hyde, John R.; *et al.* 2017. Population genomics reveals high gene flow in grass rockfish (Sebastes rastrelliger).Marine Genomics.. 33:57-63

Pita, Alfonso; Perez, Montse; Velasco, Francisco; *et al.* 2017. Trends of the genetic effective population size in the Southern stock of the European hake. Fisheries Research. 191. 108-119.

Life history parameters (Contributor: Richard McBride)

An interdisciplinary approach to stock structure, with a nice balance of life history and genetic information, is emerging for European flounder (*Platichthys flesus*) in the Baltic Sea. Erlandsson *et al.* (2017) report that size, growth, and maturity vary in a clinal pattern in the Baltic (ICES subdivisions 25-28), suggesting that flounder in the Baltic consists of several loosely defined subpopulations. Such spatially-explicit phenotypic data are consistent with genetic data. In addition, differences in spawning patterns – demersal spawning in the low salinity regions of the northern Baltic versus pelagic spawning elsewhere – coupled with genomic divergence actually indicates emerging speciation in this region (Momigliano *et al.* 2017).

Large data sets of fish size and age, common to data-rich fisheries, can be exploited to learn more about stock structure. Barrios *et al.* (2017) report that growth of whiting (*Merlangius merlangus*) varied among most ICES divisions in the eastern North Atlantic. They examined growth trajectories of 100s of individuals, and length-at-age data of 1000s of individuals, using a mixed effects model. Although phenotypic traits such as growth may be environmentally driven, rather than genetically based, spatial variation in growth rates may affect fishery yield, and is therefore of interest to assessment modelers and managers.

References

Barrios, A., B. Ernande, K. Mahe, V. Trenkel, and M. J. Rochet. 2017. Utility of mixed effects models to inform the stock structure of whiting in the Northeast Atlantic Ocean. *Fisheries Research*, 190:132-139.

Erlandsson, J., O. Ostman, A. B. Florin, and Z. Pekcan-Hekim. 2017. Spatial structure of body size of European flounder (*Platichthys flesus* L.) in the Baltic Sea. *Fisheries Research*, 189:1-9.

Momigliano, P., H. Jokinen, A. Fraimout, A.-B. Florin, A. Norkko, and J. Merilä. 2017. Extraordinarily rapid speciation in a marine fish. *Proceedings of the National Academy of Sciences*, 114(23):6074-6079.

Morphometrics and Meristics (Contributor: Zachary Whitener)

Body morphometrics and meristics are important methods for stock discrimination and their use is well established. Although basic meristics have long been described for many species, for others, basic meristics at the taxonomic identification are still being established. These may be useful for stock identification purposes in the future.

Sley *et al.* (2016) describe the morphometric and meristic characteristics of two Carangidae species in the Gulf of Tunisia, the blue runner *Caranx cryso* and the false scad *Caranx rhonchus*. Although stock identification was not performed in this study, the authors provided baseline information that contributes to species identification in a multispecies fishery and this information may be useful for stock identification in the future.

Allaya *et al.* (2016) used 13 morphometric and 4 meristic characteristics to discriminate between Atlantic chub mackerel *Scomber colias* samples taken from 3 sites on the Tunisian coast. They were able to do so with an 83.87% and 49% correct classification rate, respectively. Differences between sample sites were hypothesized to be due to genetic or environmental differences.

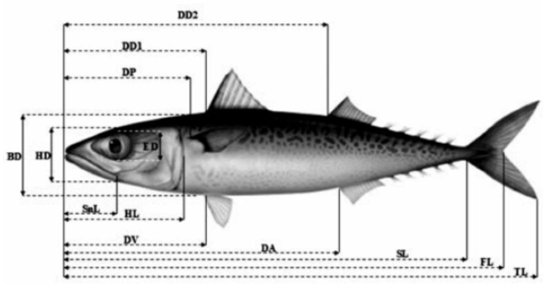


Figure 2. *Scomber colias.* Schematic drawing body with measured dimensions: (1) Snout Length (SnL), (2) Eye Diameter (ED), (3) Body depth (BD), (4) Head depth (HD) , (5) Head Length (HL), (6) Distance of pectoral fin (DP), (7) Distance of the first dorsal fin (DD1), (8) Distance of the second dorsal fin (DD2), (9) Distance of ventral fin (DV), (10) Distance of anal fin (DA), (11) Standard Length (SL), (12) Fork Length (FL) and (13) Total Length (TL).

Figure from Allaya *et al.* (2016).

References

Allaya, H., A. Ben Faleh, M. Rebaya, S. Zrelli, G. Hajjej, A. Hattour, J.-P. Quignard, M. Trabelsi. 2016. Identification of Atlantic chub mackerel *Scomber colias* population through the analysis of body shape in Tunisian waters. *Cahiers de Biologie Marine*, 57: 197-207.

Sley, A., L. A. Jawad, G. Hajjej, O. Jarboui, A. Bouain. 2016. Morphometric and meristic characters of blue runner *Caranx crysos* and false scad *Caranx rhonchus* (Pisces: Carangidae) from the Gulf of Gabes, Tunisia, Eastern Mediterranean. *Cahiers de Biologie Marine*, 57: 309-316.

Tagging (conventional, acoustic, satellite) (Contributors: Hélène de Pontual, Steve Cadrin, Karin Hüssy)

Site fidelity and connectivity between largely remoted habitats was demonstrated on whale shark (Hearn *et al.*, 2016). An integrated assessment framework (IAF) was designed for understanding hammerhead population structure and connectivity where genetic and tagging data were used to produce conceptual models of stock structure and movement, generating several hypotheses (Chin *et al.*, 2017). Pop-up satellite archival tagging (PSAT) was used to investigate the survival, movements, and habitat use of mature female school shark as bycatch of demersal longlines targeting gummy shark in the Great Australian Bight (Rogers *et al.*, 2017). Hazen *et al.* (2016) used 16 years of electronic tagging data on bluefin tuna to predict the impact of oil exposure on spawning grounds of the Gulf of Mexico population. Below we report the abstracts of the cited papers.

Chin *et al.* (2017) studied population structure and connectivity of hammerhead shark species in the Australasian region. They developed an Integrated Assessment Framework capable of incorporating a suite of data, including a combination of genetic and tagging data. This study found geographic trends in stock structuring related to sex and size of the sharks.

Hazen *et al.* (2016) used electronic tagging data to identify habitat preferences of the heavily exploited bluefin tuna in the Gulf of Mexico, with the objective to evaluate the species' exposure to the Deepwater Horizon oil spill. The overlap between oil spill and spawning habitat was found to be limited, but combined with other drivers such as ocean warming and fishing mortality, may contribute to stagnation in stock recovery.

Hearn *et al.* (2016) tagged adult whale shark with satellite tags in the Galapagos Island with the objective to study stock structuring. They found strong temporal patterns in migration directions. Apparent return migrations documented a strong connectivity between populations at Galapagos and mainland Ecuador/Peru.

Using pop-up satellite tags, Rogers *et al.* (2017) studied survival, movements and habitat use of school shark in southern Australia after capture as bycatch by demersal automatic longlines with subsequent release. This study showed that school shark survive being released, exhibit a semi-pelagic habitat use, and undertake extensive offshore migrations.

References

Chin, A., Simpfendorfer, C. A., White, W. T., Johnson, G. J., McAuley, R. B., Heupel, MR. 2017. Crossing lines: a multidisciplinary framework for assessing connectivity of hammerhead sharks across jurisdictional boundaries. *Scientific Reports*, 7.

Hazen, E. L., Carlisle, A. B., Wilson, S. G., Ganong, J. E., Castleton, M. R., Schallert, R. J., Stokesbury, M. J. W., *et al.* 2016. Quantifying overlap between the Deepwater Horizon oil spill and predicted bluefin tuna spawning habitat in the Gulf of Mexico. *Scientific Reports*, 6.

Hearn, A. R., Green, J., Roman, M. H., Acuna-Marrero, D., Espinoza, E., Klimley, A. P. 2016. Adult female whale sharks make long-distance movements past Darwin Island (Galapagos, Ecuador) in the Eastern Tropical Pacific. *Marine Biology*, 163: 214.

Rogers, P. J., Knuckey, I., Hudson, R. J., Lowther, A. D., Guida, L. 2017. Post-release survival, movement, and habitat use of school shark Galeorhinus galeus in the Great Australian Bight, southern Australia. *Fisheries Research*, 187: 188-198.

Otolith Shape (Contributors: Kelig Mahe, Christoph Stransky, Helene De Pontual)

In the past year, there were 13 papers published using otolith shape analysis. Three of these studies detailed methodological developments and their applications to otolith shape analysis (Harbitz, 2016; Wong *et al.*, 2016; Mapp *et al.*, 2017) and one study compared otolith and scale shape (Ibanez *et al.*, 2017). Mille *et al.* (2016) observed the effect of diet on otolith shape. Additionally, eight papers used otolith shape as a tool for stock identification (round sardinella *Sardinella aurita,* Bacha *et al.*, 2016; vocal toadfish *Porichthys notatus,* Bose *et al.*, 2017; sharpsnout seabream *Diplodus puntazzo,* Bostanci *et al.*, 2016*; Atherina boyeri,* Boudinar *et al.*, 2016*; Mugil cephalus,* Callicó Fortunato *et al.*, 2017a; *Mugil liza,* Callicó Fortunato *et al.*, 2017b; *Liza ramada,* Rebaya *et al.*, 2017, *Sardinops sagax,* Izzo *et al.*, 2017). We report, below, the abstracts of the papers that apply otolith shape only and those that apply otolith shape in combination with other techniques are reported in the *Interdisciplinary Analysis* section.

Bacha *et al.* (2016) examined the geographic variability in otolith shape of round sardinella *Sardinella aurita* as a tool for stock discrimination. Fish were analysed from six sampling locations from Senegal to the Mediterranean coast of Morocco. A combination of otolith shape indices and elliptic Fourier descriptors was investigated by multivariate statistical procedures. Within the studied area, three distinct groups were identified with an overall correct classification of 78%. Group A: Nador (Alboran Sea), group B: Casablanca (northern Morocco) and group C: Senegalese–Mauritanian. The results of this study confirm the absence of an Atlantic Ocean–Mediterranean Sea transition for this species, the Gibraltar Strait acting as an efficient barrier for *S. aurita* population separation. Off north-west Africa, fish from northern Morocco form a single group which is clearly isolated from Senegalese–Mauritanian waters, confirming the existence of a distinct stock in this area. Among group C, some discontinuity exists and suggests the existence of a sedentary fraction of *S. aurita* in northern Mauritania (Arguin Bank). The results are discussed in relation to oceanographic features and physical barriers to dispersal and fish management strategy in the study area.

Bose *et al.* (2017) compared the morphology of sagittal otoliths of the plainfin midshipman fish *Porichthys notatus* between populations, sexes and male alternative reproductive phenotypes (known as 'type I males or guarders' and 'type II males or sneakers'). Sagitta size increased with *P. notatus* size and changes in shape were also detected with increasing body size. *Porichthys notatus sagittae* begin as simple rounded structures, but then elongate as they grow and take on a more triangular and complex shape with several prominent notches and indentations along the dorsal and caudal edges. Moreover, the *sagittae* of the two geographically and genetically distinct populations of *P. notatus* (northern and southern) differed in shape. *Porichthys notatus* from the north possessed taller *sagittae* with deeper caudal indentations compared to *P. notatus* from the south. Sagitta shape also differed between females and males of the conventional guarder tactic. Furthermore, guarder males had smaller *sagittae* for their body size than did sneaker males or females. These differences in sagittal otolith morphology are discussed in relation to ecological and life history differences between the sexes and male tactics of this species. This is the first study to investigate teleost otolith morphology from the perspective of alternative reproductive tactics.

Bostanci *et al.* (2016) studied the morphology, biometry, and shape indices of the left and right sagittal otoliths for sharpsnout seabream, *Diplodus puntazzo* species from Aegean Sea. The shape, *sulcus acusticus* shape, proximal and distal surfaces, anterior and posterior regions of left and right sagittal otoliths for a total of 52 *D. puntazzo* were analyzed. The morphometric measurements such as weight, length, width, area, and perimeter were recorded for each pair of sagittal otoliths of the sharpsnout seabream. The shape indices such as form factor, roundness, aspect ratio, circularity, rectangularity, and ellipticity were calculated for left and right sagittal otoliths of *D. puntazzo*. The otolith width and ellipticity were significantly different ($P < 0.05$) for left and right sagittal otolith measurements and shape indices, respectively in *D. puntazzo* inhabiting the Aegean Sea. Morphological characteristics of fish otoliths were highly variable in species and populations; there was limited information on the sagittal otolith morphology and shape indices. The present study provided sufficient information of the sharpsnout seabream left and right otolith morphologies, biometry, and shape indices in the Aegean Sea, that they may provide a useful tool for marine and freshwater species discrimination and identification in further investigations.

Harbitz (2016) studied parameter-sparse modification of Fourier methods to analyse the shape of closed contours with application to otolith outlines. Elliptical Fourier descriptors (EFDs) have been used extensively in shape analysis of closed contours and have a range of marine applications, such as automatic identification of fish species and discrimination between fish stocks based on EFDs of otolith contours. A recent method (the 'MIRR' method) transforms the two-dimensional contour to a one-dimensional function by mirroring (reflecting) the lower half of the contour around a vertical axis at the right end of the contour. MIRR then applies the fast Fourier transform (FFT) to the vertical contour points corresponding to equidistant coordinate values along the horizontal axis. MIRR has the advantage of reducing the number of Fourier coefficients to two coefficients per frequency component compared with four EFDs. However, both Fourier methods require several frequency components to reproduce a pure ellipse properly. This paper shows how the methods can be easily modified so that a virtually perfect reproduction of a pure ellipse is obtained with only one frequency component. In addition, real otolith examples for cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*) are used to demonstrate that the modified methods give better approximations to the large-scale shape of the original contour with fewer coefficients than the traditional Fourier methods, with negligible additional computing time.

Ibanez *et al.* (2017) compared the discrimination of phenotypic stocks between otolith and scale shapes for *Mugil curema* specimens collected at five different locations in the Gulf of Mexico and two locations along the Pacific coast during two consecutive years. Geometric morphometric methods were used to determine the discrimination among locations using seven and 22 landmarks for scales and otoliths, respectively. The cross-validated discriminant analysis by location correctly classified 43.2 and 40.2% based on shape variables (Principal Components scores) for otoliths for all locations jointly, while for scales the classification percentages were 48.7 and 47.4% for the first and second years, respectively. Classification results improved when the discrimination analyses were carried out for pairs of locations, with 51.4 to 82.6% for otoliths and 72.7 to 97.1% for scales. The analysis was run for two consecutive years and the results for both years were best for the scales. Thus, fish scale shape offers a straightforward, non-destructive, accessible, quick and inexpensive method to trace fish phenotypic stocks.

Mapp *et al.* (2017) explored stock-separation of highly mobile Clupeids (sprat – *Sprattus sprattus* and herring – *Clupea harengus*) using otolith morphometrics. Analysis focused on three stock discrimination problems with the aim of reassigning individual otoliths to source populations using experiments undertaken using a machine learning environment known as WEKA (Waikato Environment for Knowledge Analysis). Six feature sets encoding combinations of size and shape together with nine learning algorithms were explored. To assess saliency of size/shape features half of the feature sets included size indices, the remainder encoded only shape. Otolith sample sets were partitioned by age so that the impact of age on classification accuracy could be assessed for each method. In total we performed 540 experiments, representing a comprehensive evaluation of otolith morphometrics and learning algorithms. Results show that for juveniles, methods encoding only shape performed well, but those that included size indices held more classification potential. However, as fish age, shape encoding methods were more robust than those including size information. This study suggests that methods of stock discrimination based on early incremental growth are likely to be effective, and that automated classification techniques will show little benefit in supplementing early growth information with shape indices derived from mature outlines.

Mille *et al.* (2016) investigated the potential correlation between diet and otolith shape in 5 wild marine fish species by addressing 4 complementary questions. First, is there a global relationship between diet and otolith shape? Second, which prey categories are involved in this relationship? Third, what are the respective contributions of food quantity and relative composition to diet–otolith shape co-variation? Fourth, is diet energetic composition related to otolith shape? For each species, they investigated how otolith shape varies with diet. These questions were tackled by describing diet in the analysis in 4 different ways, while also including individual-state variables to remove potential confounding effects. First, besides the strong effect of individual-state, a global relationship between diet and otolith shape was detected for 4 out of 5 fish species. Second, both main and secondary prey categories were related to variability in otolith shape, and otolith outline reconstructions revealed that both otolith global shape and its finer details co-varied with these prey categories. Third, the contribution of relative diet composition to diet–otolith shape co-variation was much higher than that of ingested food quantity. Fourth, the energetic composition of diet was related to otolith shape of only 1 species. These results suggest that diet in marine fish species may influence the quantity and composition of saccular endolymph proteins which play an important role in otolith biomineralization and their resulting 3D structure.

Rebaya *et al.* (2017) tested otolith shape discrimination of *Liza ramada* (Actinopterygii: Mugiliformes: Mugilidae) from marine and estuarine populations in Tunisia. The specimens of L. ramada were collected during three months (from March to May 2013) at two sampling sites: the marine (Cap Zebib sea resort) and the estuarine (Mellegue Dam) in Tunisia. They analysed sagittal otolith shape variation for 120 individuals (60 fish of each study site comprising 30 males and 30 females) for both sexes (males and females) and two sides (left and right otolith) for each specimen. Statistical- and discriminant function analysis of the sagittal otolith shape clearly demonstrated statistically significant differences from the two populations. These results were also confirmed by highly statistically significant difference between otolith shape (left and right) for both sexes. An asymmetry was detected when comparing otoliths of the same side (RR–LL) between different sampling sites. The shape variability of otolith between these two sampling sites is probably correlated with local environmental and ecological factors.

Wong *et al.* (2016) tested automated otolith image classification with multiple views. Combined multiple 2D views (proximal, anterior and ventral aspects) of the sagittal otolith are proposed here as a method to capture shape information for the classification. Classification performance of single view compared with combined 2D views show improved classification accuracy of the latter, for nine species of Sciaenidae. The effects of shape description methods (shape indices, Procrustes analysis and elliptical Fourier analysis) on classification performance were evaluated. Procrustes analysis and elliptical Fourier analysis perform better than shape indices when single view is considered, but all perform equally well with combined views. A generic content-based image retrieval (CBIR) system that ranks dissimilarity (Procrustes distance) of otolith images was built to search query images without the need for detailed information of side (left or right), aspect (proximal or distal) and direction (positive or negative) of the otolith. Methods for the development of this automated classification system are discussed.

References

Bacha, M., A. M. Jeyid, S. Jaafour, A. Yahyaoui, M. Diop, R. Amara. 2016. Insights on stock structure of round sardinella *Sardinella aurita* off north-west Africa based on otolith shape analysis. *Journal of Fish Biology*, 89: 2153–2166.

Bose, A. P. H., J. B. Adragna, S. Balshine. 2017. Otolith morphology varies between populations, sexes and male alternative reproductive tactics in a vocal toadfish *Porichthys notatus*. *Journal of Fish Biology*, 90: 311–325.

Bostanci, D., M. Yilmaz, S. Yedier, G. Kurucu, S. Kontas, M. Darçin, N. Polat. 2016. Sagittal otolith morphology of sharpsnout seabream *Diplodus puntazzo* (Walbaum, 1792) in the Aegean sea. *International Journal of Morphology*, 34(2): 484-488.

Harbitz, A. 2016. Parameter-sparse modification of Fourier methods to analyse the shape of closed contours with application to otolith outlines. *Marine and Freshwater Research*, 67: 1049-1058.

Ibánez, A. L., K. Hernández-Fraga, S. Alvarez-Hernández. 2017. Discrimination analysis of phenotypic stocks comparing fish otolith and scale shapes. *Fisheries Research*, 185: 6–13.

Mapp, J., E. Hunter, J. Van Der Kooijc, S. Songer, M. Fisher. 2017. Otolith shape and size: The importance of age when determining indices for fish-stock separation. *Fisheries Research*, 190: 43–52.

Mille, T., K. Mahé, M. Cachera, M. C. Villanueva, H. de Pontual, B. Ernande. 2016. Diet is correlated with otolith shape in marine fish. *Marine Ecology Progress Series*, 555: 167-184.

Rebaya, M., A. R. Ben Faleh, H. Allaya, M. Khedher, M. Trojette, B. Marsaoui, M. Fatnassi, A. Chalh, J.-P. Quignard, M. Trabelsi. 2017. Otolith shape discrimination of *Liza ramada* (Actinopterygii: Mugiliformes: Mugilidae) from marine and estuarine populations in Tunisia. *Acta Ichthyologica et Piscatoria*, 47(1): 13–21.

Wong, J. Y., C. Chu, V. C. Chong, S. K. Dhillon, K. H. Loh. 2016. Automated otolith image classification with multiple views: an evaluation on Sciaenidae. *Journal of Fish Biology*, 89: 1324-1344.

Otolith Chemistry (Contributors: Lisa Kerr and Dave Secor)

In the past year, otolith chemistry has been applied as a stock identification tool to discern stock structure of fish species around the world. Below is a summary of recent applications of otolith chemistry to fish stock identification of ICES species of interest, as well as an update on advances in the field.

Three papers utilized otolith chemistry to understand connectivity of fish species in an around marine protected areas. Lazartigues *et al.* (2016) applied otolith microchemistry to determine the source of capelin to a marine protected area in Canada (Saguenay-St. Lawrence Marine Park). Results indicated that the principal source of capelin to the marine park was the St. Lawrence estuary, outside the conservation area boundaries. Gibb *et al.* (2016) examined connectivity in the lesser sandeel, *Ammodytes marinus*, using otolith microchemistry within areas subjected to spatial management. Otoliths from juveniles were examined from four Scottish spawning areas predicted from modelled estimates of larval dispersal to differ in terms of larval retention rates and connectivity. Results revealed that one area (Firth of Forth) had a largely separate natal source. Regnier *et al.* 2017 analysed the otolith chemical signature the roundnose grenadier (*Coryphaenoides rupestris*) to evaluate the level of connectivity between the Rosemary Bank seamount, considered for inclusion in a network of MPAs, the Scottish west coast, and two adjacent locations. The elemental signatures of the fish from the seamount were distinguishable from the fish from the two other areas and authors concluded that once juveniles settled on the seamount they remain there for the rest of their lives.

Thomas *et al.* (2017) compared the elemental composition of otoliths versus endolymph. The authors applied size exclusion chromatography-inductively coupled plasma-mass spectrometry (SEC-ICP-MS) of endolymph to determine the binding interactions for a range of elements. The authors also applied solution ICP-MS to quantify element concentrations in paired otolith and endolymph samples and determined relative enrichment factors for each. The authors concluded that elements occurring only in the salt fraction are most likely to reflect changes in the physico-chemical environment experienced during life; elements occurring only in the proteinaceous fraction are more likely to reflect physiological rather than environmental events; and elements occurring in both the salt and proteinaceous fractions are likely to be informative about both endogenous and exogenous processes.

A special issue entitled *Frontiers in otolith chemistry: insights, advances and applications* was published in Journal of Fish Biology in 2017. The Special Issue grew out of a symposium held at the 2015 American Fisheries Society annual meeting in Portland, Oregon. The Special Issue consisted of nine manuscripts, including an overview of the special issue (Walther and Limburg 2017). Several of the contributions point out the necessity of validating basic assumptions about the chemical composition of otoliths as well as the selected analytical approach. In addition to otolith chemistry studies, a rapidly expanding area of interest is the use of alternative biological structures that may substitute as analogues for otoliths. These include scales, fin rays, vertebrae, scutes, and eye lenses. The papers are summarized below.

Limburg and Elfman (2017) highlighted the potential for heterogeneity in composition of sectioned otoliths in elements such as strontium, barium, manganese and selenium, a result relevant to analyzing otolith transects. Pracheil *et al.* (2017) investigated the composition of acipenserid otoliths and found that the crystal form was heterogenous with up to a third of the otoliths composed of calcite and the remainder vaterite, depending on the species. This study emphasized the need to carefully examine the underlying assumptions when interpreting otolith-derived migratory or environmental histories in fish. Jones *et al.* (2017) assessed alternative classification methods, including discriminant function analyses (linear and quadratic) and machine-algorithm methods. When parametric assumptions were met, the traditional parametric classification methods performed best, indicating that when data can be transformed to meet assumptions parametric classifiers should be used. This work highlights the need to carefully consider the statistical methods employed to classify unknown-origin individuals. Humston *et al.* (2017) coupling model-derived estimates of spatial heterogeneity in water ^{87}Sr:^{86}Sr ratios (Sr 'isoscapes') with field-collected water samples to assess model performance in a mainstem and tributary system. Water samples verified model isoscape predictions, and the study employed these markers to assess relative contributions of tributary spawning habitat and exchange among these two habitat types for a migratory centrarchid species.

In addition to otolith chemistry studies, a rapidly expanding area of interest is the use of alternative biological structures (e.g., scales, fin rays, vertebrae, scutes, and eye lenses). McMillan *et al.* (2017) discuss the assumptions and limitations of these approaches similar to the assessment of Elsdon *et al.* (2008) for otoliths. McMillan *et al.* (2017) highlighted the fact that elemental analyses in elasmobranchs is currently a young field, with few experimental validations of uptake and incorporation dynamics. As such, investigators must be cautious not to apply otolith-derived uptake dynamics to these structures and are advised to continue experimental assessments to allow confidence in interpreting patterns from wild-caught specimens.

Three papers in this Special Issue validated the utility of otolith analogues and employed them to infer migratory movements of wild-captured fishes. Bock *et al.* (2017) quantified relationships of elemental and isotope ratios between water and dentary material in paddlefish *Polyodon spathula* (Walbaum 1792), and found strong support for the use of these markers in reconstructing water chemistry history with these structures. Tzadik *et al.* (2017) investigated elemental and isotope ratio profiles across fin rays of a number of species and found strong concordance in patterns of some constituents between otoliths and fin rays from the same individuals, supporting the utility of fin rays as a non-lethal alternative to sampling otoliths.

Phelps *et al.* (2017) employed elemental signatures in acipenserid fin rays sampled non-lethally to determine movement of individuals between reaches of large river systems. The use of non-lethal alternatives to otoliths is critical for these types of vulnerable species where mortality must be avoided. A review by Carlson *et al.* (2017) evaluated the application of otolith chemistry as a fisheries management tool, including its application to resolving questions of stock identification. The review demonstrated that otolith chemistry has diverse implications and applications for fisheries management worldwide.

References

Bock, L. R., G. W. Whitledge, B. Pracheil, P. Bailey. 2017. Relationships between water and paddlefish Polyodon spathula dentary elemental and stable-isotopic signatures: potential application for reconstructing environmental history. *Journal of Fish Biology*, 90(2): 595-610.

Carlson, A. K., Q. E. Phelps, B. D. S. Graeb,. 2017. Chemistry to conservation: using otoliths to advance recreational and commercial fisheries management. Journal of Fish Biology, 90 (2): 505-527.

Gibb, F. M., K. Donald, P. J. Wright. 2017. Connectivity in the early life history of sandeel inferred from otolith microchemistry. Journal of Sea Research, 119: 8-16.

Humston, R., S. S. Doss, C. Wass, C. Hollenbeck, S. R. Thorrold, S. Smith, C. P. Bataille. 2017. Isotope geochemistry reveals ontogeny of dispersal and exchange between main-river and tributary habitats in smallmouth bass *Micropterus dolomieu*. *Journal of Fish Biology*, 90(2): 528- 548.

Jones, C. M., M. Palmer, J. J. Schaffler. 2017. Beyond Zar: the use and abuse of classification statistics for otolith chemistry. *Journal of Fish Biology*, 90(2): 492-504.

Lazartigues, A. V., S. Plourde, J. J. Dodson, O. Morissette, P. Ouellet, P. Sirois. 2016. Determining natal sources of capelin in a boreal marine park using otolith microchemistry. *ICES Journal of Marine Science*, 73 (10): 2644-2652. doi: 10.1093/icesjms/fsw104

Limburg, K. E., M. Elfman. 2017. Insights from two-dimensional mapping of otolith chemistry. *Journal of Fish Biology*, 90(2): 480-491.

McMillan, M. N., C. Izzo, B. Wade, B. M. Gillanders. 2017. Elements and elasmobranchs: hypotheses, assumptions and limitations of elemental analysis. *Journal of Fish Biology*, 90(2): 559-594.

Phelps, Q. E., R. N. Hupfeld, G. W. Whitledge. 2017. Lake sturgeon Acipenser fulvescens and shovelnose sturgeon Scaphirhynchus platorynchus environmental life history revealed using pectoral fin-ray microchemistry: implications for interjurisdictional conservation through fishery closure zones. *Journal of Fish Biology*, 90(2): 626-639.

Pracheil, B. M., B. C. Chakoumakos, M. Feygenson, G. W. Whitledge, R. P. Koenigs, R. M. Bruch. 2017. Sturgeon and paddlefish (Acipenseridae) sagittal otoliths are composed of the calcium carbonate polymorphs vaterite and calcite. *Journal of Fish Biology*, 90(2): 549-558.

Régnier, T., J. Augley, C. D. Robinson, P. J. Wright, F. C. Neat. 2017. Otolith chemistry reveals seamount fidelity in a deepwater fish. *Deep Sea Research Part I: Oceanographic Research Papers*, 121: 183-189.

Thomas, O. R., B. K. Ganio, B. R. Roberts,S. E. Swearer. 2017. Trace element–protein interactions in endolymph from the inner ear of fish: implications for environmental reconstructions using fish otolith chemistry. *Metallomics*, 9: 239-249.

Tzadik, O. E., E. B. Peebles, C. D. Stallings. 2017. Life-history studies by non-lethal sampling: using microchemical constituents of fin rays as chronological recorders. *Journal of Fish Biology*, 90(2): 611-625.

Parasites (Contributor: Ken Mackenzie)

In the past year, nine papers were published related to the use of parasites as biological tags in studies of the population structure of marine fish.

Three papers from the southwest Atlantic followed up on previous studies by Argentinian and Brazilian researchers who had identified different biogeographic regions in this area, each characterized by its own distinctive fauna of generalist parasites. Braicovich *et al.* (2016) referenced the use of parasites in fish stock assessment studies and assessed the role of different host traits (size, mass, age and their interactions with sex) as drivers of the abundance of long-lived parasites in this area. The results of generalised linear mixed models indicated fish length as a slightly better predictor than age or mass, leading the authors to recommend that comparisons of parasite abundance should be restricted to fish of similar length. The Brazilian flathead *Percophis brasiliensis* was the target host in both that study and another by Braicovich *et al.* (2017) which evaluated the utility of long-lived larval parasites (digeneans, cestodes, nematodes and acanthocephalans) as indicators of the previously identified zoogeographical regions off the coasts of Argentina, Uruguay and Brazil. Multivariate analyses showed a close fit between parasite assemblages and the existing zoogeographical classifications. The third paper from this region (Lanfranchi *et al.* 2016) focused on ecotonal regions – regions of convergence of different water masses – and analysed data on assemblages of long-lived larval parasites of silvery John Dory *Zenopsis conchifer* caught in the ecotonal region between two current systems. The results showed that parasite communities can be used as reliable indicators to define such regions, which are usually subjected to strong fishery pressures requiring the implementation of good management programmes.

Two papers examined parasites of fish in South African waters to address questions of stock identity. Nunkoo *et al.* (2016) investigated the community ecology of snoek *Thyrsites atun* in the Benguela system with respect to area, seasonality and life history stage of the host species. The homogeneity of the community structure of long-lived endoparasites suggested a single stock of snoek off South Africa. De Moor *et al.* (2017) followed up previous studies on the use of a "tetracotyle"-type metacercaria for stock identification of sardine *Sardinops sagax* off the west and south coasts of South Africa. New data enabled the authors to provide more precise estimates of annual movement and the extent of mixing of different age-groups of sardine between two different stocks.

In Mediterranean waters, Feki *et al.* (2016) used differences in the occurrence of 10 parasite taxa to identify three distinct areas within the distribution of juvenile and young adult horse mackerel *Trachurus trachurus* off the coast of Tunisia. In the North Atlantic, Klapper *et al.* (2017) investigated the spatial and temporal occurrence of the parasitic copepod *Sphyrion lumpi* on beaked redfish *Sebastes mentella* in the Irminger Sea. The authors found that abundance of *S. lumpi* remained constant during summer over the period 2001 to 2015, confirming its validity as a biomarker. Two stock units were identified, supporting continuation of the current management strategy.

Violante-González *et al.* (2016) surveyed the parasite faunas of green jack *Caranx caballus* from three locations off the Pacific coast of Mexico and evaluated their utility as biological tags. Of the 24 parasite taxa recorded, they identified 8 as being potentially useful tags. Multivariate discriminant analyses indicated the existence of three separate stocks with no evidence of migration between the three sampling locations.

References

Braicovich, P.E., E. N. Ieno, M. Sáez, J. Despos J. T. Timi. 2016. Assessing the role of host traits as drivers of the abundance of long-lived parasites in fish-stock assessment studies. *Journal of Fish Biology*, 89: 2419-2433.

Braicovich, P.E., C. Pantoja, A. N. Pereira, J. L. LuqueJ. T. Timi. 2017. Parasites of the Brazilian flathead *Percophis brasiliensis* reflect West Atlantic biogeographic regions. *Parasitology*, 144: 169-178.

de Moor, C. N., D. S. Butterworth, C. D. van der Lingen 2017. The quantitative use of parasite data in multistock modelling of South African sardine (*Sardinops sagax*). *Canadian Journal of Fisheries and Aquatic Sciences*, dx.doi.org/10.1139.cjfas-2016-0280.

Feki, M., M. Châari, L. Neifar L. Boudaya. 2016. Spatial variability of helminth parasites to recognize the discrimination of juvenile and young adult areas of horse mackerel, *Trachurus trachurus* (Linnaeus, 1758) off the coast of Tunisia. *Fisheries Research*, 183: 318-325.

Klapper, R., M. Bernreuther, J. Wischneski S. Klimpel. 2017. Long-term stability of *Sphyrion lumpi* abundance in beaked redfish *Sebastes mentella* of the Irminger Sea and its use as biological marker. *Parasitology Research*, 16: 1561-1572.

Lanfranchi, A. L, P. E. Braicovich, D. M. P. Cantatore, A. J. AlarcosJ. L. Luque 2016. Ecotonal marine regions – ecotonal parasite communities: helminth assemblages in the convergence of masses of water in the southwestern Atlantic Ocean. *International Journal for Parasitology*, 46: 809-818.

Nunkoo, M. A. I., C. C. Reed, S. E. Kerwath 2016. Community ecology of the metazoan parasites of snoek *Thyrsites atun* (Euphrasen, 1791) (Perciformes: Gempylidae) off South Africa. *African Journal of Marine Science*, 38: 363-371.

Violante-González, J., Y. Gallegos-Navarro, S. Monks, S. García-Ibáñez, A. A. Rojas-Herrera, G. Pulido-Flores, S. Villerías-Salinas, E. Larumbe-Morán. 2016. Parasites of the green jack *Caranx caballus* (Pisces: Carangidae) in three locations from Pacific coasts of Mexico, and their utility as biological tags. *Revista Mexicana de Biodiversidad*, 87: 1015-1022.

Interdisciplinary analysis (Contributors: All Participants)

Using interdisciplinary methods to investigate stock identity is a continuing trend in the field. Below we have summarized applications which involved multiple techniques applied to address questions of stock identity.

Boudinar *et al.* (2016) investigated genetic differentiation and species delimitation among nine *Atherina boyeri* populations from several marine and lagoon/brakish habitat sites in Algeria, Tunisia and France using three mitochondrial (control region, Cyt b and 16S) and one nuclear markers (2nd intron of S7). Five groups were found. Two of them perfectly corresponded to two species already recognized *Atherina presbyter* and *Atherina hepsetus*, both living in marine waters; and three additional, including *Atherina boyeri* (brackish and freshwater environments) and two independent groups of marine punctated and unpunctated individuals. Those findings are corroborated by the study of the otolith contour shape of 362 individuals of seven populations from different habitats using Fourier analysis. Samples from Ziama inlet, marine punctuated individuals and unpunctuated marine specimens from Annaba's Gulf formed three well separated groups. Specimens from Mellah and Mauguio lagoons formed another group. The last one includes individuals from Bizerte and Thau lagoons. The divergences between them strongly support the potential species within the *A. boyeri* species complex.

Callicó Fortunato *et al.* (2017a) characterized juvenile *Mugil cephalus* (flathead grey mullet) habitats in the Valencian community using otolith morphometry and microchemistry. Morphometric results showed, by an ANOVA with Bonferroni contrasts, that saccular otoliths from AV individuals had more edge complexity, hence a higher circularity index ($p < 0.001$), but that there was less otolith percentage occupied by the sulcus ($p < 0.001$). When analyzing the morphometric variables simultaneously, both sites differed significantly (Hotelling's T2 < 0.001). A paired t-test among sites of the microchemical variables showed that otoliths of AV presented higher values of Ba/Ca ratios and lower Sr/Ca ratios ($p < 0.001$). This coincides with water values obtained and could be associated with the low salinity observed in the lake. The opposite pattern was observed in SP, both for otolith and water samples, this being associated with the high-salinity waters of the area. Results obtained in the present research suggest, by the use of otolith morphometry and microchemistry that the nursery grounds of juvenile *M. cephalus* in the Valencian community could be differentiated. Even though habitats could be separated using otolith morphometry, only a few of the studied shape indices were important in area differentiation. Nevertheless, the use of both methodologies simultaneously could be robust habitat markers for this species.

Izzo *et al.* (2017) integrated genetic, morphological, otolith, growth, reproductive and fishery data collected over 60 years using a Stock Differentiation Index (SDI). The absence of strong separation (SDI[0.66) of most adjacent sub-groups supports the hypothesis that sardine (*Sardinops sagax*) in Australian waters is a meta-population, but with effective isolation of at least four stocks: south western coast (off Western Australia); Great Australian Bight and Spencer Gulf; Bass Strait and Port Phillip Bay (off Victoria and Tasmania); and eastern Australia. There is also evidence for sub-division of the stocks off Western Australia and the east coast. They examined age-related and inter-annual patterns of stock structure off South Australia and the east coast through integrated analysis of otolith chemistry and shape data. For the east coast, there were significant differences between northern and southern sub-groups for all three age cohorts examined. Fish were correctly classified to sampling region with a high degree of success ([80%), supporting the sub-division of the east coast stock suggested by the SDI. For South Australia, there were significant differences among two sub-groups for most cohorts examined across two sampling years. However, spatial discriminatory power was poor, with allocation success ranging from 48 to 64%. Results suggest that movements between the two South Australian subgroups may vary among years, which is consistent with inconclusive SDI (0.5). Integrating historical data using a SDI is suitable for identifying fishery management units. Integrated analysis of otoliths from archival collections is useful for examining temporal variability in stock structure, which is also important for fisheries management. Our findings are relevant to fisheries where sustainability risks are increased by management arrangements based on assumptions that stock structure is absent or stable.

Callicó Fortunato *et al.* (2017b) investigated the mullet *Mugil liza* that lives southernmost in the western Atlantic Ocean. Knowledge about migration, movements and identification of stocks of this important fishery resource is scarce. Thus, they aimed to study movement patterns and to identify the presence of different fish stocks in the southwestern region of the Atlantic Ocean, using cumulative otolith shape morphometric and microchemical analyses of sagittae otoliths. Specimens (n = 99) were obtained in four coastal areas: Paranaguá Bay in Brazil, Samborombón Bay, Mar Chiquita Coastal Lagoon, and San Blas Bay in Argentina. Otolith shape indices (circularity, rectangularity, aspect ratio, percentage occupied by sulcus, ellipticity and form factor) were used for stock identification analysis; and otolith microchemistry using LA-ICP-MS (Sr/Ca and Ba/Ca ratios chronological variation) was used for both the analysis of movement behaviours and the identification of fish stocks (otolith edge ratios). Morphometrical indices did not reveal a clear separation among areas. San Blas bay individuals presented otoliths tending to be longer than wider, with a more elliptic shape than the otoliths from other studied areas; also, this area did not share individuals with the most northern one, Paranaguá Bay in Brazil. The analysis of microchemical lifetime profiles revealed three types of behaviour pattern: Type I: most frequent use of estuarine environments; Type II: a fluctuating behaviour between estuarine and sea/high salinity waters; Type III: most frequent use of sea/high salinity habitats. Otolith edge analysis did not reveal differences among Sr/Ca and Ba/Ca ratios for the different areas. Thus, it cannot be assured that there is more than one stock in the studied region. *Mugil liza* revealed different environmental migratory behaviours in the Southwestern Atlantic Ocean showing a facultative use of estuarine waters; hence, the species appears to be mostly coastal with the use of low estuaries, as seen also by the Sr/Ca otolith cores ratios; differing from the general mugilid behaviour previously described.

Lowerre-Barbieri *et al.* (2016) used a combination of acoustic tagging data with aerial surveys and capture statistics to study migration patterns and stock structure in juvenile and adult red drum off Florida, USA. They documented strong spatio-temporal patterns in spawning site selection with population-specific spawning site fidelity and natal homing.

Taillebois *et al.* (2017) applied parasite tagging, together with genetics and otolith chemistry, used in a study of the stock structure of the sciaenid fish *Protonibea diacanthus* in coastal waters of northern Australia (Taillebois *et al.* 2017). All three methods suggested strong spatial variation between sampling locations, indicating the existence of a number of locally discrete populations with restricted exchange between them.

Duarte *et al.* (2017) investigated the composition of Caranx spp. catch from Rio de Janeiro State, Brazil with classical taxonomic, multivariate morphometry, and allozyme molecular markers to determine that at least three species were present. However, using Bayesian methods, it was determined that there is evidence to suggest that four species may be present, whereas only two species are recorded in commercial fisheries landings reports, complicating the management of the fishery.

Parsons *et al.* (2016) tested the use of morphological and meristic characteristics for stock identification of snapper off New Zealand with the combined use of otolith chemistry and tag-recapture data from taggings with external dart tags. While no morphological differences were observed between stock components, otolith chemistry and tag-recapture information showed strong geographical complexity in population structure, highlighting the need to revisit spatial stock management units.

Ulrich *et al.* (2017) evaluated stock management units of plaice in the North Sea- Skagerrak – Kattegat area using the combined information from a century of T-bar tagging data coupled with genetics, otolith growth and hydrogeographical drift modelling. Considerably connectivity in populations between Skagerrak and the North Sea resulted in these two management units being merged into a single one.

Pérez-Quiñónez *et al.* (2017) used a combined method of geometric morphometrics and genetic analysis to identify species within the *Opisthonema* complex of Pacific threadfin herring in the eastern Mexican Pacific. These species are harvested together in mixed aggregations and proper determination of catch share is important to future management.

Ozerov *et al.* (2016) combined genetic markers with the traditionally utilized gill-raker count to improve mixed-stock analysis in Baltic whitefish (***Coregonus lavaretus s.l***.) to identify sea- and river-spawning ecotypes.

Vieira *et al.* (2016) analyzed specimens of forkbeard *Phycis phycis* from the Northeast Atlantic Ocean (Azores, Madeira, and mainland Portugal) for geometric morphometric analysis and genetic differences. Additional genetic samples from Spain, Italy, and Croatia were analyzed to effectively cover the entire range of the forkbeard. Although the morphology among the three locations was found to be highly variable and hypothesized to be due to environmental factors, genetic differentiation overall was low. The authors conclude that this is possibly indicative of recent population expansions to the Northeast Atlantic from the Mediterranean Sea during the Last Glacial Maximum.

Stern *et al.* (2017) conducted a global study to determine the differentiation among the five putative sardine species within the subgenus *Sardinella*, including morphological and genetic analyses. Morphometric analysis found only two morphospecies and the three species-delimination analyses failed discriminated the five putative species, with the authors suggesting a single global cosmopolitan species *Sardinella aurita* with ecophenotypic variations. This study calls for the merging of phylogenetic and population genetic approaches to test the feasibility of taxonomic theory relating to this species. This in turn underscores the importance validating basic species identification with the use of typical stock identification methods.

References

Boudinar, A. S., L. Chaoui, J. P. Quignard, D. Aurelle, M. H. Kara. 2016. Otolith shape analysis and mitochondrial DNA markers distinguish three sand smelt species in the *Atherina boyeri* species complex in western Mediterranean A.S. *Estuarine, Coastal and Shelf Science*, 182: 202-210.

Callicó Fortunato, R, V. Benedito Durà, A. Volpedo1. 2017a. Otolith morphometry and microchemistry as habitat markers for juvenile *Mugil cephalus* Linnaeus 1758 in nursery grounds in the Valencian community, Spain, *Journal of Applied Ichthyology*, 33: 163–167.

Callicó Fortunato, R., M. González-Castro, A. Reguera Galán, I. García Alonso, C. Kunert, V. Benedito Durà, A. Volpedo. 2017b. Identification of potential fish stocks and lifetime movement patterns of *Mugil liza* Valenciennes 1836 in the Southwestern Atlantic Ocean. *Fisheries Research*, 193: 164-172.

Duarte, M. R., R. A. Tubino, C. Monteiro-Neto, R. R. M. Martins, F. C. Viera, M. F. Andrade-Tubino, E. P. Silva. 2017. Genetic and morphometric evidence that jacks (Carangidae) fished off the coast of Rio de Janeiro (Brazil) comprise four different species. *Biochemical Systematics and Ecology*, 71: 78-86.

Izzo, C., T. M. Ward, A. R. Ivey, I. M. Suthers, J. Stewart, S. C. Sexton, B. M. Gillanders. 2017. Integrated approach to determining stock structure: implications for fisheries management of sardine, *Sardinops sagax*, in Australian waters. *Reviews in Fish Biology and Fisheries,* 27: 267-284.

Lowerre-Barbieri, S. K., S. L. W. Burnsed, J. W. Bickford. 2016. Assessing reproductive behaviour important to fisheries management: a case study with red drum, Sciaenops ocellatus. *Ecological Applications*, 26: 979-995.

Ozerov, M. Y., M. Himberg, P. V. Debes, H. Hägerstrand, A. Vasemägi. 2016. Combining genetic markers with an adaptive meristic trait improves performance of mixed-stock analysis in Baltic whitefish. *ICES Journal of Marine Science*, 73 (10): 2529-2538.

Parsons, D. M., M. A. Morrison, B. M. Gillanders, K. D. Clements, S. J. Bury, R. Bian, K. T. Spong. 2016. Variation in morphology and life-history strategy of an exploited sparid fish. *Marine and Freshwater Research*, 67: 1434-1444.

Pérez-Quiñónez, C. I., C. Quiñónez-Velázquez, J. S. Ramírex-Pérez, F. J. Vergara-Solana F. J. García-Rodríguez. 2017. Combining geometic moprhometircs and genetic analysis to identify species of *Opisthonema* Gill, 1861 in the eastern Mexican Pacific. *Journal of Applied Ichthyology*, 33 (1): 84-92.

Stern, N., J. Douek, M. Goren, B. Rinkevich. 2017. With no gap to mind: a shallow genealogy within the world's most widespread pelagic fish. *Ecography*, 40: 1-13.

Taillebois, L., D. P. Barton, D. A. Crook, T. Saunders, J. Taylor, M. Hearnden, R. J. Saunders, S. J. Newman, M. J. Travers, D. J. Welch, A. Greig, C. Dudgeon, S. Maher, J. R. Ovenden. 2017. Strong population structure deduced from genetics, otolith chemistry and parasite abundances explains vulnerability to localised fishery collapse in a large Sciaenid fish, *Protonibea diacanthus*. *Evolutionary Applications*, doi: 10.111/eva.12499.

Ulrich, C., J. Hemmer-Hansen, J. Boje, A. Christensen, K. Hussy, H. L. Sun, L. W. Clausen. 2017. Variability and connectivity of plaice populations from the Eastern North Sea to the Baltic Sea, part II. Biological evidence of population mixing. *Journal of Sea Research*, 120: 13-23.

Vieira, A. R., A. S. B. Rodrigues, V. Sequeira, A. Neves, R. B. Paiva, O. S. Paulo. 2016. Genetic and morphological variation of the forkbeard, *Phycis phycis* (Pisces, Phycidae): evidence of panmixia and recent population expansion along its distribution area. *PLoS ONE*, https://doi.org/10.1371/journal.pone.0167045.

Published Theme Set Update (Contributor: Lisa Kerr)

In last year's SIMWG report, we referenced the plan to publish a theme set entitled: *Beyond Ocean Connectivity* in the ICES Journal of Marine Science that followed up a session by the same name at ICES ASC 2015 (Conveners: Manuel Hidalgo , Lisa Kerr, and Claire Paris). The theme set was published in July 2017 (volume 74, Issue 6) and contained nine papers that were grouped into four topic areas: methodological advances, population dynamics and assessment implications of connectivity, spatial and management implications, and connectivity in ecosystem processes.

Methodological advances - Kaplan *et al.* (2017) developed probabilistic statistical methods for estimating uncertainty of a broad range of larval mark-recapture connectivity estimators, including otolith microchemistry and genetic parentage analysis. Additionally, the use of larval mark-recapture experiments to estimate marine connectivity was explored in two studies, one using artificial chemical tagging of larval otoliths (Secor *et al.*, 2017), the other applying genetic approaches to assign recruits to source populations (Christie *et al.*, 2017). In other methodological andvances, Christie *et al.* (2017) applied a forward-time agent-based model of genetic information to Kellet's whelk (*Kelletia kelletii*) in southern California, incorporating key life history and physical oceanographic information, to assess the advantages and disadvantages of two commonly used methods to assign individuals back to their natal origin. Monroy *et al.* (2017) presented an assessment of Lagrangian Flow Networks, a numerical modelling technique to estimate larval connectivity.

Population dynamics and assessment implications of connectivity - Kerr *et al.* (2017) presented a review of approaches applied to resolve mismatches between the scale of biological populations and spatially defined stock units. The review included case studies that applied the following approaches: (i) status quo management, (ii) "weakest link" management, (iii) spatial and temporal closures, (iv) stock composition analysis, and (v) alteration of stock boundaries.

Spatial and management implications - Gallego *et al.*(2017) investigated the connectivity of epi-benthic species as a part of the Scottish nature conservation MPA designation process. Nicolle *et al.* (2017), examined great scallop (*Pecten maximus*) dispersal pathways and the patterns of connectivity between fishing grounds in the English Channel. Zemeckis *et al.* (2017) investigated the seasonal movement in the Gulf of Maine.

Connectivity in ecosystem processes - Lough *et al.* (2017), eluents and connectivity of the spring spawning component of Atlantic cod in the westestrated how prey selection by juvenile pelagic cod for zooplankton of different size (*Centropages spp.* vs. *Pseudocalanus spp.*) under different climatic regimes can affect growth and survival rates.

References

Christie M. R., Meirmans P. G., Gaggiotti O. E., Toonen R. J., White C. 2017. Disentangling the relative merits and disadvantages of parentage analysis and assignment tests for inferring population connectivity. ICES Journal of Marine Science , 74: 1749–1762.

Gallego A., Gibb F. M., Tullet D., Wright P. J. 2017. Bio-physical connectivity patterns of benthic marine species used in the designation of Scottish nature conservation Marine Protected Areas. ICES Journal of Marine Science , 74: 1797–1811.

Kaplan D. M., Cuif M., Fauvelot C., Vigliola L., Nguyen-Huu T., Tiavouane J., Lett C. 2017. Uncertainty in empirical estimates of marine larval connectivity. ICES Journal of Marine Science , 74: 1723–1734.

Kerr L. A., Hintzen N. T., Cadrin S. X., Clausen L. W., Dickey-Collas M., Goethel D. R., Hatfield M. C., Kritzer J. P., Nash R. D. 2017. Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish. ICES Journal of Marine Science , 74: 1708–1722.

Lough G., Broughton E., Kristiansen T. 2017. Changes in spatial and temporal variability of prey affect functional connectivity of larval and juvenile cod. ICES Journal of Marine Science. doi.org/10.1093/icesjms/fsx080.

Monroy P., Rossi V., Ser-Giacomi E., López C., Hernández-García E. 2017. Sensitivity and robustness of larval connectivity diagnostics obtained from Lagrangian Flow Networks. ICES Journal of Marine Science , 74: 1763–1779.

Nicolle A., Moitié R., Ogor J., Dumas F., Foveau A., Foucher E., Thiébaut E. 2017. Modelling larval dispersal of Pecten maximus in the English Channel: a tool for the spatial management of the stocks. ICES Journal of Marine Science , 74: 1812–1825.

Secor D. H., Houde E. D., Kellogg L. L. 2017. Estuarine retention and production of striped bass larvae: a mark-recapture experiment. ICES Journal of Marine Science , 74: 1735–1748.

Zemeckis D. R., Liu C., Cowles G. W., Dean M. J., Hoffman W. S., Martins D., Cadrin S. X. 2017. Seasonal movements and connectivity of an Atlantic cod (Gadus morhua) spawning component in the western Gulf of Maine. ICES Journal of Marine Science , 74: 1780–1796.

Advances in Stock Identification Methods in 2018

In 2018, there were several notable advances in stock identification methods and a proliferation of applications, with many results relevant to ICES science and advice. Here, we summarize advances and results accounting for research in genetics, growth marks in calcified structures, life history parameters, morphometrics/meristics, tagging, otoliths, parasites, simulation approaches, and interdisciplinary approaches.

- Genetics (Contributor: Stefano Mariani)
- Growth marks in calcified structures (Contributor: Rich McBride)
- Life history parameters (Contributor: Rich McBride)
- Morphometrics/ meristics (Contributor: Steve Cadrin)
- Tagging (Contributor: Steve Cadrin)
- Otolith shape (Contributor: Kelig Mahe)
- Otolith chemistry (Contributors: Lisa Kerr and Zachary Whitener)
- Parasites (Contributor: Ken Mackenzie)
- Simulation approaches (Contributor: Lisa Kerr)
- Interdisciplinary approaches (Contributor: Stefano Mariani, Lisa Kerr, Steve Cadrin)
- Published Theme Set Update (Contributor: Stefano Mariani)
- Review of Pitmann *et al.*'s Seascape Ecology: Dave Secor

Genetics (Contributor: Stefano Mariani)

Our annual monitoring of the patterns of usage of molecular markers in fisheries stock identification continues to document a gradual, slow decrease in studies using microsatellites, paralleled by a gradual increase of studies employing SNPs as marker of choice. Despite the trend, however, the proportional change does not differ significantly between 2016 and 2017 (chi-square: 0.7, p-value: 0.3), and interestingly, the total number of studies published on the subject appears to be decreasing overall (see dotted black line in Figure 1). However, it is important that the data for 2018 are not complete at this time (August 2018).

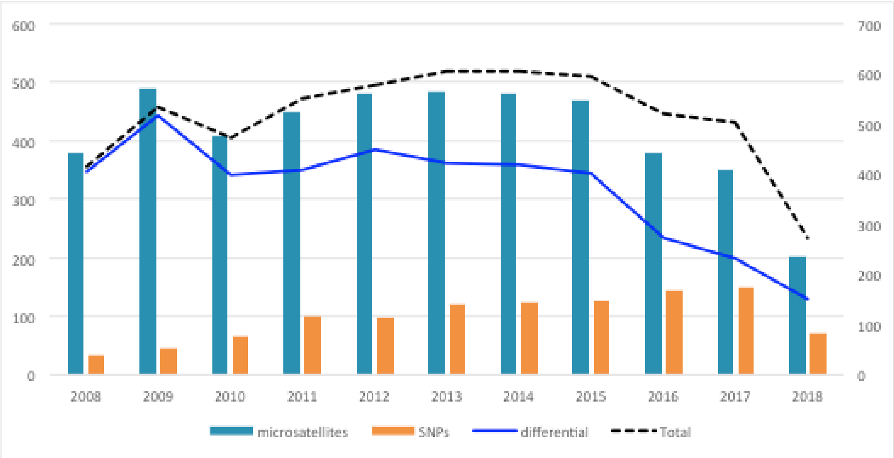


Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (blue bars) and SNPs (orange bars), as listed in the Clarivate Analytics Web-of-Science. The search criteria were: "fish* AND gene* AND (population OR stock) AND 'molecular marker*'," where 'molecular marker*' means "Microsatellite*" or "SNP*". Only papers in the following disciplinary areas were considered: 'Fisheries', 'Environmental Sciences & Ecology', 'Biodiversity Conservation', 'Marine & Freshwater Biology' and 'Oceanography'. Data for 2018 only represent papers published through to the present date (August 2018).

Nevertheless, there were a few recent studies that showed the importance of genetic approaches in resolving population structure and providing evidence for reconsidering assessment and management guidelines.

Using a panel of around 50 SNPs, Westgaard *et al.* (2017) document the existence of spatial genetic heterogeneity between expanding hake (*Merluccius merluccius*) populations around Norwegian and Swedish coasts and more southern locations in the North Sea and the Bay of Biscay, which suggests that a single North-East Atlantic stock assessment unit for this species may not be appropriate.

Saha *et al.* (2017) show how a panel of just 13 microsatellites can separate three different evolutionarily significant units of golden redfish, *S. norvegicus*, which should also raise consideration for stock assessment.

Drinan *et al.* (2018) used >6400 SNPs to refine stock structure in Pacific cod (*Gadus macrocephalus*) along the western coast of North America, recovering high assignment probability for population of origin (i.e. >77–84%), and describing an isolation-by-distance pattern that largely mirrored that previously found using microsatellites.

Puncher *et al.* (2018) contributed new understanding of stock identity and mixing of Bluefin tuna (*Thunnus thynnus*) in the North Atlantic. Their analysis, based on around 100 high-graded SNPs, confirms, in line with previous indications, significant use of western Atlantic feeding aggregations by adult tuna spawned in the Mediterranean.

References

Saha A. *et al.* Cryptic *Sebastes norvegicus* species in Greenland waters revealed by microsatellites. ICES J. Mar. Sci. 74: 2148-2158. https://doi.org/10.1093/icesjms/fsx039

Drinan D.P. (2018). Population assignment and local adaptation along an isolation-by-distance gradient in Pacific cod (Gadus macrocephalus). Evol. Appl. https://doi.org/10.1111/eva.12639

Puncher G.N. *et al.* (2018). Spatial dynamics and mixing of bluefin tuna in the Atlantic Ocean and Mediterranean Sea revealed using next-generation sequencing. Mol. Ecol. Resour. 18: 620-638. DOI: 10.1111/1755-0998.12764

Westgaard J.I. *et al.* (2017). Large and fine scale population structure in European hake (*Merluccius merluccius*) in the Northeast Atlantic. ICES J. Mar. Sci. 74: 1300-1310. ttps://doi.org/10.1093/icesjms/fsw249

Growth marks in calcified structures (Contributor: Rich McBride)

Long-term monitoring of fish and their fisheries produce datasets that can be explored for identifying stock structure, as done by Du Pontavice *et al.* (2018) for the common sole (Soleidae, *Solea solea*) in the eastern English channel. Previous research had proposed fine-scale stock structure within this area, assessed as a unit stock, and Du Pontavice *et al.* confirm that growth varied among three subareas of the channel. They used otolith-derived ages, a von Bertalanffy growth function, and an information-theoretic approach, offering a particularly exhaustive treatment of data. They account for sex differences of this well recognized dimorphic flatfish; they demonstrate the effect of using fishery-independent data (i.e., UK-beam trawl survey on both sides of the channel) versus fishery-dependent data (i.e., French commercial landings); they also included an alternative (logistic) growth model, which was rejected compared to the AIC/BIC values of the VBGF. In terms of specifics, the estimated asymptotic fish length was largest for females (v. males), from commercial landings (v. UK-BTS), and the southwest, French subarea of the channel (v. northeast or UK side). The authors note that tagging data so far suggests limited adult movements, which would contribute to this fine-scale stock structure. It was also of interest that the subarea with the lowest asymptotic length also had the highest fishing mortality, as estimated by Archambault *et al.* (2016), which suggests that fishing-induced change in growth characters could be involved. Because data was only examined for a recent period (2010–2015), but data exist since 1989, additional analyses across historic periods would be possible to determine if these are persistent or more recent phenotypic patterns, addressing questions about environmental or fishing-induced effects on common sole growth in this region.

References

Adams, G. D., R. T. Leaf, J. C. Ballenger, S. A. Arnott, and C. J. McDonough. 2018. Spatial variability in the growth of Sheepshead (*Archosargus probatocephalus*) in the Southeast US: Implications for assessment and management. Fisheries Research 206:35-43. DOI: 10.1016/j.fishres.2018.04.023

Archambault, B., O. Le Pape, L. Baulier, Y. Vermard, M. Véron, and E. Rivot. 2016. Adult-mediated connectivity affects inferences on population dynamics and stock assessment of nursery-dependent fish populations. Fisheries Research 181:198-213. DOI: 10.1016/j.fishres.2016.03.023

Du Pontavice, H., M. Randon, S. Lehuta, Y. Vermard, and M. Savina-Rolland. 2018. Investigating spatial heterogeneity of von Bertalanffy growth parameters to inform the stock structuration of common sole, Solea solea, in the Eastern English Channel. Fisheries Research 207:28-36. DOI: 10.1016/j.fishres.2018.05.009

Life history parameters (Contributor: Rich McBride)

Age, length and weight data for sheepshead (Sparidae: *Archosargus probatocephalus*) demonstrates geographic patterns of length-at-age and weight-at-length across much of this species' range, in the southeast United States (Adams *et al.*, 2018). Sheepshead from northern Atlantic sampling locations are larger at age and heavier at length than southern Atlantic and Gulf of Mexico locations. Adams *et al.*'s results outline both the value and limitations of the Bayesian approach they incorporated. For example, Texas was represented by only a small sample size and few ages. The setting of priors that Bayes encourages allowed inclusion of the Texas samples in the size at age comparison, but the uncertainty of the estimates were evident, asserting that more data would be useful going forward with management applications. Likely unknown to the ICES community, sheepshead is an emerging example of the interdisciplinary approach to stock identification. Since the 1950s, sheepshead morphometric characters have been used to support three subpopulations across temperate, subtropical, and tropical latitudes, from North to South America. Also, the genetic stock structure of sheepshead, recently reported by Seyoum *et al.* (2017), identified two genetic breaks within Florida, whereas Adams *et al.* results did not recognize growth differences within this state. The recreational sheepshead fishery is the 10th most important in the United States in landings, so these new phenotypic and genotypic reports will certainly be used soon to inform this species' assessment and management.

References

Adams, G. D., R. T. Leaf, J. C. Ballenger, S. A. Arnott, and C. J. McDonough. 2018. Spatial variability in the growth of Sheepshead (*Archosargus probatocephalus*) in the Southeast US: Implications for assessment and management. Fisheries Research 206:35-43. DOI: 10.1016/j.fishres.2018.04.023

Seyoum, S., R. S. McBride, C. Puchutulegui, J. Dutka-Gianelli, A. C. Alvarez, and K. Panzner. 2017. Genetic population structure of sheepshead, Archosargus probatocephalus (Sparidae), a coastal marine fish off the southeastern United States: multiple population clusters based on species-specific microsatellite markers. Bulletin of Marine Science 93: 691-713. DOI: 10.5343/bms.2016.1069

Morphometrics/meristics (Contributor: Steve Cadrin, with input from Christoph Stransky)

Morphological variation remains a valuable approach to phenotypic stock identification. Recently published case studies demonstrate that advanced methodologies and technologies are being commonly applied, with many recent contributions from India:

- Berg *et al.* (2018) confirmed previous studies that found high heritability of meristic, morphometric and growth traits. They investigated both genetic factors and salinity gradients on phenotypic plasticity of Atlantic herring from the Atlantic Ocean into the Baltic Sea using breeding experiments. They concluded that otolith shape and vertebral counts have a significant genetic component and are therefore useful for stock identification.
- Jakubavičiūtė *et al.* (2018) studied morphological variation and differentiation of three-spined stickleback (*Gasterosteus aculeatus*) from two major genetic clusters inhabiting coastal Baltic Sea areas, using geometric morphometrics, body plate numbers and otolith shape. Their results show that fish from one area (Curonian Lagoon) representing one of the clusters had a significantly higher number of body plates, potentially indicating a response to higher predation pressure compared to the other areas studied. Body shape also significantly differed among locations with deeper bodied fish in the Curonian Lagoon. The most conservative and least plastic trait studied, otolith shape, did, however, not show any divergence among the areas studied. The results suggest morphological divergence in plastic traits like body plates and body shape in response to local environmental conditions. The lack of divergence in otolith shape further suggests that the degree of population differentiation is weak or rather recent, as also highlighted in earlier studies using molecular markers or synchrony in population abundances. Overall, this study shows that at least the number of body plates can serve as an effective stock delineator among genetic clusters of three-spined sticklebacks in the Baltic Sea.
- Rawat *et al.* (2017) provide a review of truss morphometrics for stock identification. They provide twelve case studies from India and conclude that truss networks are effective for measuring shape and discriminating stocks.
- Geladakis *et al.* (2017) used landmark morphometrics to compare putative stocks of sardine from seven locations in the eastern Mediterranean. The found that body condition was strongly related to principal coordinate scores. Despite the confounding effect of body condition, discrimination of different morphotypes from the Aegean and Ionian Sea was significant and supported 81% correct classifications.
- Canty *et al.* (2018) evaluated geographic variation of yellowtail snapper from three locations off Honduras in an attempt to enforce area-based management. Their analysis included genotyping, otolith microchemistry and morphometrics to identify geographic origin and found that morphometric analysis supported 80% classification accuracy, otolith microchemistry supported 54% accuracy and genetic analyses supported 52% accuracy. Although the authors make conclusions about the most appropriate approach to discriminating capture location, better understanding of stock identity (e.g., distribution patterns, connectivity, reproductive isolation, environmental patterns) would provide better guidance on the most appropriate scale of spatial management and approach for stock discrimination.
- Perez-Quinonez *et al.* (2017) discriminated three species of thread herrings in the Gulf of California using meristic, morphometric and mtDNA characters. They counted gill rakers, quantified geometric morphometrics of body shape, and analyzed Cytochrome Oxidase Subunit I of mtDNA. Three distinct morphotypes were genetically different.
- Kocabaş *et al.* (2017) investigated phenotypic variation in three trout species and found differences in spotting pattern, colour pattern or fin pigmentation traits.
- Pazhayamadom *et al.* (2017) found significant morphometric differences between the Red Sea and the Mediterranean Sea associated with swimming and visibility.

- Vikas *et al.* (2018) correctly classified orangefin labeo from five locations with 50–80% accuracy based on morphometrics.
- Purushothaman *et al.* (2018) used a morphometric truss network to investigate stock structure of Arabian red shrimp from five locations off India and found significant geographic variation.
- Sreekanth *et al.* (2017) studied stock structure of Japanese threadfin bream from four locations off India using truss network analysis with 69-79% classification accuracy.

References

Berg F, OW Almeland, J Skadal, A Slotte, L Andersson & A Folkvord. 2018. Genetic factors have a major effect on growth, number of vertebrae and otolith shape in Atlantic herring (*Clupea harengus*). PLoS ONE 13(1): e0190995. https://doi.org/10.1371/journal.pone.0190995

Canty SWJ, NK Truelove, RF Preziosi, S Chenery, MAS Horstwood & SJ Box. 2018. Evaluating tools for the spatial management of fisheries. J. Applied Ecology 2018: 1-8 DOI: 10.1111/1365-2664.13230

Geladakis G, N Nikolioudakis, G Koumoundouros & S Somarakis. 2017. Morphometric discrimination of pelagic fish stocks challenged by variation in body condition. ICES Journal of Marine Science, doi:10.1093/icesjms/fsx186.

Jakubavičiūtė E, De Blick Y, Dainys J, Ložys L, Olsson J. 2018. Morphological divergence of three-spined stickleback in the Baltic Sea—Implications for stock identification. Fisheries Research 204: 305–315.

Rawat S, S Benakappa, J Kumar, AS Kumar Naik, G Pandey & CW Pema. 2017. Identification of fish stocks based on Truss Morphometric: A review. J. Fisheries and Life Sci. 2: 9-14.

Kocabaş M, F Kutluyer & N Başçinar. 2017. Phenotypic differentiation analysis: A case study in hybridizing Çoruh trout (*Salmo coruhensis*), Rize trout (*Salmo rizeensis*) and brown trout (*Salmo trutta fario*). Acta Zoologica 2017: 1-7.

Pazhayamadom DG, LA Jawad & M Hassan. 2017. Stock differentiation of goldband goatfish Upeneus moluccensis from the Red Sea and the Mediterranean Sea using morphometric analysis. International Journal of Marine Science 7(5): 37-50 doi: 10.5376/ijms.2017.07.0005.

Perez-Quinonez CI, C Quinonez-Velazquez, JS Ramırez-Perez, FJ Vergara-Solana & FJ Garcıa-Rodrıguez. 2017. Combining geometric morphometrics and genetic analysis to identify species of *Opisthonema* Gill, 1861 in the eastern Mexican Pacific. J. Appl. Ichthyol. 33: 84–92.

Purushothaman P, RD Chakraborty, G Kuberan, G Maheswarudu, PK Baby, L Sreesanth, N Ragesh & DG Pazhayamadom. 2018. Stock structure analysis of the Arabian red shrimp (*Aristeus alcocki* Ramadan, 1938) in the Indian coast with truss network morphometrics. Canadian Journal of Zoology 96: 411-424. https://doi.org/10.1139/cjz-2016-0283

Sreekanth GB, SK Chakraborty & AK Jaiswar. 2017. Stock structure analysis of Japanese threadfin bream, *Nemipterus japonicus* (Bloch, 1791) along the Indian coast based on truss network analysis. International J. Marine Sci. 46: 1836-1841.

Vikas AM, S Chennuri, B Madhusudhana Rao, S Kumar & M Kumar. 2018. A multivariate morphometric investigation to delineate the stock structure of *Labeo calbasu* (Cypriniformes - Cyprinidae). Journal of Entomology and Zoology Studies 6: 632-638.

Tagging (Steve Cadrin, with input from Ben Galuardi, Haritrz Arrizabalaga, and Kurt Schaefer)

Applications of conventional and electronic tagging for stock identification continue to be informative for inferences of connectivity and migration patterns. Several new advances in technology and statistical analysis were recently published, largely from large pelagic species:

Methods

- Heerah *et al.* (2017) developed a method to combine spectral analysis and hidden Markov models for the identifying behavioural patterns. Detection of behavioural switches is essential for geolocation from archival tag data. An new approach was developed to extract cyclic behaviours and activity levels from a time-frequency analysis of movement time series and include spectral signatures of cyclic patterns into a Hidden Markov Model framework. The approach was demonstrated with data for European sea bass, showing different activity regimes with tidal rhythms (when fish were less active and dived shallower), and diurnal behaviour (when more active and deeper in the water column). Occurrence of behaviours during similar periods in the annual cycle suggest seasonal functional behaviours (e.g. feeding, migrating and spawning).
- Braun *et al.* (2018a) developed an R package for geolocation of archival-tagged fishes using a hidden Markov method. The R package HMMoce uses available tag and oceanographic data to improve position estimates derived from electronic tags. They demonstrate the package using blue and mako shark archival tag data. In comparison to results from other geolocation approaches, HMMoce produced a six-fold improvement in location.
- Liu *et al.* (2017) validated a hidden Markov model for the geolocation of Atlantic cod using moored tags and cod tagged with both archival and acoustic tags. Validation was used to determine optimal model features.

Case Studies

- Horton *et al.* (2017) reviewed route fidelity of marine megafauna based on case studies of satellite telemetry for humpback whale, great white shark and northern elephant seal. They conclude that all three species are capable of route fidelity movements across millions of square kilometers of open ocean with a spatial accuracy of better than 150 km despite temporal separations as long as seven years between individual movements. Route fidelity movements reflect lunar periodicities, and gravitational cues are strong predictors of route fidelity
- Le Bris *et al.* (2017) studied annual migration patterns of Atlantic halibut in the Gulf of St. Lawrence using satellite archival tags. Seasonal migrations involved moving from deeper offshore waters in the winter to shallower nearshore waters in the summer. Results suggest that Atlantic halibut in the Gulf of St. Lawrence is a philopatric population, supporting the current separate management unit definitions.
- Strøm *et al.* (2017) documented ocean migrations of Atlantic salmon using satellite archival and acoustic tags. Fish tagged from the Miramichi River in Canada exclusively utilized areas within the Gulf of St Lawrence and the Labrador Sea, and showed little overlap with known distributions of European stocks. Strøm *et al.* (2018) studied migration of six post-spawned Atlantic salmon from a North Norwegian river, during the entire ocean migration. The tagged fish moved long-distances through Arctic areas, and most exhibited a strong fidelity towards Jan Mayen Island, particularly during winter.
- Arregui *et al.* (2018) overwintering of juvenile bluefin tuna and fidelity to the Bay of Biscay using internal and satellite archival tags. They found high concentration in the Bay of Biscay during summer, when bluefin tuna inhabit in the mixed layer, and substantial geographic dispersion from autumn to spring. Half of the fish overwintered in the mid-

Atlantic, near the Azores or Madeira Islands, while three made trans-Atlantic round trips, and one individual travelled to and remained off the eastern coast of the United States. A high percentage of tagged fish returned the next year, suggesting a strong fidelity to the area. One third of tagged fish overwintered in the Bay of Biscay and surrounding areas. These findings appear to contradict assumptions about seasonality and annual movement patterns of bluefin tuna in the Bay of Biscay.

- Arrizabalaga *et al.* (2018) reviewed the subpopulation structure of Atlantic bluefin tuna of Mediterranean origin based on electronic tagging and genetic studies to revise some life history and movement paradigms. Although is somewhat equivocal to test several hypotheses, they conclude that it seems more likely that bluefin tuna spawned in the western Mediterranean use the Atlantic more intensively than those spawned in the eastern Mediterranean. Schaefer *et al.* (2015) studied movement patterns and mixing of bigeye tuna in the central Pacific Ocean using over 31 thousand tag deployments. Linear movements from conventional tags and most probable tracks from archival tags suggest some regional fidelity and substantial mixing of bigeye tuna between release longitudes. Mixing is greatest among adjacent areas.
- Skomal *et al.* (2017) studied broad-scale movements of the white shark in the western North Atlantic using satellite-based tags. They found that white sharks are more broadly distributed than previously believed. Young fish were located in near-coastal and shelf-oriented habitat but ontogentically shifted to pelagic habitat with frequent excursions to mesopelagic depths.
- Braun *et al.* (2018b) studied basking shark movements in the western Atlantic using archival tag data and an oceanographic model. Many individuals spent several months at meso- and bathy-pelagic depths where accurate light-level geolocation was impossible during fall, winter and spring. Integration of archival tag data analysis with three-dimensional depth-temperature profile data indicated that basking sharks moved over 17 000 km from Massachusetts to Brazil, and most demonstrated seasonal fidelity to Cape Cod and the Gulf of Maine.
- Mansfield *et al.* (2017) documented seasonal variation in trans-equatorial movement of South Atlantic yearling loggerhead turtles using satellite tags. Yearling loggerhead turtles from Brazilian rookeries transited south with strong southward currents. When currents flowed in the opposite direction late in the hatching season, turtles moved northwards across the Equator. Swimming helps to maintain position within frontal zones seaward of the continental shelf.
- Curtis *et al.* (2018) investigated movements of young white sharks in the western North Atlantic. Satellite and acoustic tag data indicated that young white sharks remained resident in New York Bight waters through summer, suggesting that the region is a nursery area. Southward movements were observed during fall, with overwintering habitat identified off North and South Carolina shelf waters. Return migrations toward the New York Bight were observed in some individuals the following spring.
- Schaefer *et al.* (2011) investigated movement patterns of yellowfin tuna off Baja California using from archival tag data. Analyses indicated four distinct behaviours: 1) diving less than 50 m at night and greater than about 100 m during the day; 2) ten or more dives greater than 150 m during the day; 3) surface-oriented behaviour; and 4) deep-diving behaviour exceeding 1000 m.
- Secor *et al.* (2017) used a mark-recapture experiment to evaluate larval retention of striped basin Chesapeake Bay. More than 25 million larvae were released with chemically marked otoliths. They conclude that increased nursery volume reduces variance in water quality and enhances retention of larvae within the nursery.
- Gaube *et al.* (2018) found that mesoscale eddies influence the movements of mature female white sharks in the Gulf Stream and Sargasso Sea using satellite and archival tags.

Two mature female white sharks inhabited the interiors of anticyclonic eddies, characterized by warm temperature anomalies. One shark with an archival tag made frequent dives to 1000 m in anticyclones, where it was presumably foraging on mesopelagic prey. Prey may be more accessible in warm temperature anomalies in anticyclones.

References

Arregui I, B Galuardi, N Goni, CH Lam, I Fraile, J Santiago, M Lutcavage & H Arrizabalaga. 2018. Movements and geographic distribution of juvenile bluefin tuna in the Northeast Atlantic, described through internal and satellite archival tags. ICES Journal of Marine Science, doi:10.1093/icesjms/fsy056.

Arrizabalaga H, I Arregui, A Medina, N Rodríguez-Ezpeleta, JM Fromentin & I. Fraile. 2018. Life history and migrations of Mediterranean bluefin populations. In Bluefin Futures (in Press).

Braun CD, B Galuardi B & S Thorrold. 2018a. HMMoce : An R package for improved geolocation of archival-tagged fishes using a hidden Markov method. Methods Ecol. Evol. doi:10.1111/2041-210X.12959.

Braun CD, GB Skomal & S Thorrold. 2018b. Integrating Archival Tag Data and a High-Resolution Oceanographic Model to Estimate Basking Shark (*Cetorhinus maximus*) Movements in the Western Atlantic. Front. Mar. Sci. 5. doi:10.3389/fmars.2018.00025.

Curtis TH, G Metzger, C Fischer, B McBride, M McCallister, LJ Winn, J Quinlan & MJ Ajemian. 2018. First insights into the movements of young-of-the-year white sharks (*Carcharodon carcharias*) in the western North Atlantic Ocean. Sci. Rep. 8(1): 10794. doi:10.1038/s41598-018-29180-5.

Gaube P, CD Braun, GL Lawson, DJ McGillicuddy, AD Penna, GB Skomal, C Fischer & S Thorrold. 2018. Mesoscale eddies influence the movements of mature female white sharks in the Gulf Stream and Sargasso Sea. Sci. Rep. 8(1): 7363. doi:10.1038/s41598-018-25565-8.

Heerah K, M Woillez, R Fablet, F Garren, S Martin & H De Pontual. 2017. Coupling spectral analysis and hidden Markov models for the segmentation of behavioural patterns. Movement Ecology 5:20 DOI 10.1186/s40462-017-0111-3.

Horton TW, N Hauser, AN Zerbini, MP Francis, ML Domeier, A Andriolo, DP Costa, PW Robinson, CAJ Duffy, N Nasby-Lucas, RN Holdaway & PJ Clapham. 2017. Route Fidelity during Marine Megafauna Migration. Front. Mar. Sci. 4:422. doi: 10.3389/fmars.2017.00422

Le Bris A, JAD Fisher, HM Murphy, PS Galbraith, M Castonguay, T Loher, & D Robert. 2017. Migration patterns and putative spawning habitats of Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of St. Lawrence revealed by geolocation of pop-up satellite archival tags. ICES J. Mar. Sci. 75(1): 135–147. doi:10.1093/icesjms/fsx098.

Liu C, G Cowles, DR Zemeckis, SX Cadrin & MJ Dean. 2017. Validation of a hidden Markov model for the geolocation of Atlantic cod. Can. J. Fish. Aquat. Sci. 74: 1862–1877.

Mansfield KL, ML Mendilaharsu, NF Putman, MAG dei Marcovaldi, AE Sacco, G Lopez, T Pires & Y Swimmer. 2017. First satellite tracks of South Atlantic sea turtle ‘lost years’: seasonal variation in trans-equatorial movement. Proc. R. Soc. B Biol. Sci. 284(1868): 20171730. doi:10.1098/rspb.2017.1730.

Secor DH, ED Houde & LL Kellogg. 2017. Estuarine retention and production of striped bass larvae: a mark-recapture experiment. ICES Journal of Marine Science doi:10.1093/icesjms/fsw245.

Schaefer KM, DW Fuller & BA Block. 2011. Movements, behaviour, and habitat utilization of yellowfin tuna (*Thunnus albacares*) in the Pacific Ocean off Baja California, Mexico, determined from archival tag data analyses, including unscented Kalman filtering. Fisheries Research 112: 22– 37.

Schaefer K, D Fuller, J Hampton, S Caillot, B Leroy & D Itano. 2015. Movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus*) tagged and released in the equatorial Central Pacific Ocean, with conventional and archival tags. Fisheries Research 161: 336–355.

Skomal G, C Braun, J Chisholm & S Thorrold. 2017. Movements of the white shark *Carcharodon carcharias* in the North Atlantic Ocean. Mar. Ecol. Prog. Ser. 580: 1–16. doi:10.3354/meps12306.

Strøm JF, EB Thorstad, G Chafe, SH Sørbye, D Righton, AH Rikardsen & J Carr. 2017. Ocean migration of pop-up satellite archival tagged Atlantic salmon from the Miramichi River in Canada. ICES J. Mar. Sci. 74(5): 1356–1370. doi:10.1093/icesjms/fsw220.

Strøm JF, EB Thorstad, RD Hedger & AH Rikardsen. 2018. Revealing the full ocean migration of individual Atlantic salmon. Anim. Biotelemetry 6: 2. doi:10.1186/s40317-018-0146-2.

Otolith shape (Contributor: Kelig Mahe, with input from Christoph Stransky)

From July 2017 to July 2018, there were 12 papers using otolith shape as tool to identify species, stocks or morphotypes. The analyzed species are very different: bastard grunt (*Pomadasys incises*; Villegas-Hernández *et al.*, 2018); *Sebastes* species (Afanasyeva *et al.*, 2017; Chistensen *et al.*, 2018); *Scomber* species (He *et al.*, 2018); North Atlantic albacore tuna (*Thunnus alalunga*; Duncan *et al.*, 2018); blue jack mackerel (*Trachurus picturatus*, Vasconcelos *et al.*, 2018); *Astyanax* species (Avigliano *et al.*, 2018), *Gobiidae* species (Banaru *et al.*, 2017 ; Lombarte *et al.*, 2018), cod (*Gadus morhua*; Bardarson *et al.*, 2017); Whitemouth croaker (*Micropogonias furnieri,* Da Silva Santos *et al.*, 2017), Lebranche mullet (*Mugil liza*; Callico Fortunato *et al.*, 2017). However, the methodology most often used to describe the otolith shape is Elliptic Fourier Descriptors.

Afanasyeva *et al.* (2017) applied geometric morphometrics and elliptical Fourier analysis to otolith samples to analyze species identification and population structure of seven *Sebastes* species. *Sebastes* are notoriously difficult to distinguish using body morphology. So, the discrimination of species based on otolith shape is promising for stock identification.

Avigliano *et al.* (2018) evaluated Fourier descriptors and shape indices of lapillus otoliths for the discrimination among three sympatric species of the genus *Astyanax* inhabiting streams of the Atlantic Rain Forest (Argentina). Aspect ratio, roundness and ellipticity of otoliths were significantly different between the species ($p < 0.05$), while no significant differences were found for circularity, rectangularity and form factor ($p > 0.05$). PERMANOVA analysis revealed significant differences between species using Fourier descriptors ($F = 96.7$, $0.0001 < p < 0.02$) and the reclassification rates of quadratic discriminant analysis were high, averaging 86.3% (82.7–88.6%). Multivariate analyses of shape indices were not effective to discriminate between species. Instead, high classification percentages suggest that the otolith outline is a potential tool for the identification of sympatric morphologically similar species of *Astyanax*.

Banaru *et al.* (2017) analyzed the otolith shape and age of three species of Gobiidae: *Neogobius melanostomus* (Pallas, 1814), *Ponticola eurycephalus* (Kessler, 1974) and *Mesogobius batrachocephalus* (Pallas, 1814) from the Western part of the Black Sea. These phylogenetically close species showed otolith shape differences. The round goby, Neogobius melanostomus, showed differences in otolith shape between local populations, probably related to differences in diet and environmental variability influenced by the Danube River inputs in the North of the study area. The age of these commercially exploited species was estimated by otolith microstructural analysis and the results were linked to sex, size and weight. This information is valuable for fishery management purposes.

Bardarson *et al.* (2017) used otolith shape to identify ecotypes of the Icelandic cod (*Gadus morhua*) stock. The use of data storage tags has increased our knowledge of the stock structure of Icelandic cod. The profiles of tagged cod reveal different migratory strategies. This has led to the definition of two ecotypes within the cod stock. Frontal ecotypes reside in deep waters during feeding season and express a highly variable temperature profile associated with thermal fronts, while coastal ecotypes stay in shallow waters all year round. In this study, the data storage tag profiles were analysed with cluster analysis, which revealed the existence of an intermediate behaviour that expresses a variable depth profile and feeding migration that is both shorter in time and not as deep. The main objective was to develop a morphological key based on otoliths to distinguish the ecotypes. The shape of the otoliths was extracted with shape measurements and fast Fourier transforms. A discriminant function analysis indicated a difference in morphology between the ecotypes, resulting in successful classification.

Callico Fortunato *et al.* (2017) studied movement patterns of the mullet *Mugil liza* and to identify the presence of different fish stocks in the southwestern region of the Atlantic Ocean, using cumulative otolith shape morphometric and microchemical analyses of sagittae otoliths. Specimens (n = 99) were obtained in four coastal areas: Paranaguá Bay in Brazil, Samborombón Bay, Mar Chiquita Coastal Lagoon, and San Blas Bay in Argentina. Otolith shape indices (circularity, rectangularity, aspect ratio, percentage occupied by sulcus, ellipticity and form factor) were used for stock identification analysis; and otolith microchemistry using LA-ICP-MS (Sr/Ca and Ba/Ca ratios chronological variation) was used for both the analysis of movement behaviours and the identification of fish stocks (otolith edge ratios). Morphometrical indices did not reveal a clear separation among areas. San Blas bay individuals presented otoliths tending to be longer than wider, with a more elliptic shape than the otoliths from other studied areas; also, this area did not share individuals with the most northern one, Paranaguá Bay in Brazil. The analysis of microchemical lifetime profiles revealed three types of behaviour pattern: Type I: most frequent use of estuarine environments; Type II: a fluctuating behaviour between estuarine and sea/high salinity waters; Type III: most frequent use of sea/high salinity habitats. Otolith edge analysis did not reveal differences among Sr/Ca and Ba/Ca ratios for the different areas. Thus, it cannot be assured that there is more than one stock in the studied region. *Mugil liza* revealed different environmental migratory behaviours in the Southwestern Atlantic Ocean showing a facultative use of estuarine waters; hence, the species appears to be mostly coastal with the use of low estuaries, as seen also by the Sr/Ca otolith cores ratios; differing from the general mugilid behaviour previoulsy described.

Chistensen *et al.* (2018) analysed otolith shape variation of *Sebastes mentella* and *S. norvegicus* caught on the continental slope of East Greenland using the R package "Shape R". Results were evaluated against genetic analysis of the same fish, and compared to results of both a visual identification of the two species and a separation based on a linear discriminant analysis on standardised values of fish length, fish weight and otolith weight. It was concluded that the objective otolith shape analysis using the Shape R package analysis achieve a reasonable classification success, however with a clear bias towards *S. mentella.* Classification using the otolith weight achieved a slightly higher success than the shape analysis making it a promising method. Furthermore, the method is at the same time both objective, less time consuming than the otolith shape analysis and less expensive than genetic analysis. However, the visual classification method of the whole fish had the highest success rate of the three tested methods, which despite the need for trained technicians makes it the most successful method.

Da Silva Santos *et al.* (2017) assessed changes in otolith shape of *Micropogonias furnieri* along its geographical distribution range between the tropical and warm temperate coastal of Southwestern Atlantic. Ten otoliths from each of six areas along the South American coast were examined: 1) Rio de Janeiro State (23°S); 2) São Paulo State (24°S); 3) Santa Catarina State (27°S), 4) Rio Grande do Sul State (32°S); 5) Uruguayan coast (35°S); 6) Northern coast of Argentine (39°S). The sagitta otolith contour and shape were characterized using the Elliptical Fourier Analysis (EFA) and the morphometric measurements of both otoliths and respective sulcus acusticus were performed using the software ImageJ. Variations of otolith shape were assessed by five explanatory variables (area, perimeter, width, circularity and the maximum Feret diameter) and a Principal Components Analysis (PCA) was applied to Elliptical Fourier Descriptors. We found significant differences in area, perimeter and circularity of otoliths. Clustering the range of the 30 first harmonics using Ward's hierarchical algorithm yielded three otolith morphotypes. Plots of the two first Principal Component (PCs) axes for the 60 examined otoliths did not discriminate the population distribution along the six areas. The three different otolith morphotypes do not seem to be subjected to a clinal variation for this transition area in the Southwestern Atlantic, and suggest an overlap of individuals of different stocks/populations mixing along their geographical distribution range favored by their eurythermic and euryhaline characteristics.

Duncan *et al.* (2018) investigated the stock structure of North Atlantic albacore tuna using otolith shape analysis. Juvenile albacore tunas were collected from the commercial fishery in the Bay of Biscay region over a three-year period (2012–2014). Catches were concentrated in two main areas: within the Bay of Biscay (East) and off the western shelf edge (West). Otolith shape was defined using Elliptical Fourier analysis and was compared between albacore from these two catch locations using generalised canonical discriminant analysis. The results show significant differences in otolith shape between albacore from the Eastern and Western locations using Elliptical Fourier descriptors. The discriminant analysis and jack-knifed cross-validation classification correctly classified East and West samples with a success rate of 72% and 75% respectively. The results suggest that two components with distinct environmental life histories contribute to the fishery in the Northeast Atlantic. It also implies that albacore juveniles display some degree of fidelity to their feeding areas.

He *et al.* (2018) used morphometric analysis of otolith shapes to differentiate three species of *Scomber*. The sagittae morphology of *S. scombrus* otolith is totally different from that of *S. japonicus* and *S. australasicus*. Multivariate analysis consistently showed that *S. japonicus* was morphologically similar to S. australasicus, whereas a significant difference in otolith shapes was detected between *S. scombrus* and other two species of *Scomber*. The rostrum, antirostrum, excisural notch and dorsal-posterior margin of the otolith reflect the main variations between the three species of *Scomber*. Shape indices and Fourier coefficients were used to discriminate fish species using analysis of variance and Fisher discriminant analysis. The shape indices successfully differentiated 100%, 95.7% and 96.4% of otoliths in *S. japonicus, S. australasicus and S. scombrus*, respectively, while the Fourier coefficients only discriminated 70.0%, 61.9% and 91.3% of the sagittae in S. *japonicus, S. australasicus and S. scombrus*. This study indicates that the shape analysis on the sagittae morphometrics of otoliths is a better method to differentiate species of *Scomber*.

Lombarte *et al.* (2018) describe and analyse the morphology of the sagitta, the largest otolith, of 25 species of Gobiidae inhabiting the Adriatic and north-western Mediterranean seas. Our goal was to test the usefulness and efficiency of sagittal otoliths for species identification. Our analysis of otolith contours was based on mathematical descriptors called wavelets, which are related to multi-scale decompositions of contours. Two methods of classification were used: an iterative system based on 10 wavelets that searches the Analisi de Formes d'Otlits (AFORO) database and a discriminant method based only on the fifth wavelet. With the exception of paedomorphic species, the results showed that otolith anatomy and morphometry can be used as diagnostic characters distinguishing the three Mediterranean phylogenetic goby lineages (*Pomatoschistus* or sand-goby lineage, *Aphia* lineage and *Gobius* lineage). The main anatomical differences were related to overall shape (square to rhomboid), the development and shape of the postero-dorsal and antero-ventral lobes and the degree of convexity of dorsal and ventral margins. Iterative classifications and discriminant analysis of otolith contour provided very similar results. In both cases, more than 70% of specimens were correctly classified to species and more than 80% to genus. Iterations in the larger AFORO database (including 216 families of teleosts) attained a 100% correct classification at the family level.

Vasconcelos *et al.* (2018) applied geometric morphometrics and otolith shape analysis for population identification of the blue jack mackerel (*Trachurus picturatus,* Osteichthyes, Carangidae) in waters off Madeira, Peniche (mainland Portugal), and the Canary Islands. Multivariate analysis of variance (MANOVA) revealed no body shape differences between males and females in each area studied, and therefore the sexes were combined for the analysis. The results of the discriminant analysis showed that a low misclassification occurred among areas; 78.0% of individuals were correctly classified. MANOVA performed on the otolith normalized elliptic Fourier descriptors revealed significant areal differences, but no difference between sexes. An overall classification success of 73.3% in the canonical discriminant analysis was achieved. These results indicate the usefulness of both otolith and body shape analysis for differentiation of blue jack mackerel stocks from the northeast Atlantic and indicate the existence of at least three distinguishable populations of this species.

Villegas-Hernández *et al.* (2018) have investigated the effects of sex, age, and environment on the shape of the bastard grunt (*Pomadasys incisus*) otoliths from the north-western Mediterranean. Specimens of this species were collected from two separate sampling areas in the north-western Mediterranean with different thermal regimes. Sex, growth rates, and age of *P. incisus* were determined by using gonad histology techniques, biometric analyses, and otolith microstructure analyses, respectively. The shape was described using normalized Elliptic Fourier descriptors (EFDs), and studied by means of multivariate statistics as predictive variables with age-specific discriminant analyses. There were no consistent differences found between sexes, but otolith shapes varied significantly between environments within different age classes. Total classification success varied between 87.3% and 89.2% between environments for the different age classes and provided a phenotypic basis for *P. incisus* population separation within an environmental gradient in determining its otolith shape. In addition, significant differences were observed between sampling areas in von Bertalanffy's growth parameters, as well as in the fish length-weight (LWR) and fish length-otolith radius (TL-Ro) relationships. Data was discussed considering that the physical habitat variability could underlie a marked change in otolith shape during the animals' growth. In this matter, we discussed the relative importance of both ontogenetic and environmental conditions (such as water temperature) on otolith shape.

References

Afanasyev PK, AM Orlov & AY Rolsky. 2017. Otolith Shape Analysis as a Tool for Species Identification and Studying the Population Structure of Different Fish Species. Biology Bulletin 44: 952–959.

Avigliano E, Rolón ME, Rosso JJ, Mabragaña E, Volpedo AV. 2018. Using otolith morphometry for the identification of three sympatric and morphologically similar species of *Astyanax* from the Atlantic Rain Forest (Argentina). Environ Biol Fish 101: 1319–1328.

Banaru, D.; Morat, F.; Creteanu, M. 2017. Otolith shape analysis of three gobiid species of the Northwestern Black Sea and characterization of local populations of *Neogobius melanostomus*. CYBIUM, 41(4): 325-333.

Bardarson, H.; McAdam, B. J.; Thorsteinsson, V.; Hjorleifsson, E., Marteinsdottir, G. 2017. Otolith shape differences between ecotypes of Icelandic cod (*Gadus morhua*) with known migratory behaviour inferred from data storage tags. CANADIAN JOURNAL OF FISHERIES AND AQUATIC SCIENCES, 74(12): 2122-2130.

Callico Fortunato, R.; Gonzalez-Castro, M.; Reguera Galan, A.;García Alonso, I.; Kunert, C.; Benedito Durà, V.; Volpedo, A. 2017. Identification of potential fish stocks and lifetime movement patterns of *Mugil liza* Valenciennes 1836 in the Southwestern Atlantic Ocean. FIISHERIES RESEARCH, 193: 164-172

Christensen, H.T.; Riget, F; Backea, M.B.; Saha, A; Johansen, T; Hedeholm, R.B. 2018. Comparison of three methods for identification of redfish (*Sebastes mentella* and S. *norvegicus*) from the Greenland east coast. FISHERIES RESEARCH, 201: 11-17.

Duncan, R.; Brophy, D.; Arrizabalaga, H. 2018. Otolith shape analysis as a tool for stock separation of albacore tuna feeding in the Northeast Atlantic. FISHERIES RESEARCH, 200: 68-74.

He, T.; Cheng, J.; Qin, J.G.; Li, Y.; Gao, T.X. 2018. Comparative analysis of otolith morphology in three species of Scomber. ICHTHYOLOGICAL RESEARCH, 65(2): 192-201.

Lombarte, A.; Miletic, M.; Kovacic, M.; Otero-Ferrer, J.L.; Tuset V.M. 2018. Identifying sagittal otoliths of Mediterranean Sea gobies: variability among phylogenetic lineages. JOURNAL OF FISH BIOLOGY, 92(6): 1768-1787.

Santos, R. da S.; Costa de Azevedo, M. C.; de Albuquerque, C. Q. ; Geerson Araujo, F. 2017. Different sagitta otolith morphotypes for the whitemouth croaker *Micropogonias furnieri* in the Southwestern Atlantic coast. FISHERIES RESEARCH, 195: 222-229.

Vasconcelos, J.; Vieira, A.R.; Sequeira, V.; Gonzalez, J.A.; Kaufmann, M.; Gordo, L.S. 2018. Identifying populations of the blue jack mackerel (*Trachurus picturatus*) in the Northeast Atlantic by using geometric morphometrics and otolith shape analysis. FISHERY BULLETIN, 116(1): 81-92.

Villegas-Hernandez, H.; Lloret, J.; Munoz, M.; Poot-López G. R.; Guillén-Hernández S.; González-Salas, C. 2018. Age-specific environmental differences on the otolith shape of the bastard grunt (*Pomadasys incisus*) in the north-western Mediterranean. ENVIRONMENTAL BIOLOGY OF FISHES, 101(5): 775-789.

Otolith Chemistry (Contributors: Lisa Kerr and Zachary Whitener)

In the past year, otolith chemistry has been applied as a stock identification tool to discern stock structure of fish species around the world. Below is a summary of recent applications of otolith chemistry to fish stock identification of ICES species of interest, as well as an update on advances in the field.

Reis-Santos *et al.* (2018) used linear and nonlinear modelling to assess the importance of environmental conditions (temperature, salinity, and water chemistry) and fish size on otolith chemical composition (Li, Mg, Mn, Sr, and Ba) in European seabass *Dicentrarchus labrax* in estuaries. Ontogeny was found to be more important than the combined influence of temperature and salinity and may indicate that intrinsic factors might outweigh environmental effects on otolith chemistry and elemental incorporation.

Moreira *et al.* (2018) used elemental and isotopic signatures of 120 whole blue jack mackerel otoliths from 6 important fishery areas (including the Azores, Madeira, Canaries, and Portuguese mainland) to determine whether chemistry could provide insight into regional population structure. A combination of elemental and isotopic ratios (Sr/Ca, Ba/Ca, Li/Ca, and $d^{13}C$) gave distinct regional signatures with high reclassification rates (overall 81%) that suggest for the first time that the Azores, Madeira, the Canaries, and the Portuguese mainland should each be considered separate population units.

The lesser sandeel, *Ammodytes marinus*, is now managed as 7 stocks in the North Sea as delineated by the predictions of biophysical model of limited larval mixing. Using isotopic composition of otoliths, Wright *et al.* (2018a) determined significant geographic differences in near-core chemistry suggested 4 natal sources. Consistency in early life mixing predicted by biophysical models and chemistry support the present stock units used in assessments.

Wright *et al.* (2018b) use a two-stage otolith chemistry approach to study a year-class of North Sea cod from juvenile to adult stage and consider how these mechanisms can be used to study population structure. Their results indicated natal homing and suggested philopatry.

McMillan *et al.* (2017) use LA-ICPMS to assay concentrations of 12 isotopes found in *Etmopterus spinax* vertebrae from French and Norwegian waters to study stock structure in the first application of this technique to a deep-sea shark. Three stocks were identified, with strong population mixing at finer scales, and the authors believe that the methodology will expedite future research in stock structure of deep-sea sharks.

Régneir *et al.* (2017) analysed the chemical signature of otoliths from roundnose grenadier (*Coryphaenoides rupestris*) to test the connectivity of populations on a seamount and adjacent areas off the west coast of Scotland. Using flow-injection ICPMS, trace element concentrations were measured from micromilled otolith portions corresponding to juvenile and adult life stages, with seamount fish being distinguishable at both life stages. This suggests that juveniles that settle on the seamount remain there for the rest of their lives and the authors call for this population structuring to be considered in future management.

Fornato *et al.* (2017) used LA-ICPMS and microchemistry on flathead grey mullet otoliths to study the migratory patterns in three different Spanish wetlands and study the potential presence of multiple stocks within the region. The study revealed 4 typical behaviour strategies and 2 potential stocks. A mesoscale current associated with the Balearic front were posited as influencing the separation of these two stocks.

Darnaude and Hunter (2018) explored use of otolith δ*18*O for geolocation of North Sea plaice. They compared intra-annual otolith $\delta^{18}O$ measurements from individuals of 3 distinct sub-stocks of North Sea plaice with different spawning locations to predicted sub-stock specific temperatures and salinities. Measured otolith $\delta^{18}O$ values largely mirrored seasonally predicted values, but occasionally fell outside expected $\delta^{18}O$ ranges..

References

Darnaude, A. M., Hunter, E. 2018. Validation of otolith $\delta^{18}O$ values as effective natural tags for shelf-scale geolocation of migrating fish. MEPS 598: 167-185.

Forunato, R. C., A. R. Galán, I. G. Alonso, A. Volpedo, and V. B. Durà. 2017. Environmental migratory patterns and stock identification of *Mugil cephalus* in the Spanish Mediterranean Sea, by means of otolith microchemistry. Estuarine, Coastal and Shelf Science, 188: 174-180.

McMillan, M. N., C. Izzo, C. Junge, O. T. Albert, A. Jung, and B. M. Gillanders, and ed. D. Secor. 2017. Analysis of vertebral chemistry to assess stock structure in a deep-sea shark, *Etmopterus spinax*. ICES Journal of Marine Science, 74(3): 793-803. https://doi.org/10.1093/icesjms/fsw176.

Moreira, C., E. Froufe, A. N. Sial, A. Caeiro, P. Vaz-Pires, and A. T. Correia. 2018. Population structure of blue jack mackerel (*Trachurus picturatus*) in the NE Atlantic inferred from otolith microchemistry. Fisheries Research, 197:113-122.

Reis-Santos, P., R. P. Vaconcelos, S. E. Tanner, V. F. Fonseca, H. N. Cabral, and B. M. Gillanders. 2018. Extrinsic and intrinsic factors shape the ability of using otolith chemistry to characterize estuarine environmental histories. Marine Environmental Research, *in press*. DOI: https://doi.org/10.1016/j.marenvres.2018.06.002.

Régnier, T., J. Augley, S. Devalla, C. D. Robinson, P. J. Wright, and F. C. Nest. 2017. Otolith chemistry reveals seamount fidelity in a deepwater fish. Deep sea Research Part I: Oceanographic Research Papers, 121: 183-189.

Wright, P. J., T. Régnier, F. M. Gibb, J. Augley, and S. Devalla. 2018a. Identifying stock structure in the sandeel, A*mmodytes marinus*, from otolith microchemistry. Fisheries Research, 199:19-25.

Wright, P. J., T. Régnier, F. M. Gibb, J. Aigley, and S. Devalla. 2018b. Assessing the role of ontogenetic movement in maintaining population structure in fish using otolith microchemistry. Ecology and Evolution, 1-14. DOI: 10.1002/ece3.4186.

Parasites (Contributor: Ken Mackenzie)

Nine papers involving the use of parasites as tags in stock identification of marine fish were published in the past year – the same number as in the previous year. Four of the target host species were pelagic, three were benthopelagic and two demersal. The study areas were three for the eastern Atlantic and two each for Australasia, the southwestern Atlantic and the Mediterranean. Seven of these studies used only parasites tags for stock identification, with the remaining two using parasites in combination with other methods.

In the eastern Atlantic, Vasconcelos *et al.* (2017) assessed the use of parasites as tags for stock identification of blue jack mackerel *Trachurus picturatus* by examining samples of fish caught off mainland Portugal and off the Madeira and Canary Islands archipelagos. Four parasite taxa were selected as possible biological tags: *Anisakis* sp. larvae (Nematoda), *Rhadinorhynchus* sp. and *Bolbosoma* sp. (Acanthocephala), and *Nybelinia* sp. (Cestoda). Analyses of the infection data suggested the existence of three stocks of blue horse mackerel in the Northeast Atlantic, thereby supporting the current management strategy. Also in this region, Hermida *et al.* (2018) carried out a parasitological survey of 30 skipjack tuna, *Katsuwonus pelamis* from around Madeira with the aim of identifying parasites that might be useful as tags in stock identification by comparing their results with those of studies in other parts of the Atlantic and Mediterranean. Long-lived parasites such as anisakid nematode larvae and the plerocercoids of the trypanorhych cestode *Tentacularia coryphaenae* were selected as potentially useful tags, in combination with some temporary or semi-permanent parasites. A study by Mattiucci *et al.* (2018) focused on *Anisakis simplex* (s.s.) larvae, which they collected from herring *Clupea harengus* caught at fishing grounds in the Norwegian Sea, Baltic Sea, North Sea and the English Channel. The nematodes were identified to species level using diagnostic allozymes and sequence analysis of DNA genes. The results showed the population genetic structure of *A. simplex* (s.s.) to be in accordance with that of herring throughout its range in the Northeast Atlantic.

In the southwestern Atlantic, Soares *et al.* (2018) analysed and compared the metazoan parasite assemblages of the benthopelagic fish *Pagrus pagrus* in samples taken from two regions in southern Brazil and one off northern Argentina. Three guilds of parasites were recognized: ectoparasites, long-lived larval endoparasites and short-lived gastrointestinal parasites. Assemblages of long-lived parasites were considered to be the best indicators for purposes of stock identification; the results of analyses of data on this guild of parasites indicated the existence of three stocks of *P. pagrus* within the study area. One of the few papers published to date on the use of parasites as tags for elasmobranch hosts also came from the southwestern Atlantic. In this study, Irigoitia *et al.* (2018) attempted to evaluate the potential of parasites as tags for stock identification of the smallnose fanskate *Sympterigia bonapartii* from samples taken in different years and seasons from most of its distributional range off the coasts of Uruguay and Argentina. Of the 19 parasite taxa recorded, only three were considered to be long-lived and were thus recommended for use as tags: larvae of the two anisakid nematodes *Anisakis* sp. and *Pseudoterranova* sp. and the adult digenean *Otodistomum pristipophori*, which is found in the coelomic cavity. Analyses of the infection data on these parasites suggested the existence of three stocks of skate in the study area. The authors suggest that with careful selection, long-lived parasites can be as useful as tags for stock identification of elasmobranchs as for teleost fish.

In the Mediterranean, Feki *et al.* (2018) used 9 species of ecto- and endo-parasitic helminth parasites, both larval and adult, as tags for stock identification of chub mackerel *Scomber colias* off the coast of Tunisia. Discriminant analyses were used to investigate differences between sampling zones and on this basis the authors were able to identify three potentially different stocks of mackerel in Tunisian waters. The study of Marengo *et al.* (2017) had as its aim the identification of the stock structure of the benthopelagic fish *Dentex dentex* at the relatively fine spatial scale of four zones around the Mediterranean island of Corsica. A combination of three markers was used: microsatellite DNA, otolith shape analysis and parasite communities. Only parasites of the alimentary tract were used and multivariate analyses of their abundance data highlighted two sites with some connectivity between adjacent zones. The three markers in combination revealed a complex population structure around Corsica which served to provide a new perspective on dentex stock conservation and management strategies.

In a multidisciplinary study of the stock structure of the reef-associated fish *Lethrinus laticaudatis* across northern Australia, Barton *et al.* (2018) used a combination of host genetics, otolith microchemistry and parasite assemblage composition. Samples of fish were caught at 13 locations across a long coastal area extending from the northern part of Western Australia to southeast Queensland. Twenty-four parasite taxa were used in the analyses. The results from the combined methods showed restricted connectivity at small spatial scales, indicating that *L. laticaudis* is vulnerable to localised depletion in those areas where fishing effort is concentrated. The purpose of another study from the Australasian region carried out by Lestari *et al.* (2017) was to determine which parasites were potential stock markers for bigeye tuna, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares*, in Indonesian waters. Fish were collected from 9 sites across Indonesia and from two "outlier" sites in the Maldives and Solomon Islands. Based largely on their longevity in the host, the potentially most useful tag parasites identified were 7 types of didymozoid digeneans and one juvenile acanthocephalan.

References

Barton, D.P., Taillebois, L., Taylor, J., Crook, D.A., Saunders, T., Hearnden, M., Greig, A., Welch, D.J., Newman, S.J., Travers, M.J., Saunders, R.J., Errity, C., Maher, S., Dudgeon, C. & Ovenden, J. 2018. Stock structure of *Lethrinus laticaudis* (Lethrinidae) across northern Australia determined using genetics, otolith microchemistry and parasite assemblage composition. *Marine and Freshwater Research* 69, 487-501.

Feki, M., Châari, M., Neifar, L. & Boudaya, L. 2018. Helminth parasites of the chub mackerel *Scomber colias* off the Tunisian coasts and their use in stock discrimination. *Journal of Helminthology* 92, 90-99.

Hermida, M., Cavaleiro, B., Gouvea, L. & Saraiva, A. 2018. Parasites of skipjack, *Katsuwonus pelamis*, from Madeira, Eastern Atlantic. *Parasitology Research* 117, 1025-1033.

Irigoitia, M.M., Incorvaia, I.S & Timi, J.T. 2017. Evaluating the usefulness of natural tags for host population structure in chondrichthyans: Parasite assemblages of *Sympterygia bonapartii* (Rajiformes: Arhynchobatidae) in the Southwestern Atlantic. *Fisheries Research* 195,80-90.

Lestari, P., Lester, R.J.G. & Proctor, C. 2017. Parasites as potential stock markers for tuna in Indonesian waters. *Indonesian Fisheries Research Journal* 23, 23-28.

Marengo, M., Baudouin, M., Viret, A., Laporte, M., Berrebi, P., Vignon, M., Marchand, B. & Durieux, E.D.H. 2017. Combining microsatellite, otolith shape and parasites community analyses as a holistic approach to assess population structure of *Dentex dentex. Journal of Sea Research* 128, 1-14.

Mattiucci, S., Giullietti, L., Paoletti, M., Cipriani, P., Gay, M., Levsen, A., Klapper, R., Karl, H., Bao, M., Pierce, G.J. & Nascetti, G. 2018. Population genetic structure of the parasite *Anisakis simplex* s.s. collected in *Clupea harengus* L. from North east Atlantic fishing grounds. *Fisheries Research* 202, S1, 122-133.

Soares, I.A., Lanfranchi, A.L., Luque, J.L., Haimovici, M. & Timi, J.T. 2018. Are different parasite guilds of *Pagrus pagrus* equally suitable sources of information on host zoogeography? *Parasitology Research* 117, 1865-1875.

Vasconcelos, J., Hermida, Saraiva, A., González, J.A. & Gordo, L.S. 2017. The use of parasites as biological tags for stock identification of blue jack mackerel, *Trachurus picturatus,* in the North-eastern Atlantic. *Fisheries Research* 193, 1-6.

Interdisciplinary approaches (Contributors: Stefano Mariani, Lisa Kerr, Steve Cadrin, Christoph Stransky, David Secor)

Using interdisciplinary methods to investigate stock identity is a continuing trend in the field. Below we have summarized applications which involved multiple techniques applied to address questions of stock identity.

Reis-Santos *et al.* (2018) developed an integrated assessment of demographic and genetic connectivity of European flounder *Platichthys flesus* in the northeast Atlantic. They used otolith chemistry to characterize natal origin and microsatellite DNA markers to characterise genetic connectivity and they evaluated how the combined use of natural tags informed individual movement and long-term population exchange rates. The authors found that individual markers provided different insights on movement and the integrated use of natural tags resulted in outcomes that were not readily anticipated by individual movement or gene flow markers alone.

Arrizabalaga *et al.* (2018) reviewed the subpopulation structure of Atlantic bluefin tuna of Mediterranean origin based on electronic tagging and genetic studies to revise some life history and movement paradigms. Although is somewhat equivocal to test several hypotheses, they conclude that it seems more likely that bluefin tuna spawned in the western Mediterranean use the Atlantic more intensively than those spawned in the eastern Mediterranean.

Perez-Quinonez *et al.* (2017) discriminated three species of thread herrings in the Gulf of California using meristic, morphometric and mtDNA characters.

Canty *et al.* (2018) evaluated geographic variation of yellowtail snapper from three locations off Honduras in an attempt to enforce area-based management. Their analysis included genotyping, otolith microchemistry and morphometrics to identify geographic origin and found that morphometric analysis supported 80% classification accuracy, otolith microchemistry supported 54% accuracy and genetic analyses supported 52% accuracy. Although the authors make conclusions about the most appropriate approach to discriminating capture location, better understanding of stock identity (e.g., distribution patterns, connectivity, reproductive isolation, environmental patterns) would provide better guidance on the most appropriate scale of spatial management and approach for stock discrimination.

Bardarson *et al.* (2017) used otolith shape to identify ecotypes of the Icelandic cod (*Gadus morhua*) stock. The use of data storage tags has increased our knowledge of the stock structure of Icelandic cod. The profiles of tagged cod reveal different migratory strategies. This has led to the definition of two ecotypes within the cod stock. Frontal ecotypes reside in deep waters during feeding season and express a highly variable temperature profile associated with thermal fronts, while coastal ecotypes stay in shallow waters all year round. In this study, the data storage tag profiles were analysed with cluster analysis, which revealed the existence of an intermediate behaviour that expresses a variable depth profile and feeding migration that is both shorter in time and not as deep. The main objective was to develop a morphological key based on otoliths to distinguish the ecotypes. The shape of the otoliths was extracted with shape measurements and fast Fourier transforms. A discriminant function analysis indicated a difference in morphology between the ecotypes, resulting in successful classification.

Callico Fortunato *et al.* (2017) studied movement patterns of the mullet *Mugil liza* and to identify the presence of different fish stocks in the southwestern region of the Atlantic Ocean, using cumulative otolith shape morphometric and microchemical analyses of sagittae otoliths. Specimens (n = 99) were obtained in four coastal areas: Paranaguá Bay in Brazil, Samborombón Bay, Mar Chiquita Coastal Lagoon, and San Blas Bay in Argentina. Otolith shape indices (circularity, rectangularity, aspect ratio, percentage occupied by sulcus, ellipticity and form factor) were used for stock identification analysis; and otolith microchemistry using LA-ICP-MS (Sr/Ca and Ba/Ca ratios chronological variation) was used for both the analysis of movement behaviours and the identification of fish stocks (otolith edge ratios). Morphometrical indices did not reveal a clear separation among areas. San Blas bay individuals presented otoliths tending to be longer than wider, with a more elliptic shape than the otoliths from other studied areas; also, this area did not share individuals with the most northern one, Paranaguá Bay in Brazil. The analysis of microchemical lifetime profiles revealed three types of behaviour pattern: Type I: most frequent use of estuarine environments; Type II: a fluctuating behaviour between estuarine and sea/high salinity waters; Type III: most frequent use of sea/high salinity habitats. Otolith edge analysis did not reveal differences among Sr/Ca and Ba/Ca ratios for the different areas. Thus, it cannot be assured that there is more than one stock in the studied region. *Mugil liza* revealed different environmental migratory behaviours in the Southwestern Atlantic Ocean showing a facultative use of estuarine waters; hence, the species appears to be mostly coastal with the use of low estuaries, as seen also by the Sr/Ca otolith cores ratios; differing from the general mugilid behaviour previoulsy described.

Gwilliam *et al.* (2018) report the first integrated genetic [mitochondrial (mt)DNA and nuclear microsatellite] and morphological (morphometric, meristic and colouration) study to assess patterns of divergence between populations of *Diplodus* species in the Benguela Current system. High levels of cytonuclear divergence between the populations support a prolonged period of genetic isolation, with the sharing of only one mtDNA haplotype (12 haplotypes were fully sorted between regions) attributed to retention of ancestral polymorphism. Fish from Angolan and South African regions were significantly differentiated at a number of morphometric (69.5%) and meristic (46%) characters. In addition, fish from the two regions exhibited reciprocally diagnostic colouration patterns that were more similar to Mediterranean and Indian Ocean congeners, respectively. Based on the congruent genetic and phenotypic diversity, the authors suggest that the use of *Diplodus hottentotus*, whether for full species or subspecies status, should be restricted to South African *D. cervinus* to reflect their status as a distinct species-like unit, while the relationship between Angolan and Atlantic–Mediterranean *D. cervinus* will require further demo-genetic analysis. This study highlights the utility of integrated genetic and morphological approaches to assess taxonomic diversity within the biogeographically dynamic Benguela Current region.

The study of Marengo *et al.* (2017) had as its aim the identification of the stock structure of the benthopelagic fish *Dentex dentex* at the relatively fine spatial scale of four zones around the Mediterranean island of Corsica. A combination of three markers was used: microsatellite DNA, otolith shape analysis and parasite communities. Only parasites of the alimentary tract were used and multivariate analyses of their abundance data highlighted two sites with some connectivity between adjacent zones. The three markers in combination revealed a complex population structure around Corsica which served to provide a new perspective on dentex stock conservation and management strategies.

Sabatini *et al.* (2018) investigated sole collected during fishery-independent and fishery-dependent activities in the Adriatic by morphological and genetic approaches. A comparison of these two methods for the sole species identification was carried out to assess the most effective, accurate and practical diagnostic morphological key-character(s). Results showed that external characters, in particular features of the posterior dorsal and anal fins, are valid and accurate morphological markers. Based on these traits, a practical identification key of the two sibling species was proposed. Moreover, it was possible to estimate the extent of the error due to species misidentification introduced in the common sole stock assessment carried out in the Northerncentral Adriatic Sea (GSA17). A 5% bias in the correct identification of common sole specimens was detected. However, this bias was shown not to affect the common sole stock assessment. Moreover, the genetic profiling of the Adriatic common sole allowed estimating genetic diversity and assessing population structure. Significant divergence between common soles inhabiting the eastern part of the Southern Adriatic Sea and those collected from the other areas of the basin was confirmed. Therefore, the occurrence of genetically differentiated subpopulations supports the need to implement independent stock assessments and management measures.

Taillebois *et al.* (2017) examined the population structure of the black-spotted croaker (*Protonibea diacanthus*) across north-western Australia using three complementary methods: genetic variation in microsatellite markers, otolith elemental composition and parasite assemblage composition. The genetic analyses demonstrated that there were at least five genetically distinct populations across the study region, with gene flow most likely restricted by inshore biogeographic barriers such as the Dampier Peninsula. The otolith chemistry and parasite analyses also revealed strong spatial variation among locations within broad-scale regions, suggesting fine-scale location fidelity within the lifetimes of individual fish. The complementarity of the three techniques elucidated patterns of connectivity over a range of spatial and temporal scales. The authors conclude that fisheries stock assessments and management are required at fine scales (100 s of km) to account for the restricted exchange among populations (stocks) and to prevent localized extirpations of this species. Realistic management arrangements may involve the successive closure and opening of fishing areas to reduce fishing pressure.

For the first time, a US Fisheries Management Council developed a separate assessment and review activity solely focused on defining stock structure of an important coastal species. Atlantic cobia *Rachycentron canadum* is a large predominately recreational species that traverses several US Council regions: the Gulf of Mexico, and the US South and Mid-Atlantic. Recent surges in landings at the northern extent of the species range (Virginia) prompted the South Atlantic Fisheries Management Council to initiate a formal assessment review (Southeast Data, Assessment, and Review: SEDAR 58), which involved a data workshop, assessment document addressing ToRs related to recommendations on stock structure and stock unit boundaries. The review involved national and international experts, including those contracted through the Center for Independent Experts (http://sedarweb.org/docs/page/S58_CobiaStockIDReportCompilation_FINAL_8.17.2018.pdf.) Considerable information was assembled from life history data, conventional and electronic tagging and genetic data to support a division between the Gulf of Mexico and Atlantic, yet a proposed unit stock boundary near the Florida-Georgia state line was less well supported. In the NW Atlantic, many stocks have dynamic stock boundaries are overlap council regions. The SEDAR on cobia stock structure is an important precedence within the Council process and also a novel model for the SIMWG to consider further.

References

Arrizabalaga H, I Arregui, A Medina, N Rodríguez-Ezpeleta, JM Fromentin & I. Fraile. 2018. Life history and migrations of Mediterranean bluefin populations. In Bluefin Futures (in Press).

Bardarson, H.; McAdam, B. J.; Thorsteinsson, V.; Hjorleifsson, E., Marteinsdottir, G. 2017. Otolith shape differences between ecotypes of Icelandic cod (*Gadus morhua*) with known migratory behaviour inferred from data storage tags. CANADIAN JOURNAL OF FISHERIES AND AQUATIC SCIENCES, 74(12): 2122-2130.

Callico Fortunato, R.; Gonzalez-Castro, M.; Reguera Galan, A.;García Alonso, I.; Kunert, C.; Benedito Durà, V.; Volpedo, A. 2017. Identification of potential fish stocks and lifetime movement patterns of *Mugil liza* Valenciennes 1836 in the Southwestern Atlantic Ocean. FIISHERIES RESEARCH, 193: 164-172

Canty SWJ, NK Truelove, RF Preziosi, S Chenery, MAS Horstwood & SJ Box. 2018. Evaluating tools for the spatial management of fisheries. J. Applied Ecology 2018: 1-8 DOI: 10.1111/1365-2664.13230

Gwilliam MP, Winkler AC, Potts WM, Santos CV, Sauer WHH, Shaw PW, McKeown NJ. 2018. Integrated genetic and morphological data support eco-evolutionary divergence of Angolan and South African populations of *Diplodus hottentotus*. Journal of Fish Biology 92: 1163–1176. doi:10.1111/jfb.13582

Marengo, M., Baudouin, M., Viret, A., Laporte, M., Berrebi, P., Vignon, M., Marchand, B. & Durieux, E.D.H. 2017. Combining microsatellite, otolith shape and parasites community analyses as a holistic approach to assess population structure of *Dentex dentex*. Journal of Sea Research 128, 1-14.

Reis-Santos, P., Tanner, S. E., Aboim, M. A., Vasconcelos, R. P., Laroche, J., Charrier, G. Pérez, M., Presa, P., Gillanders, B. M., Cabral, H. N. 2018. Reconciling differences in natural tags to infer demographic and genetic connectivity in marine fish populations. Scientific Reports: 8, 10343.

Perez-Quinonez CI, C Quinonez-Velazquez, JS Ramırez-Perez, FJ Vergara-Solana & FJ Garcıa-Rodrıguez. 2017. Combining geometric morphometrics and genetic analysis to identify species of *Opisthonema* Gill, 1861 in the eastern Mexican Pacific. J. Appl. Ichthyol. 33: 84–92.

Sabatini L, Bullo M, Cariani A, Celić I, Ferrari A, Guarniero I, Leoni S, Marčeta B, Marcone A, Polidori P, Raicevich S, Tinti F, Vrgoč N, Scarcella G. 2018. Good practices for common sole assessment in the

Adriatic Sea: Genetic and morphological differentiation of *Solea solea* (Linnaeus, 1758) from *S. aegyptiaca* (Chabanaud, 1927) and stock identification. Journal of Sea Research 137: 57–64.

Taillebois L, Barton DP, Crook DA, Saunders T, Taylor J, Hearnden M, Saunders RJ, Newman SJ, Travers MJ, Welch DJ, Greig A, Dudgeon C, Maher S, Ovenden JR 2017. Strong population structure deduced from genetics, otolith chemistry and parasite abundances explains vulnerability to localized fishery collapse in a large Sciaenid fish, *Protonibea diacanthus*. Evolutionary Applications 10: 978–993.

Simulation approaches (Contributor: Lisa Kerr)

Whitlock *et al.* (2017) presented a hierarchical Bayesian model that utilized knowledge about migration timing, speed and direction from tagging studies and information about pre-migration stock abundances from ICES assessments to provide a prior for the expected stock composition of Baltic salmon in space and time.

References

Whitlock, R., Mäntyniemi S., Palm, S. Koljonen M., Dannewitz, J. Östergren, J. 2018. Integrating genetic analysis of mixed populations with a spatially explicit population dynamics model. Methods Ecol Evol.9: 1017–1035.

Book Review of Pitmann *et al.*'s Seascape Ecology: Dave Secor

Seascape Ecology. 2018. Simon J. Pittman (ed.). Wiley Blackwell. 501 p.

Intent, motivation and audience

This is a state of the science literature review of landscape ecology concepts applied to marine ecosystems. The book follows a theme session developed by Editor SJ Pitman and others published 2011 in Marine Ecology Progress Series, entitled *Seascape ecology: application of landscape ecology to the marine environment*. The book's focus is on concepts and tools drawn from landscape ecology, rather than a treatment of seascape ecology as a unique sub-discipline in its own right (see Hidalgo *et al.* 2017; Manderson *et al.* 2017). The prose and content requires background knowledge making this text more suitable for peer scientists and advanced graduate students, rather than as an undergraduate text or a book accessible to the interested layperson. Although there are well-articulated themes in the book related to landscape ecology concepts, this book primarily serves as a reference volume rather than as an integrated thesis.

Readers will be rewarded by clear prose, thorough scholarship, and careful and consistent organization throughout the book. Most chapters contain a strong statement of intent in the introduction, sub-sections that are well organized and consistent in their weighting, adequate exposition in case studies, and very strong scholarship in reviewing literature, which for the most part emanates only from the past decade for this young sub-discipline. Authors represent diverse disciplines, although most (87%) are from US or Australian institutions. Flow between chapters is likely aided by Editor SJ Pittman involvement in their construction: he authored or co-authored 9 of the book's 16 chapters.

Coverage

In four broad sections the 500-page book covers spatial patterning, habitat models and movement ecology, connectivity, and human dimensions. A final epilogue is a series of forecasts by eminent landscape ecologists. The book is replete with conceptual figures (many thankfully in color), tables and generous literature cited sections.

In the first Section, *Spatial Patterning in the Sea*, SJ Pittman first provides a comprehensive review of the origins of seascape ecology in biogeography theory and landscape ecology's focus on pattern and scale (i.e., patch-matrix and patch-mosaic concepts). A view is proffered that careful consideration of scaling can allow landscape ecology to be applied in marine environments despite Issues unique to seascape ecology, such as water column and temporal dynamics and pervasiveness of gradient-driven processes in seascapes (e.g., flow, biogeochemistry, sound). Thus seascape ecology is derived landscape ecology. The introduction telegraphs a common thread throughout the book that seascape ecology has strong application to spatial planning and management. Costa *et al.* in Chapter 2 move on to approaches to map and quantify biogeographic patterns in seascapes. They draw directly on patch metrics and considerations of scale, gradients, and ocean observation data, mostly through literature review and applications of pattern analysis to 2D seascapes. Greater exposition of seascape case studies in this early chapter would have helped readers wade into the topics of scale, observation and representing gradients. In Chapter 3, Scales *et al.* distinguishes "Pelagic Seascape Ecology" as 3D seascape ecology with an emphasis on oceanography and the movement ecology of pelagic organisms. The authors struggle a bit with applying the patch mosaic concept concluding that although observing data can support analysis of continuously varying patterns, concepts derived from landscape ecology cannot yet represent the "inherent dynamicism of pelagic systems." Schneider (Ch. 4) provides a very strong coda to the section's emphasis on scale in Chapter 4, beginning with a colorful Lilliputian allegory and moving onto a broad and eloquent review of concepts of scale, dimensional analysis, sampling error, and spatiotemporal analysis of rate processes. There is a lot for students and colleagues to sink their teeth into in this wide ranging review.

Section 2 brings ecological processes into seascape patterns, focusing initially on seagrass and saltmarsh habitat case studies. Broström *et al.* (Ch. 5) provide a comprehensive literature review on the function and application of landscape approaches to describe these biogenic habitats, thereby giving ample evidence that the patch mosaic construct is feasible and impactful in relating ecological pattern to function. Owing to its focus on exposition, this will be a more accessible chapter to students. A fairly long literature review follows on patch dynamics by Jackson *et al.* (Ch. 6) with treatments on scale of habitat structures (focus on 2D seascapes), types of patch dynamics, and methods to measure and analyze patch dynamics. The review on statistical and predictive modelling approaches to evaluate seascape dynamics at the end of the chapter is state of the science. Movement ecology within seascapes is tackled next by Pitman *et al.*'s Chapter 7 and is centered on Nathan *et al.*'s mechanistic model of movement ecology, which facilitates consideration of movements associated with habitat selection by individuals. The rich literature review of movement ecology is regrettably weighed down by a cumbersome effort to relate movements to habitat patches. The complex and highly articulated analyses proposed (see Figures 7.3 and 7.9) seem infeasible, particularly when considering that the overall goal is somewhat limited: that of relating a single species to seascape patch features. Hovel and Regan (Ch. 8) provides a well-structured overview and case studies showing the utility of individual based models to simulate (1) dispersal of organisms across 2D landscapes, and (2) response of organisms to seascape dynamics. A strong argument is made that such modelling provides key and relevant insights because empirical studies cannot evaluate the full range of feasible ecosystem states.

The section *Seascape Connectivity* includes an overview on connectivity constructs in marine ecosystems, network analysis of connectivity, and a treatment of connectivity between terrestrial and coastal ecosystems. Engaging the multifaceted topic of connectivity, Olds *et al.* (Ch 9) conduct a structured literature review, which includes a very useful glossary of types, scales, and measures of connectivity. Case studies are used effectively to demonstrate the importance of connectivity in community and life cycle function and marine spatial planning. Network analysis as a means for analyzing connectivity is presented in Chapter 10 by Treml and Kool. The chapter serially builds layers of concepts and approaches with helpful lists of network analysis terms and software packages. It ends with a case study on coral population connectivity in Hawaiian Islands, but regrettably the case study comes too late and is insufficient in demonstrating the range of approaches and concepts previously introduced. The chapter would have benefitted with more figure and case studies interspersed early coverage, including one on telemetry network analysis, which is a very exciting development in seascape ecology. Oleson *et al.* include several detailed case study examples in their treatment of land-sea connectivity (Ch 11). The role of landscape ecology approaches as decision support tools is well exemplified by several case studies on watershed run-off – coral reef inundation.

Section *People and Seascapes* starts with Pittman *et al.*'s (Ch 12) review of ecosystem management and how landscape ecology approaches bear on holistic management. This was a fairly generic review of very well-trodden material on ecosystem-based management (i.e., literature reviewed were for the most part reviews themselves or prospectus pieces), with little concrete on demonstrating how seascape ecology operationally can improve conservation and stewardship aims. An introduction to how governments are implementing ecosystem and spatial management systems would have been welcome here. Human use and economic trade-off analysis within seascapes is presented in a well-crafted chapter, *Human Ecology at Sea*, (Ch 13) by Saul and Pittman. This was welcome review for those of us initiated in emerging capabilities of vessel monitoring, participatory mapping, and social sensing. The review of the first author's dissertation work on discrete choice models of fishing behaviour were refreshing and illustrative that such human dimensions are underappreciated in current fishery stock assessments and regulations. Young *et al.* (Ch 14) conducted the second structured literature review of the book with extensive lists of landscape metrics applied to marine ecosystems and their use to evaluate the effectiveness of protected areas. It is noteworthy that all identified literature pertained to 2D seascapes. The bulk of the chapter is an interesting exercise to evaluate how landscape metrics derived from bathymetry metrics alone address a common set of MPA goals in California's central coastal Pacific Ocean. Similar to Ch 13, Ch 15 will be edifying to the marine ecologist with Barbier's treatment on seascape economics. Here connectivity itself is erected as an economic benefit through considerations of land-sea interfaces. A focused study on the trade-off in mangrove forest conservation (storm and flood protection) v. conversion to shrimp farms (commerce) is presented. This is not a conserve or convert answer, but a gradient of trade-offs depending on distance from the seaward edge of the mangrove stand.

In the final section, Editor SJ Pittman has invited pioneering landscape ecologists to comment on the state of seascape ecology. The essays by JA Wiens and J Wu are outstanding and readers may wish to first turn to these before wading deeper into the book. They both identify the current tension within seascape ecology between (1) the view promoted by the book that seascape ecology is derived landscape ecology; or (2) the view that the fluid dynamics of marine ecosystems require fundamentally different concepts and approaches.

Connections to the work of ICES and the SIMWG

Seascape Ecology contains limited application to fisheries ecology and fisheries spatial management. The focus of the volume is on habitat associations and protected areas that can be evaluated through landscape approaches. For marine fishes and invertebrates - those exhibiting complex life cycles, dynamic ranges, and fluctuating abundances - the more static concepts and analyses based on patch and connectivity metrics will be limited.

Although the reviewer is biased, greater relevancy to the work of SIMWG comes through concepts developed in a session co-sponsored by SIMWG at the Berlin ASC, which subsequently resulted in the 2016 ICES JMS volume, *Frontiers in Seascape Ecology*, and included 10 research articles. Hidalgo *et al.* (2016) in their prospectus set out an operational definition for seascape ecology that represented seascape ecology as aspirational rather than settled (i.e., derived landscape ecology):

Seascape ecology finds its roots in the concepts and analytical methods developed in landscape ecology for terrestrial ecosystems (Wedding et al., 2011). Such a framework readily applies to coastal benthic environments, studies of which have long focused on habitat heterogeneity, patchiness, edge effects, and corridors. From this perspective, seascapes are merely "flooded landscapes" (e.g. seagrass beds, intertidal zones, reefs) with stationary and fixed patch structure and topographies (Pittman et al., 2011). However, pelagic seascapes are fluid in nature; they are nonstationary with high diffusivity, advection, and turbulence (Manderson, 2016). Further, most benthic marine ecosystems may also reflect transience in their physical states that does not allow explicit characterization of spatial features that structure marine populations and communities. Physical variables within seascapes also show a broader range of scale-dependence in their actions than do terrestrial landscapes, requiring data to be collected and integrated across multiple scales (Kavanaugh et al., 2016; Manderson, 2016; Scales et al., 2016a). Therefore, techniques and metrics needed to characterize the pelagic seascape are far more challenging owing to the high frequency and spatial extent over which they must be observed (e.g. Bertrand et al., 2014; Alvarez-Berastegui et al., 2014; Scales et al., 2016a). (Hildago *et al*. 2016).

Such work is now ongoing in ICES, with examples of bringing oceanographic variables and analysis of shifting range dynamics into stock assessments and simulation models relevant to improved fisheries management.

References

Alvarez-Berastegui, D., Ciannelli, L., Aparicio-Gonzalez, A., Reglero, P., Hidalgo, M., Lo´ pez-Jurado, J. L., Tintore´, J., *et al.* 2014. Spatial scale, means and gradients of hydrographic variables define pelagic seascapes of bluefin and bullet tuna spawning distribution. PLoS ONE, 9: e109338.

Bertrand, A., Grados, D., Colas, F., Bertrand, S., Capet, X., Chaigneau, A., Vargas, G., *et al.* 2014. Broad impacts of fine-scale dynamics on seascape structure from zooplankton to seabirds. Nature Communications, 15: 5239.

Hidalgo, M., D.H. Secor, and H.I. Browman. 2016. Observing and managing seascapes: linking synoptic oceanography, ecological processes, and geospatial modelling. ICES Journal of Marine Science 73:1825-1830.

Kavanaugh, M. T., Oliver, M. J., Chavez, F. P., Letelier, R. M., Muller-Karger, F. E., and Doney, S. C. 2016. Seascapes as a new vernacular for ocean monitoring, management and conservation. ICES Journal of Marine Science, 73:1839-1850.

Manderson, J. 2016. An essay exploring differences between seascapes and landscapes using Berhard Riemann's rules for analysis. ICES Journal of Marine Science, 73:1831-1838.

Pittman, S. J., Kneib, R. T., and Simenstad, C. A. 2011. Practicing coastal seascape ecology. Marine Ecology Progress Series, 427:87–190.

Scales, K. L., Hazen, E. L., Jacox, M. J., Edwards, C. A., Boustany, A. M., Oliver, M. J., and Bograd, S. J. 2016a. Scales of inference: on the sensitivity of habitat models for wide ranging marine predators to the resolution of environmental data. Ecography, doi: 10.1111/ecog.02272.

Wedding, L. M., Lepczyk, C. A., Pittman, S. J., Friedlander, A. M., and Jorgensen, S. 2011. Quantifying seascape structure: extending terrestrial spatial pattern metrics to the marine realm. Marine Ecology Progress Series, 427: 219–232.

Advances in Stock Identification Methods in 2019

Genetics (Contributor: Rita Castilho and Stefano Mariani)

Our annual monitoring of the patterns of usage of molecular markers in fisheries stock identification identified an increase in studies using microsatellites in 2018 compared to 2017. The proportional change between microsatellites and SNP studies continues to be not significant (chi-square: 0.0, p-value: 0.98). The total number of studies published on the subject (dotted black line in Figure 1) continues to decrease. To note that the data for 2019 is not complete at this time (August 2019).

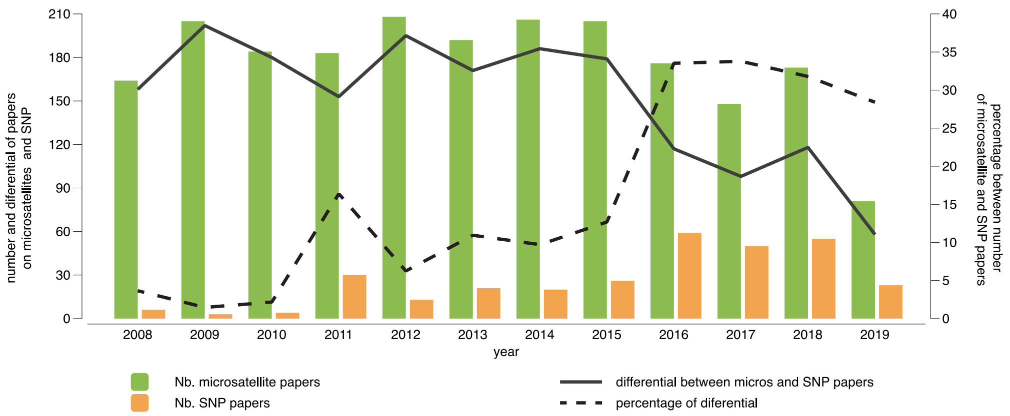


Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (blue bars) and SNPs (orange bars), as listed in the Clarivate Analytics Web-of-Science. The search criteria were: "fish* AND gene* AND (population OR stock) AND 'molecular marker*'," where 'molecular marker*' means "Microsatellite*" or "SNP*". Only papers in the following disciplinary areas were considered: 'Fisheries', 'Environmental Sciences & Ecology', 'Biodiversity Conservation', 'Marine & Freshwater Biology' and 'Oceanography'. Data for 2019 only represent papers published through to the present date (August 2019).

The field keeps on delivering studies that demonstrate the significance of genetic methodologies in determining population structure and reassessing evaluation and the management recommendations.

Therkildsen *et al.* (2019) produced evidence for a long-suspected anthropogenic effect by examining four generations of wild ancestor fish lineages of the Atlantic silverside (*Menidia menidia*). The authors conclude that there is an observable phenotypic change achieved by multiple small parallel modifications in unlinked genes associated with growth variation, and also by shifts in large blocks of linked genes, triggering substantial allele frequency changes at a few loci. The ability to expose these genomic responses allows fisheries and wildlife managers to assess human impacts on the commercially exploited species more readily.

Using a panel of 97 SNPs, Jenkins *et al.* (2018) revealed a pronounced phylogeographic break between the Atlantic and Mediterranean basins in the European lobster (*Homarus gammarus*) and a genetic cline across the northeast Atlantic area of distribution. These findings not only suggest that a single stock assessment unit for this species is not appropriate as provide the basis for a genetic tool for tracing the origin of European lobsters in the food supply chain.

Vendrami *et al.* (2019) used >82 k SNPs to refine the stock structure of the great scallop *Pecten maximus* and its sister species *P. jacobeus* along a latitudinal cline in Europe. Besides support for an Atlantic and a Norwegian group, both species found in previous studies, the authors detected a fine-scale structure (e.g., in Ireland) and identified 279 environmentally associated loci that resolved a contrasting phylogenetic pattern to neutral loci.

Svedäng *et al.* (2018) provide evidence for a putative improvement in the status of the nearly depleted stocks of Atlantic cod (*Gadus morhua*) from the Swedish Skagerrak coast.However, they could not conclusively determine whether the occurrence of eggs in that area represent a newly-established independent population or rather a physical redistribution from existing known stocks (André *et al.* 2019, Cardinale *et al.* 2019).

References

André, C., J. M. Barth, P. Jonsson, S. Jentoft, H. Knutsen, and H. Svedäng. 2019. Response to comments by Cardinale *et al.* on "Local cod (Gadus morhua) revealed by egg surveys and population genetic analysis after longstanding depletion on the Swedish Skagerrak coast" by Svedäng *et al.*(2019). ICES Journal of Marine Science, 76(4):1212-1213.

Cardinale, M., S. Mariani, and J. Hjelm. 2019. Comments on Local cod (Gadus morhua) revealed by egg surveys and population genetic analysis after longstanding depletion on the Swedish Skagerrak Coast by Svedäng *et al.* ICES Journal of Marine Science, 76(4):1209-1211.

Jenkins, T. L., C. D. Ellis, and J. R. Stevens. 2018. SNP discovery in European lobster (Homarus gammarus) using RAD sequencing. Conservation Genetics Resources, 11(3):253-257..

Svedäng, H., J. M. Barth, A. Svenson, P. Jonsson, S. Jentoft, H. Knutsen, and C. André. 2018. Local cod (Gadus morhua) revealed by egg surveys and population genetic analysis after longstanding depletion on the Swedish Skagerrak coast. ICES Journal of Marine Science, 76:418-429.

Therkildsen, N. O., A. P. Wilder, D. O. Conover, S. B. Munch, H. Baumann, and S. R. Palumbi. 2019. Contrasting genomic shifts underlie parallel phenotypic evolution in response to fishing. Science, 365:487.

Vendrami, D. L., M. De Noia, L. Telesca, W. Handal, G. Charrier, P. Boudry, L. Eberhart-Phillips, and J. I. Hoffman. 2019. RAD sequencing sheds new light on the genetic structure and local adaptation of European scallops and resolves their demographic histories. Scientific Reports, 9:7455.

Growth marks in calcified structures (Contributor: Richard McBride)

In the Gulf of Maine, Atlantic cod (Gadus morhua) spawn in overlapping inshore shelf regions in two different seasons: winter and spring; these two spawning groups are genetically distinct and they both spawn within the same management unit, confounding simple spatial management of genetic stock structure (Zemeckis *et al.*, 2014). In a recent study, Dean *et al.* (2019) developed a tool for mixed-stock analysis, using cod otolith growth marks for discriminating these two groups. The winter-spawned cod's first annulus is larger than that for spring-spawned cod. Dean *et al.* used this trait to develop a logistic regression model of first annulus diameter that had an 81% accuracy in predicting an individual to its expressed spawning period (as these fish were caught during spawning events). They also applied these data to examine relative composition of each spawning group among spawners and recruits. Spring-spawned fish, which constituted about 1/3 of the spawning biomass, were more concentrated in areas closed to fishing, and as a consequence, they were larger and older than the winter-spawned spawners because they experienced a lower cumulative mortality; however, these spring-spawned fish contributed only about 1% of the recruits in the region, which was lower than might be expected if larger, older spawners have higher reproductive potential. Presumably these sympatric spawning types are a reason for continued concentrations of cod in this region, but there is more to learn in how this diversity functions in spawner-recruit relationships, even in a relative sense among winter and spring spawners.

Across the pond, along the Norwegian Skagerrak coast, two genetically distinct Atlantic cod groups have been identified and associated with different habitats: a 'fjord' ecotype and a 'North Sea' ecotype. Knutsen *et al.* (2018) examined SNPs and sectioned otoliths from thousands of individuals collected from more than a decade at over 100 locations. Using a linear mixed effect model with otolith-derived ages to predict size, they associate larger size for the North Sea ecotype – about 80% heavier than the fjord ecotype. Both cod mix in the coastal environment but little is know about the mechanisms of reproductive isolation between the two types or whether the growth differences are genetic or environmental. Still, the strong growth differences between the two types that mix in the coastal Skagerrak, currently managed as a single unit, suggests that this should be accounted for in monitoring, assessment, and management of cod in this region.

References

Dean M, Elzey S, Hoffman W, Buchan N and Grabowski JH. Online/2019. The relative importance of sub-populations to the Gulf of Maine stock of Atlantic cod. ICES Journal of Marine Science: Journal du Conseil. https://doi.org/10.1093/icesjms/fsz083

Knutsen H, Jorde PE, Hutchings JA, Hemmer-Hansen J, Grønkjær P, Jørgensen K-EM, André C, Sodeland M, Albretsen J and Olsen EM. 2018. Stable coexistence of genetically divergent Atlantic cod ecotypes at multiple spatial scales. Evol Appl. 11: 1527-1539. https://doi.org/10.1111/eva.12640

Zemeckis DR, Martins D, Kerr LA and Cadrin SX. 2014. Stock identification of Atlantic cod (*Gadus morhua*) in US waters: an interdisciplinary approach. ICES Journal of Marine Science,: Journal du Conseil. 71: 1490-1506. https://doi.org/10.1093/icesjms/fsu032

Life history parameters (Contributor: Richard McBride)

Two related papers report fine-scale (< 10 km) differences in realized reproductive output of Atlantic cod (*Gadus morhua*) in the Skagerrak of coastal Norway. Roney *et al.* (2018, 2019/online) examined daily estimates of parentage and offspring-quality metrics for thousands of cod larvae from a free-spawning group of several dozen wild-adult Atlantic cod in the Risør fjord. They report that cod spawning in the outer fjord produced fewer egg batches over shorter periods of time than those spawning in the inner fjord. These differences occurred after accounting for the number of individuals, average body size, sex ratio, initiation of spawning period, and body condition. Although this spatial scale may be too small for monitoring or assessment of this unit stock, it points to mechanisms that may drive individual variations in reproductive success and in may aid in policy to select spawning area closures.

Although the attention to Atlantic herring (*Clupea harengus*) stock structure is a leading example among small pelagic fishes, another excellent example is that of horse mackerel (*Trachurus trachurus*), which was the focus of a multi-investigator, interdisciplinary study throughout most of its range in the eastern Atlantic Ocean and the Mediterranean Sea (Abaunza *et al.* 2008). Regardless, some areas did not receive sampling coverage, leading Ferreri *et al.* (2019) to investigate size at female reproduction for horse mackerel in two regions of the Central Mediterranean Sea. Females in the Strait of Sicily were smaller at median maturity then in the Tyrrhenian Sea. These differences may be related to environmental differences in productivity, in which case future monitoring may reveal hydrodynamic effects that enhance productivity either due to estuarine outflows, which would be more likely along the coast of the Tyrrhenian Sea where large rivers exist, or due to upwelling, which would be more likely in the Strait of Sicily in association with meandering of the Atlantic Ionian Stream (Basilone *et al.* 2013).

References

Abaunza P, Murta AG, Campbell N, and 20 others. 2008. Considerations on sampling strategies for an holistic approach to stock identification: The example of the HOMSIR project. Fish Res. 89: 104-113. https://doi.org/10.1016/j.fishres.2007.09.020

Basilone G, Bonanno A, Patti B, Mazzola S, Barra M, Cuttitta A and McBride R. 2013. Spawning site selection by European anchovy (*Engraulis encrasicolus*) in relation to oceanographic conditions in the Strait of Sicily. Fish Oceanogr. 22 309-323. http://dx.doi.org/10.1111/fog.12024

Ferreri R, McBride RS, Barra M, Gargano A, Mangano S, Pulizzi M, Aronica S, Bonanno A and Basilone G. 2019. Variation in size at maturity by horse mackerel (*Trachurus trachurus*) within the central Mediterranean Sea: Implications for investigating drivers of local productivity and applications for resource assessments. Fish Res. 211: 291-299. https://doi.org/10.1016/j.fishres.2018.11.026.

Roney NE, Oomen RA, Knutsen H, Olsen EM and Hutchings JA. 2018. Temporal variability in offspring quality and individual reproductive output in a broadcast-spawning marine fish. ICES J Mar Sci. 75: 1353-1361. https://doi.org/10.1093/icesjms/fsx232

Roney NE, Oomen RA, Knutsen H, Olsen EM and Hutchings JA. Online/2019. Fine-scale population differences in Atlantic cod reproductive success: A potential mechanism for ecological speciation in a marine fish. Ecol Evol. https://onlinelibrary.wiley.com/doi/abs/10.1002/ece3.4615

Morphometrics/meristics (Contributor: Michaël Gras)

Between 1 July 2018 and 30 June 2019, eleven scientific papers describing the use of morphometrics and meristics in order to identify stocks were published in peer reviewed journals. A summary of each paper is presented below. Five papers presented work performed using only morphometrics, one a combination of morphometrics and genetics, one a combination of morphometrics and meristics, two a combination of morphometrics and otolith shape. Finally one paper was published to describe a new software that has been developed to collect morphometric information.

Morphometrics

Farfantepenaeus brasiliensis and *Farfantepenaeus paulensis* are commercial valuable species from the Brazilian coast. Carvalho *et al.* (2019) studied how the carapace length, body length, wet weight and abdomen size to identify populations of those species. Linear regressions were used to analyse collected data. Authors found that the ratio between body length and carapace length could be primarily used to identify popultions that experienced different salinity during their life. As a conclusion, morphometrics seems to be a useful tool to identify shrimps coming from different stocks.

Nemipterus japonicus is distributed in the Indian Ocean and the western part of the Pacific Ocean. Hakim *et al.* (2019) used body morphometric measurements to identify the stock structure of *Nemipterus japonicus* in Indian waters. Authors collected 435 fish from 6 geographical locations. Fifteen landmarks were used to measure 16 linear distances. Principal Component Analysis as well as Discriminant Function Analysis were used to analyse data. That method showed the existence of two different stocks and mixing between fish of the other 4 studied areas.

Knowledge about the bluemouth (*Helicolenus dactylopterus*) population structure in the NE Atltantic and the Mediterranean Sea is currently limited. Rodriguez–Mendoza *et al.* (2019) used landmark-based geometric morphometric analysis to identify three populations in the western Mediterranean Sea (two in the Alboran basin and one in the Balearic Sea and Catalonian coast) and one in the central Mediterranean. Authors also identified at least 4 populations in the NE Atlantic and highlighted that the Strait of Gibraltar does not seem to act as a barrier as with other stocks.

Bakhshalizadeh and Bani (2018) used the morphological characteristics of the pectoral fin spine to describe the stock structure of the Persian Sturgeon (*Acipenser persicus*). The data analysis was performed using Principal Component, Discriminant Function, and Cluster Analyses. The methods enabled the identification of fish from eastern and western part of the Caspian Sea with a reliability rate of 83%.

In Brazil, some pleuronectiforme fish are caught in multi–species fisheries. Santos *et al.* (2019) collected samples at landing ports and used geometric morphometrics derived from body landmarks to identify species. A canonical analysis was used to process data. The study enabled to identify 4 groups associated with 4 species (*Paralichthys isosceles*, *P. patagonicus*, *P. orbignyanus*, *Xystreurys rasile*). *P. isosceles* and *X. rasile* were found to be isolated while *P. patagonicus* and *P. orbignyanus* were found to be associated. To identify species, the tail shape as well as the relative eye and jaw position gave the best results.

In China, Octopus landings constitute half of the cephalopod landings. Four octopus species (*Amphioctopus fangsiao*, *Amphioctopus ovulum*, *Octopus minor* and *Octopus sinensis*) are primarily landed and a tool for identification is required to improve the assessment and the management. Fang *et al.* (2018) used geometrical morphometrics of octopus beaks combined with machine learning to identify species. ANOVA, MANOVA, and discriminant analyses were used to analyse the data collected. Both the upper and the lower beaks exhibited differences and could be used in the identification.

Genetics and Morphometrics

Paralichthys species are commercial flatfish species and are present in the southwestern Atlantic Ocean. Olsson *et al.* (2019) used a combination of morphometrics and genetics to determine the variations in genetic and morphology characteristics of 3 *Paralichthys* species inhabiting Uruguayan waters. The discriminant analysis showed that two groups existed in *P. orbignyanus*. Morphological and genetic analyses led to consistent conclusions.

Meristics and Morphometrics

The population structure of Sardines (*Sardinops sagax*) along the Namibian coast, as wel as the west and the south coasts of South Africa, was studied by Groenewald *et al.* (2019) using both meristic (vertebral counts) and morphometric (derived from 11 landmarks) characteristics. Data were analysed using a multivariate multiple regression including covariates. The influence of these covariates were removed using a canonical variate analysis. If meristics supported the existence of 2 groups, morphometric highlighted that fish collected from the 3 areas seemed to come from 3 different stocks.

Otolith and Morphometrics

The stock structure of the Pacific thread herring (*Opisthonema libertate*) population was studied using a multi–criteria approach using body, otolith and scale shapes (Pérez-Quiñonez *et al.*, 2018). The area of interest was the northwestern coast of Mexico. Data were analysed with a Canonical Variate Analysis. Results were conclusive and enabled the identification of 3 morphotypes (or phenotypic stocks). A Canonical Variate Analysis was used to analyse data. Interestingly, body shape outperformed the two other characteristics in identifying the stock structure.

In the northeastern Atlantic, the population structure of blue jack mackerel is still unknown. Vasconselos *et al.* (2018) used body morphometrics and otolith shape analysis to identify differences between fish coming from 3 areas: waters off Madeira, Peniche (mainland Portugal), and the Canary Island. Authors used a canonical discriminant analysis to highlight differences between fish coming from the 3 areas. Both body morphometrics and otolith shape could be used to identify blue jack mackerel stocks and authors showed that at least 3 stocks exist in the NE Atltantic.

Software

Hsiang *et al.* (2018) developed a new software called AutoMorph to collect morphometries of animals. The package enables the batch–processing of high number of specimens per day. Both 2D and 3D data could be collected. The 3D information is collected by processing image stacks taken at different focal planes. The software was developed in Python and is currently available for UNIX system only. A version with a GUI will be available soon, as well as a Windows version. The article briefly describes the functions available in the package. The code and detailed documentation are available from Github (https://github.com/HullLab/AutoMorph). Although that software was developed for palaeontology, it has potential to collect morphometric data for stock identification and would enable users to collect quantitative data on stocks. It could also enable the exploration of new avenues with the 3D description of specimens.

References

Bakhshalizadeh, S., & Bani, A. (2018). Morphological analysis of pectoral fin spine for identifying ecophenotypic variation of Persian Sturgeon *Acipenser persicus*. *Marine Ecology*, *39*(5), e12516.

Carvalho C, Keunecke KA, and Lavrado HP, 2019. Morphometric variation in pink shrimp populations at Rio de Janeiro coast (SE Brazil): are they really similar in closer areas?. Anais da Academia Brasileira de Ciências 91(2):1–17 e20180252. DOI 10.1590/0001-3765201920180252.

Fang, Z., Fan, J., Chen, X., & Chen, Y. (2018). Beak identification of four dominant octopus species in the East China Sea based on traditional measurements and geometric morphometrics. *Fisheries science*, *84*(6), 975-985.

Groenewald, G, Moloney CL and van der Lingen, CD, 2019. Spatial variation in meristic and morphometric characteristics of sardine Sardinops sagax around the coast of southern Africa. African Journal of Marine Science 41(1): 51–59

Hakim, M. M., Sawant, M., Pawar, R., Hussain, S., & Pawase, A. (2019). Morphometry based identification of Nemipterus japonicus unit stocks from west coast of India. Journal of Entomology and Zoology Studies 7(1): 819-826

Hsiang, A. Y., Nelson, K., Elder, L. E., Sibert, E. C., Kahanamoku, S. S., Burke, J. E., & Hull, P. M. (2018). AutoMorph: Accelerating morphometrics with automated 2D and 3D image processing and shape extraction. *Methods in Ecology and Evolution*, *9*(3), 605-612.

Olsson, D., Marquez, A., Tellechea, J. S., Carvalho, P. H., Pereira, A. N., & Norbis, W. (2019). Genetic and morphometric analyzes of *Paralichthys* species confirm the presence of *P. brasiliensis* in the Uruguayan waters. *Neotropical Biodiversity*, *5*(1), 30-35.

Pérez-Quiñonez, C. I., Quiñonez-Velázquez, C., & García-Rodríguez, F. J. (2018). Detecting Opisthonema libertate (Günther, 1867) phenotypic stocks in northwestern coast of Mexico using geometric morphometrics based on body and otolith shape. *Latin american journal of aquatic research*, *46*(4), 779-790.

Rodríguez-Mendoza, R., Muñoz, M., & Saborido-Rey, F. (2019). Structure and connectivity of bluemouth, Helicolenus dactylopterus, populations in the NE Atlantic and Mediterranean. Fisheries research, 213, 56-66.

Santos, S. R., Pessôa, L. M., & Vianna, M. (2019). Geometric morphometrics as a tool to identify species in multispecific flatfish landings in the Tropical Southwestern Atlantic. *Fisheries Research*, *213*, 190-195.

Vasconcelos, J., Vieira, A. R., Sequeira, V., González, J. A., Kaufmann, M., & Gordo, L. S. (2018). Identifying populations of the blue jack mackerel (Trachurus picturatus) in the Northeast Atlantic by using geometric morphometrics and otolith shape analysis. *Fishery Bulletin*.

Tagging (Contributor: Karin Hüssy and Ann-Britt Florin)

Tagging continues to be a useful tool for stock identification. There are plentiful of methods in use and alongside the dominating ones, acoustic telemetry and data storage tags, conventional non-electronic tags are still in use. Many studies are dealing with the impact of human activities and there is also many migration studies in rivers, not strictly stock identification, but essential habitat identification

Methods

Edwards *et al.* (2019) reviewed studies and methodological development of deep-sea telemetry, providing movement records spanning from surface waters down to 5900 m depth and across nearly all of the world's oceans. Telemetry devices employed in deep-sea tracking studies have included both commercially available and custom-built transmitters belonging to multiple tag categories: acoustic transponders/code-activated acoustic transponders, acoustic transmitters (coded and continuous, e.g., 'pingers'), pop-up satellite archival tags, and archival tags (data loggers).

Liu *et al.* (2019) developed a Particle Filter geolocation package for fish tagged with electronic archival tags using a state-space approach based on the particle filter (PF), and with graphics processing unit (GPU) acceleration. The study focused on application to demersal fish and utilized comparison of the tag-recorded depth and temperature to the same variables from an unstructured grid regional oceanographic model.

Griffiths *et al.* (2018) presented an alternative approach to gain meaningful inference from an animal's recorded movements to infer population-level patterns using of hidden Markov models (HMMs). The approach provides a promising way of adding value to tagging studies because inferences about movement behaviour can be gained from a larger proportion of datasets, making tagging studies more relevant to management and more cost-effective.

Hussey *et al.* (2018) evaluated mark report satellite tags (mrPATs) to examine horizontal movements of the Greenland shark (*Somniosus microcephalus*) in order to establish stock. The results provide a new approach to document coarse scale horizontal movements to understand migrations, stock structure and habitat use of large species.

Faust *et al.* (2019) investigated the feasibility of using acoustic telemetry to estimate spawning population contributions to a mixed-stock fishery using Lake Erie's summer walleye (Sander vitreus) by estimating post release survival and evaluating how contribution estimates could be affected by survival, sample size, and expected population contributions.

Beacham *et al.* (2019) evaluated the accuracy of coded wire tag (CWT) programs to discriminate between wild and hatchery reared coho salmon Onchorynchus kisutch by comparison of CWT-derived classification success with the accuracy of parentage-based tagging (PBT) and genetic stock identification (GSI). The results suggest that a PBT-GSI system of identification provided high-resolution estimates of stock composition, catch, and exploitation rate, providing an alternate and more effective method in the assessment and management relative to CWTs.

Case studies

TinHan *et al.* (2018) evaluated the benefits of habitat restoration by applying a combination of scale stable isotope analysis with acoustic tagging to identify spatial and temporal patterns of habitat use of 41 spotted seatrout *Cynoscion nebulosus* on Half Moon Reef, a recently restored oyster reef in Matagorda Bay, Texas. Overall, spotted seatrout residency to HMR was low, with fish being present on the reef 24% of days. When present, individual fish exhibited strong site-attachment to small portions of the reef. Residency to HMR increased significantly with size, while scale stable isotope analysis revealed fish exhibiting high residency to HMR occupied significantly smaller isotopic niches.

Galuardi *et al.* (2018) demonstrated the use of a telemetry-based method for simulating individual based movements of Atlantic bluefin tuna to produce transition matrices for movement inclusive models. This type of approach is particularly informative for stock assessment by (1) providing estimates of bluefin tuna movement for consideration as fixed values, prior probabilities on movement, or for direct comparison with estimates of movement from mixed stock assessment models (2) to facilitate discussion of movement rate assumptions and the use of electronic tagging data in various assessment models.

Kersula and Seitz (2019) studied the migratory behaviours of Atlantic halibut (*Hippoglossus hippoglossus* L.) tagged with conventional wire tags in the U.S. portion of the Gulf of Maine between 2000 and 2017. There were 412 recaptures reported out of 2573 releases, a return rate of 16.0%. These returns illustrate that although most fish are recaptured close to the release point with a median distance at recapture of 38 km, Gulf of Maine Atlantic halibut also engage in dispersive behaviour with some fish travelling at least 1564 km. Most (76%) recaptures were from waters of the Gulf of Maine and the Western Scotian Shelf off Canada, suggesting a higher level of mixing within this transnational boundary area than to elsewhere. This contrasts common assumptions about stock structure made for assessment and management purposes.

Dembkowski *et al.* (2018) tested current assumptions of stock structure of walleye *Sander vitreus* in Green Bay using a combination of molecular methods and conventional tags. Genetic differentiation was low between tributaries. Recapture data suggested that walleye spawning in the four tributaries studied typically remain – and mix – within the southern Green Bay outside the spawning season. The results suggested that walleye spawning in the Fox, Menominee, Oconto, and Peshtigo Rivers do not function as separate stocks and do not significantly contribute to the fishery outside of southern Green Bay.

De Pontual *et al.* (2018) studied migratory behaviour of European seabass in the Iroise Sea off west Brittany, France using electronic archival tags. Reconstructed fish tracks revealed that seabass is a partially migratory species, as individuals exhibited either long-distance migrations towards the Bay of Biscay or the Celtic Sea, or residency behaviour in the Iroise Sea. Fidelity to summer feeding areas and to winter spawing areas was demonstrated. These results suggest that the population is spatially structured. The Iroise Sea is likely a mixing zone for different stocks or sub-populations, and may also shelter a resident population.

Fowler *et al.* (2018) identified stock structure of *Pseudocaranx georgianus* on Australia's southeast coast using data on 6300 individuals of a tag-recapture program with convential tags. The resuts indicated restricted movement over an intermediate scale, with occasional large movements, suggesting that movements of *P. georgianus* in southeastern Australia primarily occur over smaller distances than the current spatial scale of management.

Adams *et al.* (2019) identified pre-spawning aggregation areas of bonefish *Albula vulpes* in the Bahamas in a multi-disciplinary approach using based on tracking with acoustic telemetry and mark-recapture, coupled with biological and behavioural observations. Since bonefish and many other tropical fishes that form spawning aggregation are 'data poor' and occur in regions where enforcement of fishery regulations is lacking, spatial management is often the best conservation strategy.

Benitez *et al.* (2018) evaluated the benefit of fishway installation on migration patterns and habitat accessibility of 11 potadromous fish species in the degraded river Meuse using RFID transponders. The installation of fishways was considered adequate for the restoration of the free movement because potamodromous species demonstrated their ability to migrate over long distances (>20 km) and to reach potential spawning habitats through the reopened access to a tributary.

Pennock *et al.* (2018) used passive integrated transponder (PIT) tags to study stock structure in southern redbelly dace *Chrosomus erythrogaster*, central stoneroller *Campostoma anomalum*, and creek chub *Semotilus atromaculatus*, among and within pools of an intermittent stream. Most fish remained in the pool where they were caught and released or returned after emigrating from the pool. Despite largely remaining within the release pool, distribution among four microhabitats differed significantly where the summed distance moved among antennas, differed significantly among species, and increased significantly with body length for stoneroller and chub, but not dace. This suggests ecologists can broaden the interpretation of processes influencing community structure (e.g., resource partitioning, avoidance of predators) by quantifying species distributions across a range of spatial and temporal scales.

Review

Brooks *et al.* (2019) reviewed case studies where biotelemetry data had been successfully incorporated into aspects of fishery and fish habitat management. Case studies used were from the Ocean Tracking Network (OTN), including Pacific salmon (Oncorhynchus spp.) in British Columbia, Canada; Greenland halibut (Reinhardtius hippoglossoides) in Cumberland Sound, Canada; and lemon sharks (Negaprion brevirostris) in Florida, USA, which had aimed at documenting key processes for science integration.

Siskey *et al.* (2018) highlighted the complexity of stockstatus for skates which are often managed in multispecies context. In their review of movement studies, issues with different tagging technologies confounding the perception of stockstructure were identified and suggestions were made for future practises.

References

Adams AJ, Shenker JM, Jud ZR, Lewis JP, Carey E, Danylchuk AJ (2019) Identifying pre-spawning aggregation sites for bonefish (Albula vulpes) in the Bahamas to inform habitat protection and species conservation. Environmental Biology of Fishes, 102: 159-173. doi: 10.1007/s10641-018-0802-7

Beacham TD, Wallace C, Jonsen K, McIntosh B, Candy JR, Willis D, Lynch C, Moore J-S, Berntches L, Withler RE (2019) Comparison of coded-wire tagging with parentage-based tagging and genetic stock identification in a large-scale coho salmon fisheries application in British Columbia, Canada. Evolutionary Applications, 12: 230-254. doi: 10.1111/eva.12711

Benitez J-P, Dierckz A, Matondo BN, Rollin X, Ovidie M (2018) Movement behaviours of potamodromous fish within a large anthropised river after the reestablishment of the longitudinal connectivity. Fisheries Research, 207: 140-149. doi: 10.1016/j.fishres.2018.06.008

Brooks JL, Chapman JM, Barkley AN, Kessel ST, Hussey NE, Hinch SG, Patterson DA, Hedges KJ, Cooke SJ, Risk, AT, Gruber SH, Nguyen VM (2019) Biotelemetry informing management: case studies exploring successful integration of biotelemetry data into fisheries and habitat management. Canadian Journal of Fisheries and Aquatic Sciences, 76: 1238-1252. doi:10.1139/cjfas-2017-0530

De Pontual H, Lalire M, Fablet R, Laspougeas C, Garren F, Martin S, Dogou M, Woillex M (2018) New insights into behavioural ecology of European seabass off the West Coast of France: implications at local and population scales. *ICES Journal of Marine Science*, 76: 501–515. doi:10.1093/icesjms/fsy086

Dembrowski D, Isermann DA, Hogler SR, Larson WA, Turnquist KN (2018) Stock structure, dynamics, demographics, and movements of walleyes spawning in four tributaries to Green Bay. Journal of Great Lakes Research, 44: 970-978. doi:10.1016/j.jglr.2018.07.002

Edwards JE, Pratt J, Tress N, Hussey NE, 2019. Thinking deeper: Uncovering the mysteries of animal movement in the deep sea. Deep Sea Research Part I: Oceanographic Research Papers, 146: 24-43, doi:10.1016/j.dsr.2019.02.006.

Faust MD, Vandergoot CS, Brenden TO, Kraus RT, Hartman T, Krueger CC (2019) Acoustic telemetry as a potential tool for mixed-stock analysis of fishery harvest: a feasibility study using Lake Erie walleye. Canadian Journal of Fisheries and Aquatic Sciences, 76: 1019-1030. doi:10.1139/cjfas-2017-0522

Fowler AM, Chick RC, Stewart J (2018) Patterns and drivers of movement for a coastal benthopelagic fish, Pseudocaranx georgianus, on Australia's southeast coast. Scientific Reports, 8: Article number: 16738. doi: s41598-018-34922-6

Galuardi B, Cadrin SX, Arregi I, Arrizabalaga H, Di Natale A, Brown C, Laureta M, Lutcavage M (2018) Atlantic bluefin tuna area transition matrices estimated from electronic tagging and sattagsim. Collect. Vol. Sci. Pap. ICCAT, 74(6): 2903-2921

Griffiths CA, Patterson TA, Blanchard JL, Righton DA, Wright SR, Pitchford JW, Blackwell PG (2018) Scaling marine fish movement behaviour from individuals to populations. Ecology and Evolution, 8: 7031-7043. doi: 10.1002/ece3.4223

Hussey NE, Orr J, Fisk AT, Hedges KJ, Ferguson SH, Barkley AN (2018) Mark report satellite tags (mrPATs) to detail large-scale horizontal movements of deep water species: First results for the Greenland shark (*Somniosus microcephalus*). Deep Sea Research Part I: Oceanographic Research Papers, 134: 32-40. doi: 10.1016/j.dsr.2018.03.002

Kersula M, Seitz A (2019) Diverse migratory behaviours of Atlantic halibut (Hippoglossus hippoglossus, L.) based on the 2000–2017 Maine halibut tagging program. Journal of Northwest Atlantic Fisheries Science,: 13–24. doi:10.2960/J.v50.m719

Liu C, Cowles GW, Zemeckis DR, Fay G, LeBris A, Cadrin SX (2019) A hardware-accelerated particle filter for the geolocation of demersal fishes. Fisheries Research, 213:160-171. doi:10.1016/j.fishres.2019.01.019

Pennock CA, Cathart CN, Hedden SC, Weber RE, Gido KB (2018) Fine-scale movement and habitat use of a prairie stream fish assemblage. Oecologia, 186: 831–842. doi: 10.1007/s00442-018-4073-y

Siskey, MR, Shipley, ON, Frisk MG. Fish and Fisheries: 20(2):286-302. doi.org/10.1111/faf.12340.

TinHan TC, Mohan Ja, Dumesnil M, DeAngelis BM, Wells RJD (2018) Linking Habitat Use and Trophic Ecology of Spotted Seatrout (*Cynoscion nebulosus*) on a Restored Oyster Reef in a Subtropical Estuary. Estuaries and Coasts, 41: 1793–1805. doi:10.1007/s12237-018-0391-x

Otolith shape (Contributors: Kelig Mahe and Christoph Stransky)

At present, publications involving otolith shape research reach over 600 publications, with a significant increase in the last 10 years (Figure 1). Publications deal with different objectives such as stock identification, methodologies, or otolith description.

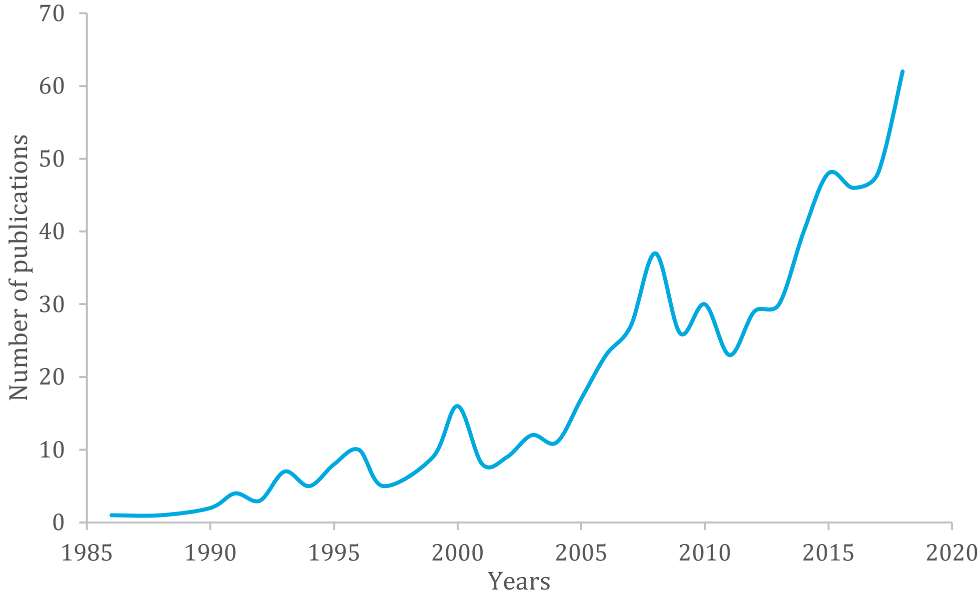


Figure 1. Evolution of the number of publications per year related to "OTOLITH" and "SHAPE" topics (source Web of Science).

Different approaches have been used to describe and compare the morphology of otoliths. There are 2 main groups of extracted data from the otolith outline with univariate and multivariate data (Figure 2). The methodology most often used to describe the otolith shape is Elliptic Fourier Analysis.

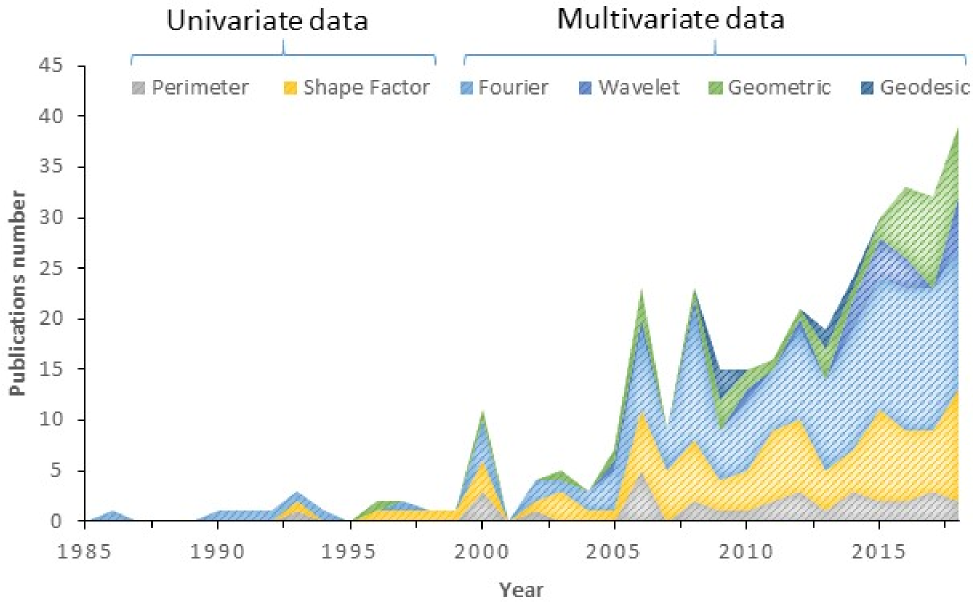


Figure 2. Evolution of the number of publications per year with prior selected "OTOLITH" and "SHAPE", by type of data extracted from the otolith outline (source Web of Science).

From July 2018 to July 2019, there were 22 papers dedicated the otolith shape with seven studies around the significant factors which drive otolith shape to identify species or morphotypes and 15 case studies on otolith shape as tool to describe stock structure. All abstracts are presented below.

Significant factors which drives otolith shape

Schulz-Mirbach *et al.* (2019) discuss questions and hypotheses on how otolith mass and shape, and the relationship between the sensory epithelium and overlying otolith, influence otolith motion. They discuss (i) the state-of-the-art knowledge regarding otolith function, (ii) gaps in knowledge that remain to be filled, and (iii) future approaches that may improve our understanding of the role of otoliths in ear functioning. They further link these functional questions to the evolution of solid teleost otoliths instead of numerous tiny otoconia as found in most other vertebrates. Until now, the selective forces and/or constraints driving the evolution of solid calcareous otoliths and their diversity in shape in teleosts are largely unknown. Based on a data set on the structure of otoliths and otoconia in more than 160 species covering the main vertebrate groups, they present a hypothetical framework for teleost otolith evolution. They suggest that the advent of solid otoliths may have initially been a selectively neutral 'by-product' of other key innovations during teleost evolution. The teleost-specific genome duplication event may have paved the way for diversification in otolith shape. Otolith shapes may have evolved along with the considerable diversity of, and improvements in, auditory abilities in teleost fishes. However, phenotypic plasticity may also play an important role in the creation of different otolith types, and different portions of the otolith may show different degrees of phenotypic plasticity. Future studies should thus adopt a phylogenetic perspective and apply comparative and methodologically integrative approaches, including fossil otoliths, when investigating otoconia/otolith evolution and their function in the inner ear.

Vignon (2018) using geometric morphometrics, discriminated if it was possible in absence of growth-related differences between control and brown trout (Salmo trutta Linnaeus, 1758) that have experienced brief thermal stress prior to their emergence but have grown in similar conditions (i.e., cohabiting within the same aquarium) during 6 months. Data emphasize that brief stress during key developmental periods can durably influence ontogenetic trajectories, subsequent otolith development, and can consequently change otolith morphology in juveniles. Therefore, differences in shape between groups of fish may not be exclusively indicative of long-time residency in contrasted and (or) separated habitats as it is generally assumed. Moving beyond long-term assumptions is fundamental if otolith shape is to be used as an effective tool for management of fisheries resources in the future.

Vandenbussche *et al.* (2019) tested whether the otolith shape of Oblada melanura juveniles could be used as indicator of anthropic impacts. Otolith shapes, defined by Fourier elliptic analysis, were compared using canonical analysis of principal coordinates. In this three-year study, geographically close sites have been compared: one with low-level pollution and one near a recreational harbour. Determining the minimum fish standard length at which the influence of fish size on otolith shape does not occult other influences, 11 mm in this study, is a prerequisite for the study of otolith shape variation in juveniles. Inter-annual environmental variations interfere with local conditions and delays between samplings are also important considerations. They have demonstrated that the comparison of O. melanura juvenile otolith shape is an effective method to compare the short-term influence of different environmental conditions.

Tuset *et al.* (2018) determined the degree of phenotypic variability and functional niche overlap between Diaphus (Myctophidae) species that could account for the high level of speciation within this genus. The Diaphus specimens which were used for our study, were obtained from a survey transect across the central Atlantic Ocean. They analysed the morpho-functional features of fish body shape and sagittae otolith shape of these specimens. Although our study included only 9 species, their findings revealed a high degree of morpho-functional variability in the fish body and otolith shapes, both of which are coupled with the variations of the bioluminescent organs of the head, especially the suborbital organ situated under eye and called So-photophore. Two morphotypes were identified: 'Diaphus-deep' (morphotype-1) with an So-photophore, and defined by a larger otolith and a deep body, larger head, eye and mouth; and 'Diaphus- slender' (morphotype-2) without an So-photophore, and characterized by an increased development of anterior- dorsal margin of otolith and an enlarged body with small head, eye and mouth. Their analyses supported both the sensory drive and niche hypotheses as forces promoting the radiation within the genus Diaphus. Future studies involving a greater number of species are necessary to advance the knowledge of speciation mechanisms in myctophids.

Ding *et al.* (2018) investigated morphological variations in the otoliths of an endemic Chinese fish (Schizothorax nukiangensis Tsao) collected from seven sites with varying environmental gradients along the Nu-Salween River. They compared morphological characters of S. nukiangensis otoliths among sampling sites and identified environmental sources of otolith morphological variation using multivariate regression trees and multiple factor analysis. Results showed that S. nukiangensis otoliths collected from different habitats were significantly different in morphology, mainly at the rostrum, excisura and posterior rim. Variations in otolith morphology (specifically the increase in otolith length) were predominantly governed by average river gradient; this might be a functional response to hydrogeomorphic conditions. Other environmental gradients (i.e., altitude, latitude and average annual temperature) played a minor role in otolith shape. This study highlighted the role of environmental factors in determining the otolith shape in riverine fish; thus, species and population discriminations based on otolith morphology should consider intraspecific variability.

Bose *et al.* (2018) compared round goby Neogobius melanostomus sagittal (saccular) otolith morphology between males of the two alternative reproductive tactics (termed guarder and sneaker males) and between males captured from sites of high or low contamination. Otolith size increased with fish size and also displayed an ontogenetic shift in shape, becoming relatively taller as otoliths grew in size. Despite a considerable overlap in age between males adopting the two reproductive tactics, size-at-age measurements revealed that guarder males are significantly larger than sneakers at any given age and that they invest more into somatic growth than sneaker males. Controlling for body size, sneaker males possessed heavier sagittal otoliths than guarder males. Subtle otolith shape differences were also found between the two male tactics and between sites of high and low contaminant exposure. Sneaker males had relatively shorter otoliths with more pronounced notching than guarder males. Fish captured at sites of high contamination had otoliths showing slower growth rates in relation to body size and their shapes had more pronounced caudal points and ventral protrusions when compared with fish captured at sites of low contamination. The results are discussed in relation to life-history tradeoffs between the male tactics in terms of reproductive and somatic investment as well as the putative metabolic costs of exposure to contaminants. Overall, this study reveals that male alternative reproductive tactics and environmental contaminants can have small, yet measurable, effects on otolith morphology and these factors should be accounted for in future research when possible.

Holmberg *et al.* (2019) studied the effect of the ocean acidification on otolith size and shape. Here, larval Clark's anemone- fish, Amphiprion clarkii (Bennett, 1830), were reared in various seawater pCO2/pH treatments analogous to future ocean scenarios. At the onset of metamorphosis, all otoliths were removed from each individual fish and analyzed for treatment effects on morphometrics including area, perimeter, and circularity; scanning electron microscopy was used to screen for evidence of treatment effects on lateral development, surface roughness, and vaterite replacement. The results corroborate those of other experiments with other taxa that observed otolith growth with elevated pCO2, and provide evidence that lateral development and surface roughness increased as well. Both sagittae exhibited increasing area, perimeter, lateral development, and roughness; left lapilli exhibited increasing area and perimeter while right lapilli exhibited increasing lateral development and roughness; and left asterisci exhibited increasing perimeter, roughness, and ellipticity with increasing pCO2. Right lapilli and left asterisci were only impacted by the most extreme pCO2 treatment, suggesting they are resilient to any conditions short of aragonite undersaturation, while all other impacted otoliths responded to lower concentrations. Finally, fish settlement competency at 10 dph was dramatically reduced, and fish standard length marginally reduced with increasing pCO2. Increasing abnormality and asymmetry of otoliths may impact inner ear function otolith-maculae interactions.

Otolith shape as tool to stock identification

Mahé *et al.* (2018) tested thee potential biases resulting from potential directional bilateral asymmetry (DA) in otolith shape, i.e. a unimodal population-level deviation form bilateral symmetry between right and left otolith shapes. In this study, 560 bogues (*Boops boops*) were sampled from 11 geographical locations from the Canary Islands to the Aegean Sea, and elliptical Fourier descriptors were used to describe their otoliths' shape. First, a significant otolith DA was observed at the global scale with an average amplitude of 2.77%. However, at the scale of sampling locations, DA was not always significant and varied in amplitude and direction. Second, population structure was investigated using the shape of either right otoliths or left otoliths or both together. Analyses based on right otoliths or both otoliths together, suggested three stock units: a North-Western Mediterranean Sea stock, an Eastern Mediterranean Sea stock, and a Central-Eastern Atlantic Ocean and South- Western Mediterranean Sea stock. In contrast, no coherent geographical pattern was found based on left otoliths. The results highlight the importance of accounting for potential otolith DA in otolith shape-based stock identification.

Neves *et al.* (2019) used different approaches to otolith analysis were used to elucidate on black seabream population structure. Otoliths from seven areas along the eastern Atlantic: English Channel, Bay of Biscay, Galicia (Spain), Peniche (west coast of Portugal), Algarve (south coast of Portugal), the Canary Islands and Angola were compared through elliptical Fourier analysis and oxygen and carbon stable isotopes ratio. Otolith shape analysis data achieved 80% of correct assigned specimens in discriminant analysis while poor correct assignment levels were achieved with the stable isotopes ratio. However, the PERMANOVA conducted on $\delta^{13}C$ and $\delta^{18}O$ values revealed significant differences between all areas, with exception of the two Portuguese areas. The results of this study indicate that black seabream spends most of its life in the same area and that the studied populations should probably be considered as different stock units. However, some mixture was detected in the European region pointing for the usefulness of life history parameters and genetic studies to enlighten the stock structure of the species.

Moreira *et al.* (2019) examined whether otolith shape is efficient to infer about the population structure of the blue jack mackerel, *Trachurus picturatus* and if the obtained data is consistent over time. Individuals of *T. picturatus* were collected in 2013 and 2016 from six important fishery regions in the NE Atlantic: Azores, Madeira, Canaries and Portugal mainland – Matosinhos, Peniche and Portimão. Otolith shape indices and elliptic Fourier descriptors were investigated by uni and multivariate statistical analyses. Data showed regional differences in the otolith shape analysis, with differences between the years. Fish sampled in 2013 showed an overall low re-classification rate (43%) with a high overlap of individuals within sampling locations, suggesting a single population unit. However, samples from 2016 allowed the discrimination of three distinct spatial groups with a moderate overall correct re-classification (62%) - group 1 with samples from the Azores; group 2 with samples from the Canaries; and group 3 with samples from Madeira and Portugal mainland. The data suggests that fish population structure could be dynamic over time, recommends a year-classes follow-up of the population units in the main fishing areas and stresses the need of holistic methodological approaches to study fish stocks. Furthermore, the observed complex spatial dynamic structure of the species demands region specific requirement actions to ensure a rational management of the fishery.

Soeth *et al.* (2019) focused on the stock structure of Atlantic spadefish, *Chaetodipterus faber* in the Southwest Atlantic. A total of 100 individuals ranging from 30 to 40 cm total length were collected from the five main fishery regions of Brazil [Espírito Santo (ES), Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR), and Santa Catarina (SC)], between December 2015 and March 2016. The shape outline of each otolith was assessed using Elliptic Fourier descriptors (EFD). Multi-Elemental signatures (MES) of whole otoliths were obtained using inductively coupled plasma mass spectrometry. Data were analyzed through uni- and multivariate statistics. Canonical analysis of principal coordinates indicated that spatial differences were mainly driven by Sr/Ca ratios, Ba/Ca ratios and EFD 14. Combining data from both techniques (EFD and MES), the leave-one-out classification re-assigned individuals to their region of origin with an accuracy of 100% (ES), 85% (RJ), 80% (SP), 85% (PR), and 65% (SC). The results indicate that the connectivity between the local population of *C. faber* in the ES region (20 °S) with the southern populations (> 22 °S) is limited; moreover, data suggest the presence of spatially structured semi-discrete groups between 23 °S and 27 °S. Despite the possibility of intermixing *C. faber* populations in the Brazilian Southwest Atlantic coast, local populations should be regarded as different stocks for fisheries management purposes. However, at present, the degree of intermixing and the contribution that each local population receive from distant recruitment sources is unknown and demands further studies.

Deepa *et al.* (2019), using otolith morphometric analysis, analysed intra-species variability in the bathy-demersal fish *Bembrops caudimacula* collected from two different ecosystems in the Indian Ocean were studied. Five otolith size parameters (ferret length, ferret width, area, perimeter and weight), and five shape indices (roundness, rectangularity, ellipticity, form factor and circularity) were taken from forty-seven otoliths collected from two regions. Principal Component Analysis (PCA) and non-parametric PERMANOVA successfully differentiate the fishes from two regions based on the otolith morphometry. PCA indicated that ellipticity and otolith weight were the major factor responsible for the variation. The study indicated that otoliths of the fishes collected from Andaman Sea (part of Bay of Bengal) were more elliptic and massy compared to those collected from the Arabian Sea. This is the first work on the differentiation of B. caudimacula population from these two unique ecosystems, using otolith morphometry which is highly imperative to understand its population structure. Our study confirmed the suitability of otolith morphometric studies as an easiest and inexpensive method for differentiating the fish populations.

Machouca *et al.* (2019) analyzed anchovy (*Engraulis ringens*) population units in three zones off the coast of Chile: 1: Arica-Iquique, 2: Coquimbo and 3: Talcahuano-Valdivia from samples obtained during the 2012 spawning season. They used 50 left sagittae otoliths from each zone to perform a morphometric analysis, which included basic measurements, shape indexes and contour analysis (Elliptical Fourier Analysis). A MANOVA and Tukey Multiple Comparison Analyses, applied on basic measures and shape indexes, showed significant differences between zone 3 and zones 1 and 2. A classification by Canonical Discriminant analysis of elliptical Fourier harmonics, indicated significant differences among zones. It is concluded, therefore, that otolith shape analysis could be used to discriminate population units of *Engraulis ringens*. Better results were achieved using elliptic Fourier coefficients than using only shape indices.

Avigliano *et al.* (2018), using Fourier descriptors and shape indices of lapillus otoliths, evaluated the discrimination among three sympatric species of the genus *Astyanax* inhabiting streams of the Atlantic Rain Forest (Argentina). Aspect ratio, roundness and ellipticity of otoliths were significantly different between the species ($p < 0.05$), while no significant differences were found for circularity, rectangularity and form factor ($p > 0.05$). PERMANOVA analysis reveal significant differences between species using Fourier descriptors ($F = 96.7$, $0.0001 < p < 0.02$) and the reclassification rates of quadratic discriminant analysis were high, averaging 86.3% (82.7–88.6%). Multivariate analyses of shape indices were not effective to discriminate between species. Instead, high classification percentages suggest that the otolith outline is a potential tool for the identification of sympatric morphologically similar species of *Astyanax*. The results could contribute to future taxonomic and phylogenetic studies and may be an interesting input for both paleontological and trophic studies in sympatric species.

Jmil *et al.* (2019) investigated, for the first time, the stock discrimination of this golden grey mullet *Liza aurata* (Risso, 1810) for two Tunisian populations based on sagittae shape, using different statistical analyses. The specimens were collected during three months from two lagoon stations in southern Tunisia: El Biban and Boughrara. In total, 120 fish were sampled from the two sites, 60 fish from each lagoon (30 males and 30 females), and included for different statistical analyses. The Discriminant Function Analysis (DFA) for otolith shape showed statistically significant differences between specimens of the two lagoons. In addition, the results revealed distinct differences in otolith shape between the two populations and left-right symmetry of otolith in both sexes of each of the two stations, except one male from Boughrara which showed an asymmetry in the shape of the otolith. Moreover, sexual dimorphism was observed only in the left side of the otolith of El Biban specimens. The shape variability between specimens of the two lagoons is probably correlated with local environmental and ecological factors.

Doustdar *et al.* (2019), using length, width, area, perimeter, form factor, aspect ratio, roundness, circularity, ellipticity, and rectangularity analyses of otoliths, analysed patterns of spatial and temporal stock structure of a wide-ranging fish, the Arabian yellow fin sea bream *Acanthopagrus arabicus*. Fish were sampled from 125 stations across the distribution range of the species in the Northern Persian Gulf and Oman Sea from June 2014 to May 2016. Analysis of morphometric parameters of otolith showed the minimum size in Khuzestan waters and the West Strait of Hormuz and the maximum size in the East Strait of Hormuz. In Bushehr waters, form factor showed the lowest and circular factor showed the highest frequency. These findings are in agreement with the irregularity in otolith margin of this area. The highest aspect ratio of otolith indicated higher growth in Khuzestan Waters. The thinner and longer otoliths were identified in the East Strait of Hormuz region. Further, rectangularity ratio factor in the Bushehr and West Strait of Hormuz waters was higher in comparison with other regions and this finding confirmed the quadrilateral otolith shape of this region. There are significant differences among otolith morphometric variables of the *A. arabicus* ($p<0.05$). The result of discriminant analysis on morphometric parameters indicated that 53/8 percent were in their geographic location accurately.

Khemiri *et al.* (2018) investigated the stock structure of anchovy caught off the open sea and the coastal area of the Gulf of Tunis, lagoon of Bizerte and Lake of Ichkeul using otolith shape. Otolith shape was determined by Fourier analysis and then compared among specimens sampled from different areas with forward stepwise canonical discriminant analysis. Significant differences in otolith shape between the open sea and inshore anchovy groups were detected. Otolith shape of anchovy collected in the Lake of Ichkeul was distinct from the other groups. This finding suggests a clear discreteness of the open sea and the continental groups. The data highlighted the potential for using otolith shape analysis for anchovy stock identification, as well as the role of oceanographic features in determining stock separation. These findings will have major implications for anchovy fisheries management in Tunisia. By using a precautionary approach and considering the three areas as separate stocks, fisheries management strategies should be adjusted to achieve optimum sustainable production from each stock and to avoid decreases in genetic variety.

Lee *et al.* (2018) investigated otolith shapes of Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*) for geographic variability within seven regions across the Patagonian Shelf, and South Georgia and the South Sandwich Islands (SGSSI). Otolith shape was characterised by its elliptical Fourier coefficients (EFCs), corrected for fish length before being analysed, using multivariate methods. Non-metric multidimensional scaling analysis suggested three main groupings: Patagonian Shelf, SGSSI, and Antarctic toothfish. This result was supported by ANOVA-like permutation tests, indicating significant ($P < 0.001$) differences in otolith shape among these three groupings. Linear discriminant analysis (LDA) cross-validation analyses of the EFCs resulted in otoliths being correctly classified to the sampling region from which they came, with an accuracy ranging from 78.95 to 100%. LDA cross-validation analyses on sampling regions within SGSSI and the Patagonian Shelf were able to classify individuals back to their sampling region with an accuracy of greater than 89.74 and 78.95% respectively. These results have provided some alternative insights into the stock structure of Patagonian toothfish across southern South America, South Atlantic and SGSSI.

Adelir-Alves *et al.* (2018) examined the morphology (shape indices and elliptic Fourier descriptors) and chemistry (Element:Ca) of *Abudefduf saxatilis* sagittal otoliths, collected in seven locations along the coast of South Brazil. Otolith morphology and chemistry were compared at short (range 0.5–2 km) and large (range 70–140 km) spatial scales using univariate and multivariate statistical approaches. Reclassification accuracy rates obtained from linear discrimination function analyses using both morphology and chemistry of otoliths were 61% and 82% for short and large spatial scales, respectively. No clear separation for individuals collected in islands within the Tamboretes Archipelago were observed suggesting that water masses are relatively homogeneous and/or that individuals could be highly mixed over short spatial scales. However, the higher reclassification success of the individuals belonging to Bom Abrigo, Galheta and Paz islands, indicates a limited movement of adults between habitats, a larval retention mechanism, or a self-recruitment process occurring at large spatial scales.

Pavlov (2018) analyzed otoliths (sagittae) of freckled goatfish *Upeneus tragula* from South Vietnam (Gulf of Thailand), southern Central Vietnam (Nha Phu and Nha Trang bays), and North Vietnam (Hanam, Gulf Long Bay). The shape indices, Elliptic Fourier Analysis, and Canonical Discriminant Analysis are applied. In the Gulf of Thailand, the samples off Hon Thom (Thom

Island, An Thoi Archipelago, to the south of Phu Quoc Island), including the red morph and black morph, collected during two subsequent years almost do not differ in otolith shape. A comparison of the samples from four regions of the Gulf of Thailand (40 km to the west of Phu Quoc, pooled sample off Hon Thom, coastal zone to the east of Phu Quoc, and 19 km to the west of Ha Tien) shows a discrimination of the stocks from the west to northeast. Substantial differentiation between the samples from Central and North Vietnam is not registered. The results are in relation to the features of life history of U. tragula and possible relative isolation of some stocks.

Barhoumi *et al.* (2018) conducted, for the first time, an otolith shape analysis to follow the stocks of saddled bream (*Oblada melanura*, Linnaeus, 1758) in three fishing zones along the Tunisian coast (Bizerte, Kelibia and Sayada). Otolith shape analysis was used on 30 otoliths for each site, sampled during the spawning period. Using elliptic Fourier descriptors (EFD), the quantification of the otolith shape was investigated by SHAPE and multivariate statistical procedures. Considering the environmental and the genotypic aspects, the preliminary results of the otolith shape analysis showed dissimilarity in silhouette of otoliths of saddled bream stocks collected from the north (Bizerte), the north-east (Kelibia) and the east (Sayada) of the Tunisian coast. Therefore, these three groups could be considered as three sub-units of the Tunisian stock, which should be managed separately.

Junjie *et al.* (2018) compared and evaluated the efficiency of two otolith shape descriptors (i.e., the elliptic Fourier transform (EFT) and discrete wavelet transform (DWT)) and morphometrics for stock discrimination. To accomplish this, sample fish from three stocks of yellow croaker *Larimichthys polyactis* along the Chinese coast (LDB stock from the Liaodong Bay of the Bohai Sea, JZB stock from the Jiaozhou Bay of the Yellow Sea and CJE stock from the Changjiang River estuary of the East China Sea) were used for otolith morphology analyses. The results showed that morphometrics produced an overall classification success rate of 70.8% in contrast with success rates of 80.0% or 82.0% obtained using EFT or DWT, respectively. This suggests that the two shape descriptors comparably discriminated among the stocks and performed more efficiently than morphometrics. During data adjustment and acquisition, some size variables were excluded from the subsequent discriminant analysis for stock discrimination because they were statistically "ineffective", which could reduce the efficiency of morphometrics and lead to relatively low overall classification success. Both EFT and DWT retain the contour coefficients and thus provide a detailed description of otolith shape, which could improve discriminatory efficiency compared with morphometrics.

References

Adelir-Alves, J, Daros, FALM, Spach, HL, Soeth, M, Correia, AT, 2018. Otoliths as a tool to study reef fish population structure from coastal islands of South Brazil, Marine Biology Research, 14(9-10): 973-988.

Avigliano, E, Eugenia Rolón, M, Rosso, JJ, Mabragaña, E, Volpedo, AV, 2018. Using otolith morphometry for the identification of three sympatric and morphologically similar species of Astyanax from the Atlantic Rain Forest (Argentina), Environ Biol Fish, 101: 1319–1328.

Barhoumi, M, Khoufi, W, Kalai, S, Ouerhani, A, Essayed, S, Zaier, G, Jaziri, H, Ben Meriem, S, Fehri-Bedoui, R, 2018. The use of Fourier analysis as a tool for Oblada melanura (Linnaeus, 1758) stock unit separation in the south central Mediterranean Sea, Journal of the Marine Biological Association of the United Kingdom, 98(7): 1725–1732.

Bose, APH, McCallum, ES, Raymond, K, Marentette, JR, Balshine, S. 2018. Growth and otolith morphology vary with alternative reproductive tactics and contaminant exposure in the round goby Neogobius melanostomus, J Fish Biol., 93: 674–684.

Deepa, KP, Aneesh Kumar, KV, Kottnis, O, Nikki, R, Bineesh, KK, Hashim, M, Saravanane N, Sudhakar, M, 2019. Population variations of Opal fish, Bembrops caudimacula Steindachner, 1876 from Arabian

Sea and Andaman Sea: Evidence from otolith morphometry, Regional Studies in Marine Science, 25: 100466.

Ding, L, Tao, J, Ding, C, Chen, L, Zhang, C, Xiang, Q, Sun, J, 2018. Hydrogeomorphic factors drive differences in otolith morphology in fish from the Nu-Salween River, Ecology of Freshwater Fish, 28:132–140.

Doustdar, M, Kaymaram, F, Seifali, M, Jamili, S, Bani, A, 2019. Stock identification of Arabian yellow fin sea bream (Acanthopagrus arabicus) using shape of otolith in the Northern Persian Gulf and Oman Sea, Iranian Journal of Fisheries Sciences, 18(1): 60-70.

Holmberg, RJ, Wilcox-Freeburg, E, Rhyne, AL, Tlusty, MF, Stebbins, A, Nye, JSW, Honig, A, Johnston, AE, San Antonio, CM, Bourque, B, Hannigan, RE, 2019. Ocean acidification alters morphology of all otolith types in Clark's anemonefish (Amphiprion clarkii) PeerJ, 7:e6152.

Jmil, I, Ben Faleh, A, Rebaya, M, Allaya, H, Ben Mohamed, S, Trojette, M, Chalh, A, Quignard, JP, Trabelsi, M, 2019. Otolith shape analysis as a tool for stock discrimination of Liza aurata from two Tunisian lagoons (Boughrara and El Biban, Cah. Biol. Mar., 60: 167-174.

Khemiri, S, Gaamour, A, Ben Abdallah, L, Fezzani, S, 2018. The use of otolith shape to determine stock structure of Engraulis encrasicolus along the Tunisian coast, Hydrobiologia, 821: 73–82.

Lee, B, Brewin, PE, Brickle, P, Randhawa, H. 2018. Use of otolith shape to inform stock structure in Patagonian toothfish (Dissostichus eleginoides) in the south-western Atlantic. Marine and Freshwater Research, 69: 1238-1247.

Machuca, C, Cerna**, F,** Muñoz, L, 2019. Identificación de stocks de Engraulis ringens en Chile utilizando morfometría de otolitos, Revista de Biología Marina y Oceanografía, 54(1): 144-149.

Mahé, K, Ider, D, Massaro, A, Hamed, O, Jurado-Ruzafa, A, Gonçalves, P, Anastasopoulou, A, Jadaud, A, Mytilineou, C, Elleboode, R, Ramdane, Z, Bacha, M, Amara, R, de Pontual, H, Ernande, B, 2019. Directional bilateral asymmetry in otolith morphology may affect fish stock discrimination based on otolith shape analysis, ICES Journal of Marine Science, 76(1): 232–243.

Moreira, C, Froufe, E, Vaz-Piresa, P, Correia, AT, 2019. Otolith shape analysis as a tool to infer the population structure of the blue jack mackerel, Trachurus picturatus, in the NE Atlantic, Fisheries Research, 209: 40–48.

Neves, A, Vieira, AR, Sequeira, V, Barros Paiva, R, Isabel Janeiro, A, Gaspar, LM, Serrano Gordo, L, 2019. Otolith shape and isotopic ratio analyses as a tool to study Spondyliosoma cantharus population structure, Marine Environmental Research, 143: 93–100.

Pavlov, DA, 2018. Differentiation of Freckled Goatfish Upeneus tragula Richardson, 1846 (Mullidae) in the Coastal Zone of Vietnam Based on Otolith Shape Analysis, Russian Journal of Marine Biology, 44(5): 404–414.

Schulz-Mirbach, T, Ladich, F, Plath, M, Heß, M, 2019. Enigmatic ear stones: what we know about the functional role and evolution of fish otoliths, Biological Reviews, 94: 457–482.

Soeth M, Spach, HL, Daros, FA, Adelir-Alves, J, Oliveria de Almeida, AC, Teodorico Correia, A, 2019. Stock structure of Atlantic spadefish Chaetodipterus faber from Southwest Atlantic Ocean inferred from otolith elemental and shape signatures, Fisheries Research, 211: 81–90.

Song, J, Zhao, B, Liu, J, Cao, L, Dou, S, 2018. Comparison of otolith shape descriptors and morphometrics for stock discrimination of yellow croaker along the Chinese coast. Journal of Oceanology and Limnology, 36(5): 1870-1879.

Tuset, V, Olivar, MP, Otero-Ferrer, JL, López-Pérez, C, Hulley, PA, Lombarte, A, 2018. Morpho-functional diversity in Diaphus spp. (Pisces: Myctophidae) from the central Atlantic Ocean: Ecological and evolutionary implications, Deep-Sea Research Part I, 138: 46–59.

Vandenbussche, PSP, Spennato, G, Pierson, PM, 2018. Assessment of the use of Oblada melanura (L. 1758) otolith fluctuating asymmetry as environmental disturbance indicator, Marine Environmental Research, 136: 48–53.

Vignon, M, 2018. Short-term stress for long-lasting otolith morphology - brief embryological stress disturbance can reorient otolith ontogenetic trajectory, Can. J. Fish. Aquat. Sci., 75: 1713–1722.

Otolith chemistry (Contributors: Lisa Kerr and Zach Whitener)

Otolith chemistry has been used as a tool for stock discrimination and life history identification for fishes from around the word, continuously advancing the utility of the technique. Following is a summary of instances which include ICES species of interest.

Bouchoucha *et al.* (2018) use otolith chemistry data obtained with HR-ICMPS from *Diplodus sargus* and *Diplodus vulgaris* as model species to test the hypothesis that juvenile fish could be correctly identified to places of capture, whether inside or outside of port facilities in the Bay of Toulon. These coastal fish are very common in the Mediterranean and juvenile habitat has been replaced in many areas by port construction. The authors found that 98% of individuals could be correctly identified to place of capture, based primarily on the concentrations of ^{138}Ba which the authors attributed to river runoff, but these concentrations varied by species. However, when comparing water chemistry from sample sites, they found that while Cu and Pb concentrations were 2.3–34 times higher inside of ports than outside, this was not consistently reflected in the otolith chemistry. As that there was not a discernable relationship between environmental concentrations and otolith concentrations of these isotopes, the authors cautioned that otolith microchemistry fingerprints may not provide a universal method for determining whether fish come from ports versus other coastal areas, it is still valuable to create a library of juvenile otolith microchemistry fingerprints from different habitats.

Brown *et al.* (2019) used a suite of 8 trace elements which were obtained with LA-ICPMS from the edges of juvenile otoliths of fishes that commonly hybridize in the coastal habitat of the inner Danish Waters (IDW). They were able to successfully identify and discriminate ~72% of sympatric European plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*), with correct allocation rates to individual species being ~70% and ~73%, respectfully. Additionally, ~67% of individual plaice were correctly re-assigned to four juvenile habitat areas and 79% of individual sole (*Solea solea*) were correctly re-assigned to three juvenile habitat areas. The authors believe that this work highlights the need for more attention to be given to these hybridizing fishes in IDW and that this could be a model system for exploring how factors that influence how trace elements are incorporated into otoliths. This study shows the utility of this technique for tracing marine fish back to juvenile habitat areas, even when found along a contiguous coastal area.

Limburg and Casini (2018) use LA-ICPMS and otolith chemistry analysis to investigate the effects of the anthropogenic hypoxic zone in the Baltic Sea on Atlantic cod growth. Ratios of Mn/Mg and Sr/Ca, among others, were determined for otoliths from different time periods (Neolithic, 1980s, 1990s, 2000s, and 2010s). While Mn presence is positively correlated with hypoxic conditions, this relationship is complicated as the Mn/Ca ratio is also affected by growth. Thus, the authors compared Mn/Mg, since Mg levels are affected by metabolic activity but not hypoxia. Mg/Ca was strongly positively correlated with Fulton's K. As hypoxia increased over time, cod growth decreased. This study shows concludes that cod otolith chemistry provides useful proxies for growth, metabolic status, and environmental changes.

Moll *et al.* (2019) used LA-ICP-MS on otoliths to develop a unique elemental fingerprinting index (EFI) for age-0 Baltic Sea herring nursery habitats. Developing the EFI using a suite of 17 elements was deemed essential as salinity gradients in the Baltic require a more complex methodology than using a single marker element. This technique allows for comparing multi-elemental chemical signatures from within and among juvenile habitats, allowing the authors to determine unique "fingerprints" for each bay and estuary. Heavy metals were found to drive the results. This study is the first step in establishing a baseline of juvenile habitats for future studies.

Neves *et al.* (2018) used otolith shape and stable isotopic ratios to study populations of *Spondyliosoma cantharus* from the English Channel, Bay of Biscay, Galicia, Peniche, Algarve, the Canary Islands, and Angola. Using elliptical Fourier analysis and discriminant analysis of otolith shape, 80% of individuals were correctly assigned to the area of origin, while the stable isotopic analysis and PERMANOVA conducted on $\delta^{13}C$ and $\delta^{18}O$ revealed significant differences among sites, particularly geographic outliers, but still classification rates were poor (overall classification = 50-58%). The authors also conclude that *Spondyliosoma cantharus* do not travel far from their place of origin throughout their lives based on these results and should be managed separately.

Using stable oxygen isotope assays from an Atlantic cod otoliths ($\delta^{18}O_{oto}$) form a single year class (1990), Neville *et al.* (2018) found that overwintering fish from Smith Sound, Newfoundland (1995–2006) differed from summer resident fish from Placentia Bay and Halibut Channel, but were not different from fish the Bonavista Corridor in summer. δ18Osw (‰ VSMOW) gradients on Newfoundland and Labrador shelves were used determine The Bonavista cod had oxygen signatures that suggested inshore temperature exposure and the authors believe that this provides direct evidence of metapopulation structure within these cod and that offshore rebuilding is the result of dispersal of cod from Smith Sound.

Walther (2019) reviews the progress and current state of "otolithology" and focuses on the tremendous advances in the field thanks to the advent of high-resolution chemical profiles of otoliths that have illuminated spatial heterogeneity and opened the field to more questions. He underscores that we must recognize that assumptions about environmental factors driving otolith elemental signatures are complete: both intrinsic and extrinsic factors can disrupt simple linear relationships between the environment and the otolith and we should treat chemical profiles as an "impressionistic image" of a fish's life history rather than a photograph and that we must have a "signal to noise" approach in interpretations and identifying the influences of intrinsic and extrinsic factors. In order to keep making progress in the field, Walther insists that researchers have a robust appreciation for how environmental drivers, physiological regulation, and calcification dynamics affect chemical patterns in otoliths.

References

Bouchoucha, M., Pécheyran, C., Gonzalez, J. L., Lenfant, P., and Darnaude, A. M. 2018. Otolith fingerprints as natural tags to identify juvenile fish life in ports. Estuarine, Coastal and Shelf Science, 212: 210-218.

Brown, E. J., Reis-Santos, P., Gillanders, B. M., and Støttrup, J. G. 2019. Juvenile fish habitat across the inner Danish waters: using otolith chemistry to discriminate between hybridising con-familials and contiguous, coastal habitat. Estuarine, Coastal and Shelf Science, 220: 111-119. https://doi.org/10.1016/j.ecss.2019.02.025.

Limburg, K. E., and Casini, M. 2018. Effect of marine hypoxia on Baltic Sea cod *Gadus morhua*: evidence from otolith chemical proxies. Frontiers in Marine Science, 5(482). https://doi.org/10.3389/fmars.2018.00482.

Moll, D., Kotterba, P., Jochum, K. P., von Nordheim, L., and Polte, P. 2019. Elemental inventory in fish otoliths reflects natal origin or Atlantic herring (*Clupea harengus*) from Baltic Sea juvenile areas. Frontiers in Marine Science, DOI: https://doi.org/10.3389/fmars.2019.00191.

Neves, A., Vieira, A. R., Sequeira, V., Paiva, R. B., Janeiro, A. I., Gaspar, L. M., Gordo, L. S. 2018. Otolith shape and isotopic ratio analyses as a tool to study *Spondyiosoma cantharusi* population structure. Marine Environmental Research, 143: 93-100.

Neville, V., Rose, G., Rowe, S., Jamieson, R., and Piercey, G. 2018. Otolith chemistry and redistributions of Northern cod: evidence of Smith Sound-Bonavista Corridor connectivity. Canadian Journal of Fisheries and Aquatic Sciences, 75(12): 2302-2312.

Walther, B. D. 2019. The art of otolith chemistry: interpreting patterns by integrating perspectives. Marine and Freshwater Research. https://doi.org/10.1071/MF18270.

Parasites (Contributor: Ken Mackenzie)

Five papers referring to the actual or potential use of parasites as biological tags for marine fish were published since July 2018. Three of these used selected groups of parasites as tags, while two focused specifically on *Anisakis* nematode larvae. The study areas for these papers were the south-west Atlantic (two papers), Indonesia (two papers), and South Africa. Also included in this report is a paper containing advice on best practice for studies of parasite community ecology, much of which is highly relevant to the use of parasites as biological tags.

In recent years, a number of successful parasite tag studies have been carried out on fish off the coasts of Argentina, Uruguay, and Brazil in the Southwest Atlantic. This region is characterized by the existence of different biogeographical zones, each of which is characterized by its own distinctive parasite fauna of mainly generalist parasites. The most recent studies to have been carried out in this region are those of Lanfranchi *et al.* (2018) and Canel *et al.* (2019). The former investigated the influence of confluent marine currents in a transitional zone between subtropical and sub-Antarctic currents on the distribution of larvae of four different species of the nematode genus *Anisakis*. Larvae from a fish species sampled in the transitional zone were compared with those from other species sampled from two adjacent clearly defined zoogeographical provinces. While the distribution of parasite species followed a clear zoogeographical pattern in fish from the adjacent zones, that from the transitional zone did not. The results contributed to the validation of *Anisakis* spp. larvae as biological tags in the region. The potential value of *Anisakis* larvae as biotags was also shown by Setyobudi *et al.* (2019), who investigated the occurrence of larvae of *Anisakis typica* in Indian mackerel of the genus *Rastrelliger* from the south coast of East Java, Indonesia. Prevalence and mean intensity of infection varied between different localities and from adjacent areas, indicating the potential of these nematodes as tags for stock discrimination.

Canel *et al.* (2019) used long-lived cestode, acanthocephalan and nematode larvae to study the stock structure of the demersal Argentine croaker *Umbrina canosai* from the coasts of southern Brazil to northern Argentina. Multivariate analyses of infra and component parasite communities showed clear geographical patterns confirming the existence of two discrete stocks with seasonal migrations. Their results represented a first step towards the implementation of measures for the sustainable management of this fishery.

A biotag study on a much larger geographical scale was that of Moore *et al.* (2019), who described movements of juvenile bigeye tuna, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares*, in the Indonesian archipelago. This study also included, as outliers, samples from the Maldives in the Indian Ocean and the Solomon Islands in the western Pacific. Nine long-lived parasite species (didymozoid digeneans and juvenile acanthocephalans), identified by both morphological and molecular analyses, were selected for use as biotags. Fish from the outlying areas had parasite faunas distinct from the Indonesian ones and the parasite data indicated little movement between Indonesian waters and the outlying areas. The results provided a first step in examining stock structuring of the two tuna species and indicated that juveniles of both species may have more restricted movements than is recognized under current management arrangements.

Morris *et al.* (2019) used parasite community structure as a predictor of host population structure in the Cape elephant fish or St. Joseph shark, *Callorhinchus capensis*, off the west and south coasts of South Africa. The parasite community consisted of five taxa from 259 host individuals caught between 2010 and 2015. The parasite data were used to calculate biodiversity indices, which were correlated with the host's biological data to determine how they affected the parasite community structure and provide insights into the host's population structure. The results indicated a uniform parasite community across the sampled host population with no evidence of any population structure.

Finally, an article by Poulin (2019) deplored the lack of standards in studies of parasite communities and offered some best practice guidelines for such studies. Those of particular relevance to the use of parasites as indicators of host stock structure are as follows.

- Achieve the highest possible taxonomic resolution. Many biological tag studies are based on parasites identified to only the genus or family level, which may include two or more species and can lead to misleading conclusions regarding host stock structure. With a genus comprising a number of cryptic species, the use of molecular methods of identification is essential.
- Treat intensity/abundance of infection as count variables. Many studies create arbitrary infection classes that lump together hosts with certain numbers of parasites – e.g light, moderate and heavy infections. Analysing data arranged in this way can also lead to misleading conclusions, so it is recommended that actual counts of parasites be used and analysed using appropriate statistical tools.
- Choose the analytical approach that best suits the hypothesis. Biotag studies frequently include the use of a variety of different methods of analysing the data, some of which may be irrelevant to the hypothesis being addressed. The recommendation is to test explicit hypotheses with only the most relevant and appropriate analytical tools.

References

Canel, D., Levy, E., Soares, I.A., Braicovich, P.E., Haimovici, M., Luque, J.L. and Timi, J.T. (2019). Stocks and migrations of the demersal fish Umbrina canosi (Sciaenidae) endemic from the subtropical and temperate Southwestern Atlantic revealed by its parasites. Fisheries Research 214, 10-18.

Lanfranchi, A.L., Braicovich, P.E., Cantatore, D.M.P., Irigoitia, M.M., Farber, M.D., Taglioretti, V. and Timi, J.T. (2018). Influence of confluent marine currents in an ecotonal region of the South-West Atlantic on the distribution of larval anisakids (Nematoda: Anisakidae). Parasites and Vectors 11:583. https://doi.org/10.1186/s13071-018-3119-7.

Moore, B.R., Lestari, P., Cutmore, S.C., Proctor, C. and Lester, R.J.G. (2019). Movement of juvenile tuna deduced from parasite data. ICES Journal of Marine Science. doi:10.1093/icesjms/fsz022.

Morris, T.C., van der Ploeg, J., Awa, S.B., van der Lingen, C.D. and Reed, C.C. (2019). Parasite community structure as a predictor of host population structure: An example using Callorhinchus capensis. IJP: Parasites and Wildlife 8, 248-255.

Poulin, R. (2019). Best practice guidelines for studies of parasite community ecology. Journal of Helminthology 93,8-11.

Setyobudi, E., Rohmah, I., Syarifa, R.F., Ramatia, L., Murwantoko and Sari, D.W.K. (2019). Presence of Anisakis nematode larvae in Indian mackerel (Rastrelliger spp.) along the Indian Ocean southern coast of East Java, Indonesia. Biodiversitas 20, 313-319.

Simulation modelling approaches (Contributor: Steve Cadrin)
Interdisciplinary approaches (Contributor: Lisa Kerr)

SIMWG Review of Relevant Published Theme Set (Contributor D. Secor)

Plugging spatial ecology into sustainable fisheries and EBM (2019)

ICES JMS Volume 76, Issue 2

A special theme series, published 2019 in ICES JMS (Vol. 76, issue 2) resulted from a session held in 2017 at the Fort Lauderdale Florida ASC. Although the heat and humidity at the session was unwelcome, the diversity of applications, new ideas, and depth of perspective communicated during the session and captured within the series was a breath of fresh air and most relevant to the work of the ICES SIMWG.

The series comprised 11 papers that fully flexed state-of-the-art approaches and perspectives on the spatial ecology of mobile species. Several themes were apparent:

1. Continued effort to understand this decade(s) of new capabilities in movement/migration ecology

In the overview paper, *Preparing for the future…* Lowerre-Barbiera, Catalán *et al.* conduct a visioning experiment about how spatial ecology advances in 20 years' time will contribute to EBM. They identify three themes: (1) new data streams from fishers, genomics, remote sensing, and biologging; (2) capacity to analyze these data streams through "big data" approaches; and (3) better integration of social dimensions. I think they squarely hit the head in this prospectus on the first two themes, ones that we developed in our ICES series on seascape ecology (Hidalgo *et al.* 2017), but the social dimension was oddly divorced from the spatial dynamics of fisheries and human behaviours in the review. Indeed, the 2018 ASC contained a session on the topic of joint spatial dynamics of fisheries and fished populations.

In a second review paper (a Quo Vadimus contribution by Lowerre-Barbiera, Kays, *et al.*) "ocean's movescape" is coined along with the pronouncement that this is the decade of bio-logging. Here, Nathan's mechanistic movement ecology paradigm is promoted as means to scale up drivers of individual behaviour to population outcomes. The authors are far more optimistic than I am in my coverage of the same topic in *Migration Ecology of Fishes* (2015). Examination of their Table 2 exhibits the difficulty as one must take a large conceptual leap from individual movement behaviours to fisheries yield, climate effects, multi-species interactions. There are simply too many intervening collective behaviours - well represented in the series that occur at aggregation (Lowerre-Barbieri, Tringali *et al.*; Nikolioudakis *et al.*; Reglero *et al.*), and contingent (Alós *et al.*; MaCall *et al.*; de Pontual *et al.*) levels. Figure 2, milestones in fisheries science conceptual models associated with stock structure, is well worth a look and possible adoption (with attribution) in student course work or talks to the public (although it missed our WG's two thematic books on the topic of stock identification!).

2. Ever-increasing feasibility and power of dynamic seascape investigations

Movement and migration responses are coupled with numerical ocean models to understand Mediterranean bluefin tuna spawning behaviours (Reglero *et al.*), applying state space models to estimate geolocations and depths of European sea bass (de Pontual *et al.*), and evaluating evacuation responses by reef fish to hurricanes (Secor *et al.*).

3. Modelling advances in plugging spatial behaviours into stock assessments

The series benefits from two very successful examples of advances in the use of modelling to simulate the possible roles of individual and social behaviours in fished populations. Alós *et al.* (2019) simulates spatial ecotypes by causing a more mobile-active contingent to also exhibit higher catchability, resulting in hyperdepletion, similar to some patterns of fisheries development. MacCall *et al.* picks up on the entrainment (adopted migration) idea that our WG has wrestled with in the past. Like Alós *et al.* and an earlier treatment on the subject (Secor *et al.* 2009) they show that incorporating social behaviours can destabilize populations against exploitation.

4. Multi-disciplinary approaches

Most papers in the series benefitted from multiple approaches, often by linking empirical and modelling approaches (see comments on dynamic seascape approaches). Still, the epitome was achieved by Lowerre-Barbieri, Tringali *et al.* whose cornucopia included purse seine sampling, aerial survey, genetic-tagged mark recapture, and acoustic telemetry to better understand the stability of aggregations and the proper scales to estimate abundances of spawning red drum, back where all this started – hot and humid Florida.

In summary, this nice cross-section of studies on spatial ecology merits skimming titles and approaches. Alós *et al.* and MacCall *et al.* best aligned with the theme of plugging spatial ecology into sustainable fisheries. Lowerre-Barbiera *et al.*'s prophecy of EBM goals being aided by bio-logging, big data, and multi-disciplinary approaches is well conceived. Still, moving from the exciting new discoveries during this bio-logging decade to their application to sustainable fisheries and EBM will require increased attention to how integrative models can wed dynamic seascapes, population dynamics, and fishery behaviours.

References

Alós, J., A. Campos-Candela, and R. Arlinghaus. 2019. A modelling approach to evaluate the impact of fish spatial behavioural types on fisheries stock assessment. Ices Journal of Marine Science 76(2):489-500.

Arechavala-Lopez, P., M. Minguito-Frutos, G. Follana-Berna, and M. Palmer. 2019. Common octopus settled in human-altered Mediterranean coastal waters: from individual home range to population dynamics. Ices Journal of Marine Science 76(2):585-597.

de Pontual, H., and coauthors. 2019. New insights into behavioural ecology of European seabass off the West Coast of France: implications at local and population scales. Ices Journal of Marine Science 76(2):501-515.

Hidalgo, M., D.H. Secor, and H.I. Browman. 2016. Observing and managing seascapes: linking synoptic oceanography, ecological processes, and geospatial modelling. ICES Journal of Marine Science 73: 1825-1830

Lowerre-Barbieri, S. K., I. A. Catalan, A. F. Opdal, and C. Jorgensen. 2019. Preparing for the future: integrating spatial ecology into ecosystem-based management Introduction. Ices Journal of Marine Science 76(2):467-476.

Lowerre-Barbieri, S. K., R. Kays, J. T. Thorson, and M. Wikelski. 2019. The ocean's movescape: fisheries management in the bio-logging decade (2018-2028). Ices Journal of Marine Science 76(2):477-488.

Lowerre-Barbieri, S. K., and coauthors. 2019. Assessing red drum spawning aggregations and abundance in the Eastern Gulf of Mexico: a multidisciplinary approach. Ices Journal of Marine Science 76(2):516-529.

MacCall, A. D., and coauthors. 2019. A heuristic model of socially learned migration behaviour exhibits distinctive spatial and reproductive dynamics. Ices Journal of Marine Science 76(2):598-608.

Nathan, R. 2008. An emerging movement ecology paradigm. Proceedings of the National Academy of Sciences of the United States of America, 105: 19050–19051.

Nikolioudakis, N., and coauthors. 2019. Drivers of the summer-distribution of Northeast Atlantic mackerel (Scomber scombrus) in the Nordic Seas from 2011 to 2017; a Bayesian hierarchical modelling approach. Ices Journal of Marine Science 76(2):530-548.

Reglero, P., and coauthors. 2019. Pelagic habitat and offspring survival in the eastern stock of Atlantic bluefin tuna. Ices Journal of Marine Science 76(2):549-558.

Secor, D.H. 2015. Migration Ecology of Marine Fishes. Johns Hopkins University Press. 304 p.

Secor, D.H., Kerr, L.A. and Cadrin, S.X. 2009. Connectivity effects on productivity, stability, and persistence in an Atlantic herring metapopulation. ICES J. Mar. Sci. 66: 1726-1732

Secor, D. H., F. Zhang, M. H. P. O'Brien, and M. Li. 2019. Ocean destratification and fish evacuation caused by a Mid-Atlantic tropical storm. ICES Journal of Marine Science 76(2):573-584.

Annex 5: ToR b) Provide technical reviews and expert opinions on matters of stock identification, as requested by specific Working Groups and SCICOM

Evaluation of European Sardine Stock Identity

ECOREGIONS: Celtic Seas Ecoregion, Greater North Sea Ecoregion, and Bay of Biscay and the Iberian Coast Ecoregion

ICES STOCK(S): Three stock units: 1) Subarea 7 (Southern Celtic Seas, English Channel); 2) divisions 8.a–b and 8.d (Bay of Biscay); 3) divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

SIMWG FINDINGS: SIMWG does not find strong evidence for splitting the previously termed northern stock into two stock areas (Subarea 7 (Southern Celtic Seas, English Channel), 2) divisions 8.a–b and 8.d (Bay of Biscay). The primary justification for splitting 7 from 8abd is that there have been different (recent) exploitation histories and different growth rates between the areas. However, there is no evidence for genetic differences and there is no information on connectivity between the Bay of Biscay and English Channel/Celtic Sea. We recommend other ways of accounting for regional differences in exploitation patterns and growth rates (e.g., regionally dis-aggregated expansion of fishery samples to produce an aggregate catch and catch at age for a combined-area assessment, or a spatially structured stock synthesis model).

Background

SIMWG was asked by members of the Workshop on Atlantic sardine (WKSAR) to provide feedback on issues of stock identity of European sardine (*Sardina pilchardus*). SIMWG was specifically requested to review and provide comments on section 3 of the WKSAR report entitled *Review of the available information on sardine stock identification, connectivity and migrations*, as well as newly published information on the topic (e.g., Garrido *et al.* 2017, Santos *et al.* 2018).

In the 2017 benchmark assessment, WGHANSA proposed a revision to the management units of European sardine from two stocks (northern and southern) to three stock units with the northern stock split into 2 components between Bay of Biscay and English Channel/Celtic Sea.

Previous ICES stock units (2017):

1. Northern stock (ICES subareas 7, and divisions 8.a–b and 8.d)
2. Southern stock (ICES divisions 8.c and 9.a)

Revised ICES stock units:

1. European sardine in subarea 7 (Southern Celtic Seas, English Channel)
2. European sardine in divisions 8.a–b and 8.d (Bay of Biscay)
3. European sardine in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

However, there was uncertainty regarding the biological support for this stock structure, notably the amount of population mixing between area 8 and 7, the magnitude of inflow of individuals from the Bay of Biscay to the English Channel in comparison to some evidence of self-sustained patch of population in the English Channel.

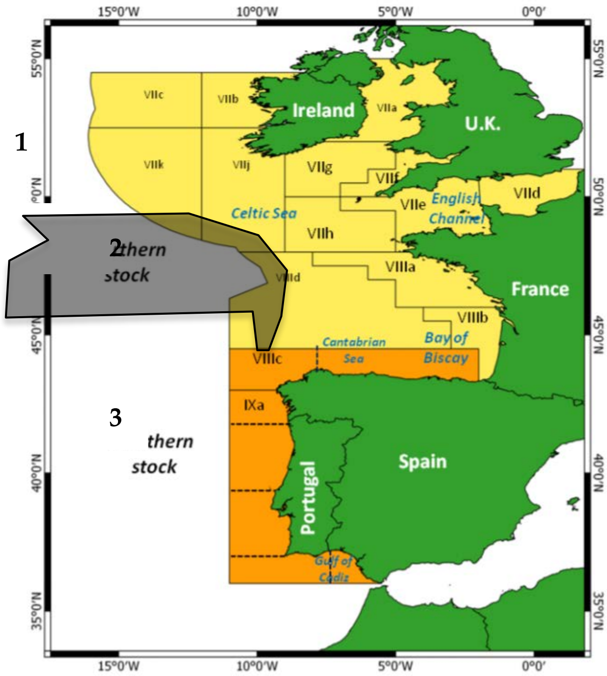


Figure 1. Revised ICES stock units: 1) European sardine in subarea 7 (Southern Celtic Seas, English Channel), 2) European sardine in divisions 8.a–b and 8.d (Bay of Biscay), 3) European sardine in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters).

Genetics

There have been two recent applications of genetics that encompass the stocks in question (Kasapidis *et al.* 2012, 2014). In these studies, four genetic stocks were identified based on areas of discontinuity (Kasapidis *et al.* 2012, 2014): 1) an African stock, 2) a northeast Atlantic stock, 3) a Mediterranean stock, and 4) Azores and Madeira stock. Overall the findings from these studies suggest that there is no genetic structure evident throughout the range of the current three ICES management units for sardine. Although the suite of genetic markers used was rather inadequate to tackle such an issue, all regions in question grouped together in the middle as a northeast Atlantic stock based on genetic analysis (Figure 2). While we expect more powerful sets of markers to be more informative, there is no evidence to date to suggest substructure within the ICES regions in question.

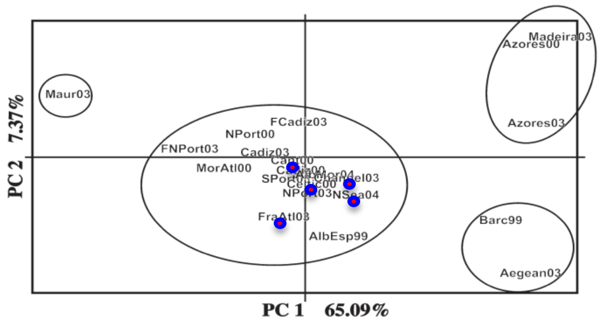


Figure 2. Figure from Kasapidis *et al.* (2012) illustrating results of principal component a*nalysis of all 21 samples of sardine* used in study for 5 polymorphic microsatellite loci. Groupings refer to the inferred stocks of sardine.

Growth

Silva *et al.* (2008) showed a general pattern of increasing growth with latitude with higher growth observed in the northern Iberia and Biscay waters and smaller lengths-at-age observed in fish off western Portuguese waters and Cadiz. Furthermore, information from the ICES WKSAR workshop (ICES, 2016) suggests higher growth rates for the populations of the English Channel and Celtic sea than for the Bay of Biscay, but it is unknown if this results from different oceanographic conditions or from population characteristics. An update by Citores *et al.* 2016 generally agreed with Silva *et al.* (2008), but this recent review of growth by regions also suggested there have been changes in growth patterns over time.

Body Morphometrics

Silva (2003) and Silva *et al.* (2012) provide morphometric analysis relevant to this question. Silva 2003 provided evidence for two sardine morphotypes: 1) southern Iberia (Gulf of Cadiz) and northern Morocco, and 2) Atlantic areas and Mediterranean Sea (Silva 2003). Expanded sampling in Silva *et al.* 2012 provided evidence of 1) differentiation between Atlantic and Mediterranean sardine at the Gibraltar Strait, 2) limited differentiation of North Sea from northeast Atlantic areas, 3) and no significant difference in the remaining northeast Atlantic areas. Although some structure is evident from body morphometric analysis, the differences do not support a morphometric break at the northwestern corner of the Iberian peninsula or provide strong support for northern and southern stock delineation.

Otolith Morphometrics

Jemaa *et al.* (2015a) looked at sardine (*Sardina pilchardus*) from the French Atlantic coast to Morocco, and in the Mediterranean. Three distinct groups were identified : Group A: northern Mediterranean Sea and Gulf of Gabès; group B: Atlantic Morocco–south Alboran–Algeroprovençal coasts; and group C: European Atlantic coast. These results do not support a break at the northwestern corner of the Iberian peninsula or provide strong support for northern and southern stock delineation

Otolith Microchemistry

Castro (2007) applied otolith chemistry to understand sardine stock structure with sampling focused within the southern stock areas (Bay of Biscay, northern Iberian Peninsula, and Gulf of Cadiz) and found differentiation among areas for fish of the smallest size classes and that discrimination between areas decreased with increasing size groups .The results are interpreted in terms of a net balance of migration of large sardine from Northern Portugal to towards Bay of

Biscay and Gulf of Cádiz. This study suggests sardine movements are significant in terms of population numbers, the existence of a single sardine stock in Atlanto-Iberian waters would be supported.

Correia *et al.* (2014) applied otolith chemistry to understand connectivity along the Portuguese coast and found that over 80% of the adults of the 2004 cohort collected in Portuguese -Cadiz waters came from the northern recruitment area. The authors concluded that while adult life stages may be derived from a common juvenile nursery area they seem to form regionally distinct adult groups with limited mixing. The results support the hypothesis of meta-population structure of the sardine stock in the Atlanto-Iberian waters. However, because of mixing among adult aggregations, and adult aggregations were largely derived from a common northern juvenile recruitment area, they cannot be classified as entirely separate stock units for fisheries management purposes.

Overall, the otolith chemistry studies reviewed by WKSAR provide broad-scale insights on population structure, but did not have sampling at the spatial scale (i.e. Southern Celtic Seas, English Channe, Bay of Biscay) that would allow for evaluation of the appropriateness of the revised stock boundary.

Oceanographic life cycle retention

Sardine population structure is influenced by larval retention/dispersal mechanisms, which relate to dominant ocean circulation features. There are limited number of studies that have related oceanographic conditions and dispersal and survival of early life stages. Santos *et al.* 2004 demonstrated a retention mechanism for sardine larvae off western Iberia in winter. In more recent work, Santos *et al.* (2018) used simulation modelling to examine larval dispersal of sardine in the Iberian upwelling system. Overall, the modelling revealed a high degree of retention along the western Iberian coastline and generally low transport of larvae between neighbouring regions. A substantial level of connectivity was found between northwest Iberian spawning areas and recruitment zones to the north (i.e., Galicia and the Cantabrian coast), and low-level transport to the south (i.e., Morocco) and east (i.e., the Mediterranean). Overall the study suggests that sardines along the Iberian Peninsula exist as a series of interacting, but spatially-separated subpopulations (i.e., metapopulations). The low-level connectivity that exists could maintain sufficient genetic flow between Iberian subpopulations and sustain demographic connectivity. The recent PELTIC surveys demonstrate the presences of all life stages of sardine (eggs, larvae, recruits and adults) in the English Channel which could be and indicator that this is a self-sustaining population. Unfortunately, there is no information on connectivity between the Bay of Biscay and English Channel/Celtic Sea. Further research addressing the influence of the major oceanographic features on sardine early life stage dispersal and connectivity are needed.

Catch Trajectories

The stock annex (pil.27.8abs_SA) includes 'different historical exploitation patterns' and part of the justification for splitting the Celtic Seas-English Channel (area 7) from the Bay of Biscay (area 8abd). However, inspection of the landings series (Figure 2) suggests that historical exploitation patterns were quite similar between the Celtic Seas-English Channel (area 7) and the Bay of Biscay (area 8abd), reflecting a period of growth from 1983 to 2006 in both areas. However, landings trends from the two areas diverged in the last decade, continuing to increase in the Bay of Biscay (area 8abd) and declining from 2006 to 2014 in the Celtic Seas-English Channel (area 7). In the context of regional landings, the sardine fishery was dominated by Iberian waters (area 8c-9) until 2011, but landings the Bay of Biscay (area 8abd) were greater than those from Iberian waters (area 8c-9) in the most recent year (2015).

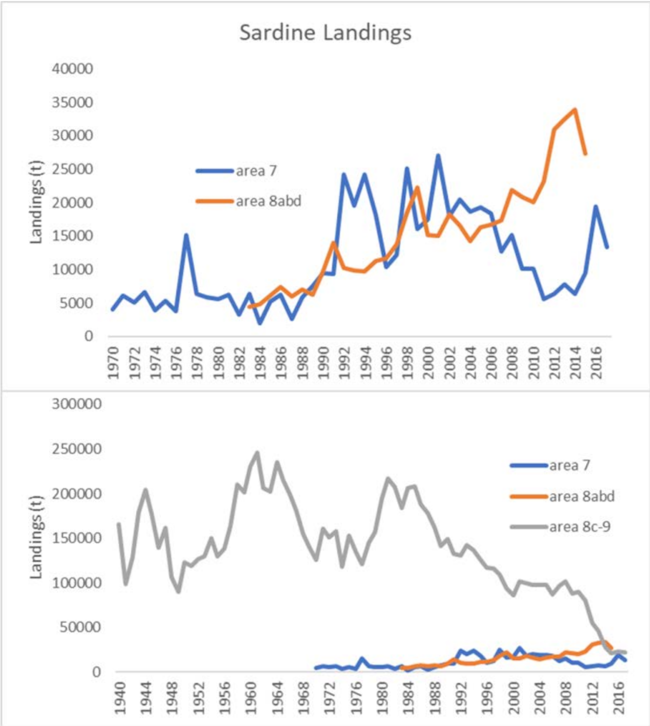


Figure 2. Sardine landings from the Celtic Seas and English Channel (area 7), from the Bay of Biscay (area 8abd) and from Iberian waters (area 8c-9).

Conclusions and Recommendations

The working document by WKSAR provides a comprehensive review of the available information on stock structure of European sardine. SIMWG does not find strong evidence for splitting the previously termed northern stock into two stock areas (Subarea 7 (Southern Celtic Seas, English Channel), 2) divisions 8.a–b and 8.d (Bay of Biscay). The primary justification for splitting 7 from 8abd is that there have been different (recent) exploitation histories and different growth rates between the areas. However, there is no evidence for genetic differences. Furthermore, studies addressing the influence of the major oceanographic features on sardine early life stage dispersal and connectivity are needed to address this question of stock structure.

We recommend other ways of accounting for regional differences in exploitation patterns and growth rates (e.g., regionally dis-aggregated expansion of fishery samples to produce an aggregate catch and catch at age for a combined-area assessment, or a spatially structured stock synthesis model). Furthermore, SIMWG is not certain that the previous stock structure (north, south) is well supported. Ongoing genetics may help to resolve this issue and SIMWG recommends the review of this new research prior to the next benchmark for a decision on this topic.

References

Castro, B.G. 2007. Element composition of sardine (Sardina pilchardus) otoliths along the Atlantic coast of the Iberian Peninsula. ICES J. Mar. Sci., 64, 512–518

Correia AT, Hamer P, Carocinho B, Silva A. 2014. Evidence for meta-population structure of Sardina pilchardus in the Atlantic Iberian waters from otolith elemental signatures of a strong cohort. Fisheries Research, 149: 76–85.

Garrido S, Cristóvão A, Caldeira C, Ben-Hamadou R, Baylina N, Batista H, Saiz E, Peck MA, Ré P, Santos AMP. 2017. Effect of temperature on the growth, survival, development and foraging behaviour of Sardina pilchardus larvae. Mar Ecol Progr Ser in press (doi: 10.3354/meps11881).

ICES. 2016. Report of the Workshop on Atlantic Sardine (WKSAR), 26–30 September 2016, Lisbon, Portugal. ICES CM 2016/ACOM:41. 351 pp

Jemaa, S., Bacha, M., Khalaf, G., Dessailly, D., Rabhi, K., and Amara, R. 2015a. What can otolith shape analysis tell us about population structure of the European sardine, Sardina pilchardus, from Atlantic and Mediterranean waters? Journal of Sea Research. 96: 11–17.

Kasapidis P. 2014. Chapter 2. Phylogeography and population genetics. In: Ganias K. (Ed.), Biology and Ecology of Sardines and Anchovies, CRC Press, 375 pp, February 2014.

Kasapidis P, Silva A, Zampicinini G, Magoulas A. 2012. Evidence for microsatellite hitchhiking selection in European sardine (Sardina pilchardus) and implications in inferring stock structure. Scientia Marina, 76, 123–132.

Santos, A.M.P., Peliz, A., Dubert, J., Oliveira, P.B., Angelico, M.M., Re´, P. 2004. Impact of a winter upwelling event on the distribution and transport of sardine eggs and larvae off Western Iberia: a retention mechanism. Continental Shelf Research 24, 149–165.

Silva A. 2003. Morphometric variation among sardine (Sardina pilchardus) populations from the Northeastern Atlantic and the western Mediterranean. ICES J. Mar. Science, 60: 1352–1360.

Silva, A., Carrera, P., Massé, J., Uriarte, A. D., Santos, M. B., Oliveira, P. B., Soares, E., *et al.* 2008. Geographic variability of sardine growth across the Northeastern Atlantic and the Mediterranean Sea. Fisheries Research, 90: 56–69.

Silva A, Kasapidis P, Laurent V, Caneco B, Planes S, Magoulas A. 2012. Integrating genetic and morphometric variation in sardine, Sardina pilchardus (Walbaum, 1792) from the Northeastern Atlantic and the Mediterranean Sea. In: S. Garcia, M. Tandstad and A.M. Caramelo, eds. Science and Management of Small Pelagics. FAO Fisheries and Aquaculture Proceedings, No. 18, 606 pp.

List of participants	
Name	Email
Steve Cadrin	scadrin@umassd.edu
Lisa Kerr (Chair)	lkerr@gmri.org
Stefano Mariani	s.mariani@salford.ac.uk
Zachary Whitener	zwhitener@gmri.org

Evaluation of Beaked redfish stock affiliation on the East Greenland slope

ECOREGIONS: Greenland Sea and Icelandic Waters

ICES STOCK(S): Beaked redfish (*Sebastes mentella*) in Division 14.b, demersal (Southeast Greenland) and Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds)

SIMWG FINDINGS: SIMWG does not recommend a combined assessment of beaked redfish along the east Greenland slope with the Icelandic slope. Furthermore, more precautionary management should be considered in managing the mixed fishery

Background

SIMWG received a request from the North Western Working Group (NWWG) to review beaked redfish (*Sebastes mentella*) stock affiliation on the East Greenland slope. In 2009, ICES reviewed the stock structure of beaked redfish, *S. mentella* in the Irminger Sea and adjacent waters (WKREDS). They recognised that there are three biological stocks of *S. mentella* in the Irminger Sea and adjacent waters: 'Deep Pelagic'; 'Shallow Pelagic'; and 'Icelandic Slope'. This separation of the stocks did not include *S. mentella* on the Greenland continental slope. ICES decided that NWWG should conduct a separate assessment for *S. mentella* in subarea 14.b until further information was available to assign stock origin. Since 2009, further studies on stock structure and species separation have been conducted. Based on this new information NWWG recommended that the separation of *S. mentella* on the Icelandic and Greenlandic slopes be revised and the possibility of a joint assessment of *S. mentella* on the Icelandic and Greenlandic slopes be evaluated. NWWG requested SIMWG review of this issue of stock identification.

Review of new genetic information

The recent work by Saha *et al.* (2017) sheds light on the stock structure of beaked redfish (*S. mentella*) in the Eastern Greenland region. SIMWG looked at the evidence to inform whether *S. mentella* in this area may be assessed together with the previously identified demersal Icelandic slope stock, rather than separately as it currently is.

Neutral genetic markers clearly identify the existence of all three main *S. mentella* populations mixing along the East Greenland slope: survey and commercial samples show large spatial overlap of Icelandic slope, deep and shallow *S. mentella* over a period of two years. There is no area where only Icelandic slope fish can be found, which makes it impossible and incorrect to pool this region with the Icelandic slope assessment.

Such extensive overlap poses a significant challenge even to the assessment of the fishery in the East Greenland slope specifically: Only at the very northernmost end of the region, there seems to be the presence of a homogeneous genetic unit, but this belongs to the 'deep' *S. mentella* and primarily includes juvenile fish. Throughout the rest of the area, stock composition should be assessed through genetic assignment and the catches partitioned to their respective stocks of origin, which of course entails a significant effort. The presence of young 'deep' fish (<20mm TL) throughout Eastern Greenland indicates that this area may be important as nursery for this very vulnerable stock; thus advice should be very precautionary and follow a weakest-link approach. Given the current prevalence of 'deep' beaked redfish in the area, catches should be in line with that stock's advice.

Conclusions and Recommendations

Neutral genetic markers provide evidence of all three main *S. mentella* populations mixing along the East Greenland slope. Furthermore, there is no area where only Icelandic slope fish can be found, making it inappropriate to pool this region with the Icelandic slope assessment. Only at the very northernmost end of the region, there seems to be the presence of a homogeneous genetic unit, but this belongs to the 'deep' *S. mentella* and primarily includes juvenile fish. Throughout the rest of the area, stock composition should be assessed through genetic assignment and the catches partitioned to their respective stocks of origin, which of course entails a significant effort. The presence of young 'deep' fish (<20mm TL) throughout Eastern Greenland indicates that this area may be important as nursery for this very vulnerable stock; thus advice should be very precautionary and follow a weakest-link approach. Given the current prevalence of 'deep' beaked redfish in the area, catches should be in line with that stock's advice.

SIMWG does not recommend a combined assessment of beaked redfish along the east Greenland slope with the Icelandic slope. Furthermore, more precautionary management should be considered in managing the mixed fishery.

References

Saha A, Johansen T, Hedeholm R, Nielsen EE, Westgaard JI, Hauser L, Planque B, Cadrin SX, Boje J. 2017. Geographic extent of introgression in *Sebastes mentella* and its effect on genetic population structure. Evolutionary Applications 10: 77–90.

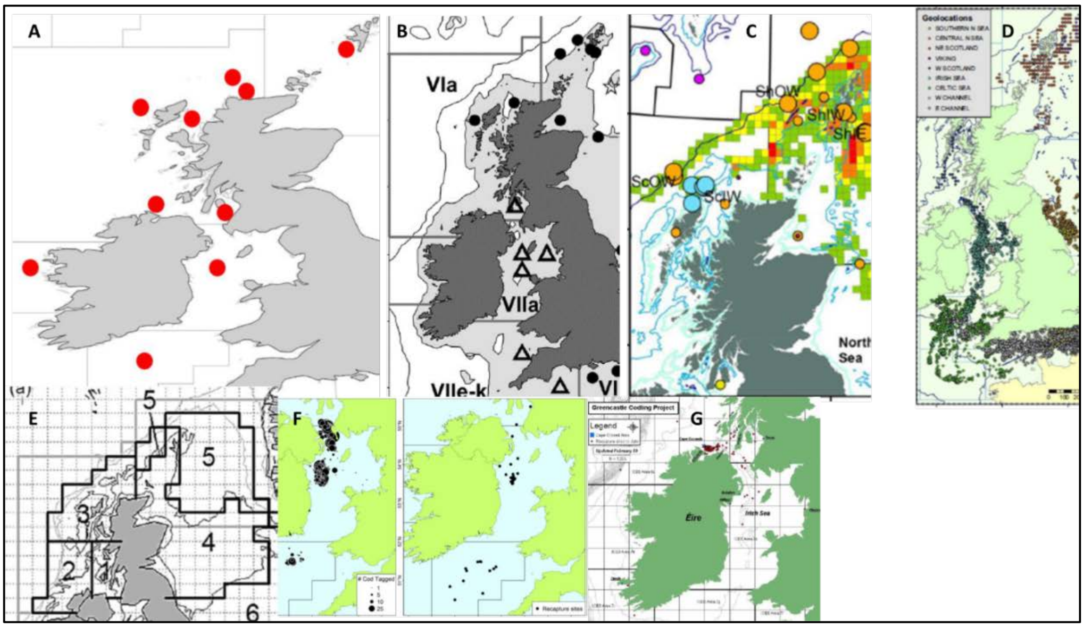
Evaluation of Proposed Stock Identification Study on Cod in ICES area 6A

Representatives of the North Western Waters Advisory Council (NWWAC) attended the MIACO (Meeting between ICES, Advisory Councils and other Observers) in Copenhagen on 19th January 2018. MIACO participants are organizations and individuals which hold observer status at ICES, including representatives from EU Advisory Councils, fishing organizations, and environmental NGOs. During the meeting, the NWWAC stated that it is looking into the options for a genetic study, financed mainly by the industry, on cod and whiting in the West of Scotland – North Sea area to determine the genetic association of the stocks in these areas. The NWWAC mentioned that they would like the support of ICES and relevant scientists for this project as the results could provide a direct input to the assessments, which could require an update, as a result. ICES welcomed the proposed work on genetic identification of stocks and recommended that the NWWAC could engage with the ICES working group on stock identification methods (SIMWG). SIMWG reviewed a proposal titled "Atlantic Cod (*Gadus morhua*) Stock identification In ICES area 6a" by Edward Farrell and Peter Wright.

SIMWG appreciates the opportunity to provide feedback on the proposed methodology for this proposal, because this request is directly relevant to the role of SIMWG in the ICES Science and Advisory process. In general, the proposal is well developed, with a strong problem statement, a concise but relatively comprehensive literature review, clearly stated objectives, a technically sound approach, a well-qualified team of scientists, and a promising partnership with the fishing industry. SIMWG offers some recommendations that we think would improve the study for consideration by the principal investigators, supporting industry groups and ICES:

1. The proposed research is appropriately focused on stock identity of cod west of Scotland (ICES Area Via) but also considers and connectivity with the North Sea, Irish Sea, Celtic Sea and west of Ireland. Therefore, we suggest that the title should be revised to "Atlantic Cod (*Gadus morhua*) Stock identification In ICES area 6a <u>and adjacent areas</u>".
2. SIMWG agrees with the problem statement that "Whilst delineation by management area may be more convenient for management and regulation purposes, accurately assessing the status, biomass and sustainable exploitation rates of mixed 'stocks' is inherently difficult if not impossible as they do not correspond to biological units." Furthermore, we suggest that understanding population structure is essential for managing the recovery of cod stocks and fisheries.
3. The proposed research is expected to address the first three 'key questions' (Are there multiple biological populations within 6a? Can they be discriminated genetically? Are they different from adjoining areas?). The fourth 'key question' (Do the stock boundaries between 4a and 6a and between 7a and 6a reflect population boundaries?) may not be definitively addressed with the proposed research, but the proposed research will be an important step toward answering the question and determining what information is needed to do so.
4. In the Golden Age of interdisciplinary stock identification, the EC made substantial investments in multi-organizational research projects (e.g., HOMSIR, REDFISH, HERGEN, WESTHER, METACOD, SARDYN, …) to address questions like the ones posed in the proposal. Those investments produced practical information for fishery management as well as advances in methodological approaches and scientific contributions. We appreciate the support from industry to fund a stock identity study, and recommend that government institutes should consider providing matching funds to allow a broader, interdisciplinary and multi-organizational approach to this project. Collecting other information (length, sex, maturity stage, otolith sample) would help to provide supporting information from other approaches.

5. The proposed literature review should attempt to synthesize previous information. For example, a spatially-explicit overlay of previous sampling locations for genetics, tagging and other relevant analyses will help to refine the sampling designs for baseline and mixture sampling.



Sample locations for studying stock identity of cod in 6a and adjacent areas: A) proposed baseline samples from Farrell & Wright; B) genetic samples and groups from Heath *et al.* (2014); C) genetic samples and groups from Doyle *et al.* (2016); D) tag geoloctions from Neat *et al.* (2014); E) putative stocks from Holmes *et al.* (2014); F) cod releases (left) and recaptures (right) from the Irish Marine Institute and Northern Ireland's AFBI and G) tag reacaptures from Ó Cuaig & Officer (2007).

6. The proposal recognizes that many studies have developed genetic markers for cod that have successfully identified population structure. A bibliographic analysis shows that Atlantic Cod is the most extensively and intensively studied marine fish for genomic techniques. In this respect, the proposal appears somewhat ambiguous: on one hand, it states that a thorough preliminary search will be carried out to identify markers from the ones already available (and there are now hundreds of thousands for cod…), on the other hand, reference is made to carry out the study along the lines of an ongoing horse-mackerel study (using 80 microsatellites). SIMWG finds that – despite the advancement in generating large numbers of marker loci for cod and a few other well-studied species – the SNP panels used differs widely among studies, which makes studies difficult to compare. It would be advisable to try employing markers that proved useful in discriminating other cod stocks, so that the results of the proposed study are comparable to previous studies and results can be interpreted in the context of results from other areas. Such an effort would greatly increase the impact of the study and lay a marker of good practice for future work. Of course, this may be time consuming and would require substantial lab validation, but in the opinion of SIMWG, if an effort like this is suggested, it should be done thoroughly. The alternative would be to simply develop a panel of new microsatellites (as suggested), to be used specifically for the task at hand. It may be a valid route, but it is a very different one from the ambition of standardization/comparison approach outlined above. SIMWG recommends that this aspect of gene marker choice is fully explained and clarified, and the outcome expectations clearly spelled out.
7. SIMWG strongly supports the sampling of spawning cod for baseline samples, because non-spawning baselines have been misleading in previous studies (e.g., Wirgin *et al.*

2007) as well as the proposed sampling over multiple spawning seasons. The target sample size of 100 per putative population is generally sufficient, but SIMWG recommends that samples for each putative population be distributed throughout the spawning period (e.g., ~1/3 early, ~1/3 peak, ~1/3 late spawning season). Collaboration with fishing partners is expected to be cost-effective for catching spawning cod for baseline samples and for representing current and traditional fishing patterns in mixture samples.

References

Doyle, A., Davie, A., Wright, P., Coull, K. and Angus, C. 2016. Determination of the Distribution of the Resident Inshore and Offshore Migratory Cod Populations Around Shetland (IVa) and Westwards into VIa, Scottish Marine and Freshwater Science, 7 (28), pp. 1-32.

Heath, M. R., Culling, M. A., Crozier, W. W., Fox, C. J., Gurney, W. S. C., Hutchinson, W. F., Nielsen, E. E., *et al.* 2014. Combination of genetics and spatial modelling highlights the sensitivity of cod (*Gadus morhua*) population diversity in the North Sea to distributions of fishing. ICES Journal of Marine Science, 71: 794–807.

Holmes, S.J., Miller, C.P., Fryer, R.J. & Wright, P.J. 2014. Gadoid dynamics: differing perceptions when contrasting stock vs. population trends and its implications to management. ICES Journal of Marine Science, 71(6): 1433–1442.

Neat F.C., Bendall V., Berx B., Wright P.J., Cuaig, M.Ó., Townhill, B., Schön, P-J., Lee, J., and

Righton D. 2014. Movement of Atlantic cod around the British Isles. Journal of Applied Ecology, 51: 1564-1574.

Ó Cuaig, M. and Officer, R. 2007. Evaluation of the Benefits to Sustainable Management of Seasonal Closure of the Greencastle Codling (*Gadus morhua)* Fishery. Marine Institute Fisheries Bulletin No 27.

Wirgin, I. Kovach, A.I., Maceda, L., Roy, N.K., Waldman, J. and Berlinsky, D.L. 2007. Stock Identification of Atlantic Cod in U.S. Waters using Microsatellite and Single Nucleotide Polymorphism DNA Analyses. Transactions of the American Fisheries Society, 136: 375–391.

Evaluation of Red Gurnard Stock Identity

ECOREGIONS: Greater North Sea, Celtics Seas, Faroes, Biscay

ICES STOCK(S): One stock unit, encompassing Subareas 3 – 8.

CORE QUESTION: Are the very different signals in the abundance series between North Sea/west of Scotland and Celtic Seas/Biscay surveys sufficient evidence that red gurnard could be assessed on this basis and considered to have separate stocks?
SIMWG FINDINGS: SIMWG does not find strong evidence for splitting the red gurnard stock into two stock areas (North Sea/west of Scotland and Celtic Seas/Biscay). Although there are different trends in abundance between the areas across surveys, it is challenging to interpret these trends without additional information. Additional understanding of seasonal and ontogenetic movements of this species is needed to more fully interpret these trends. Furthermore, there is no biological information that might allow for more in-depth assessment of stock identity between areas (e.g. genetic or phenotypic markers). We recommend further biological data collection and application of stock identification methods before any spatial management changes should be considered.

Background
SIMWG was asked by members of the Working Group on Widely Distributed Stocks (WGWIDE) to provide feedback on issues of stock identity of red gurnards (*Aspitrigla cuculus*). SIMWG was specifically requested to review and provide comments on a synthesis of the available data on stock structuring of red gurnards in Divs. 3-8 (and elsewhere) for future consideration on the stock identity and structure of this species before a new benchmark workshop is considered. The group specifically asked for consideration as to whether the very different signals in the abundance series between North Sea/west of Scotland and Celtic Seas/Biscay surveys offer sufficient evidence that they could be assessed on this basis.

Currently, red gurnards are assessed by ICES, through WGWIDE, as a single stock covering Subareas 3 – 8. The species is known to be absent from the Baltic Sea, and Icelandic and Faroese waters, and present in Spanish and Portuguese waters, however the unit of assessment does not reflect this.

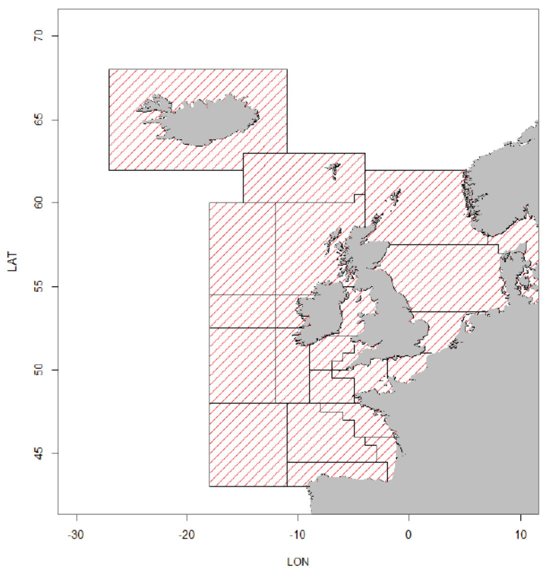


Figure 1. ICES red gurnard stock unit.

Neil Campbell, the longtime ICES coordinator for the stock, provided the SIMWG with a background document on the current state of red gurnard.

This is a species for which data is limited which presents challenges to drawing conclusions about stock structure. There is no single fishery-independent survey across the species range. In addition, fishery dependent data are limited for this species as it is commonly discarded as bycatch and large proportion of landings are recorded simple as "mixed gurnards", which also includes *Eutrigla gurnardus* and *Chelidonichthys lucerna*. Historical stock distribution of the species in the English Channel, based on fishery dependent data, was compiled by Pawson (1955) and suggested seasonal migrations but lacks evidence for any separate stocks.

Survey Trends

Based on survey trends, in 2017 two stocks were proposed to ICES WGWIDE based on distint survey trends within the North Sea (Divs. 4 and 6) and western waters (Divs. 7 and 8; WGWIDE, 2017). Standardised CPUEs series from Quarter-1 North Sea IBTS, and Quarters-1 and -4 Scottish West Coast Groundfish Surveys show a common trajectory, increasing more than four-fold between 1995 and 2013, before declining very steeply to return to near the long-term average from 2014 onwards (Figure 2). Equivalent trends were not seen in subareas 7 and 8 from the Channel and Irish Groundfish and EVHOE surveys, which varied without trend over the same period (Figure 3). This purported evidence may be indicative of separate stocks, but it is not conclusive and the data insufficient to rule out other factors affecting local abundances.

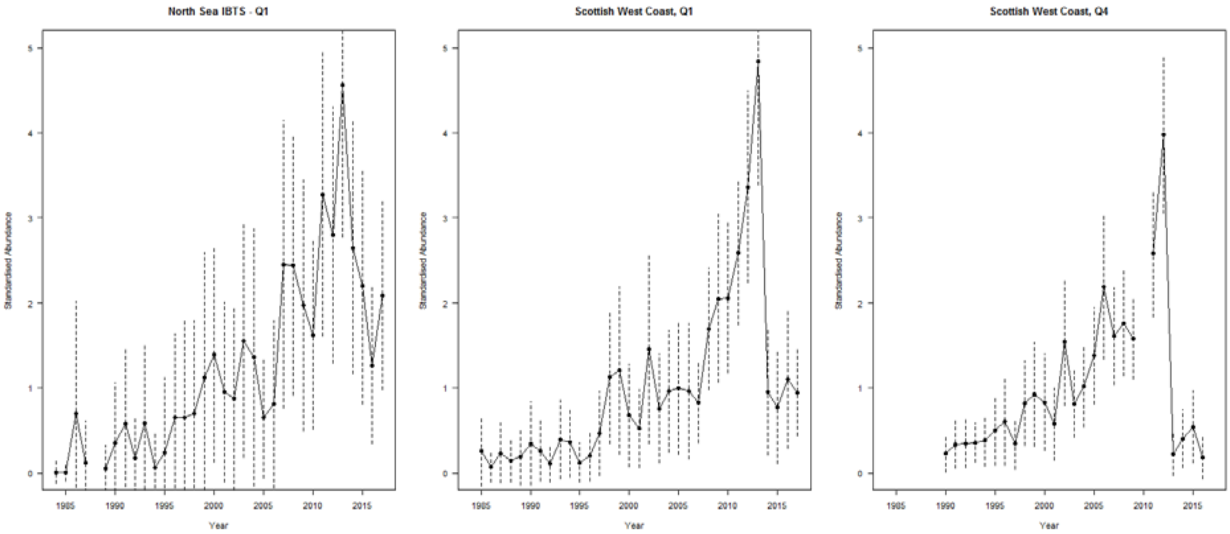


Figure 2. Standardized abundances for red gurnard from NS IBTS Q1, SCOWCGFS Q1, and Q4 series.

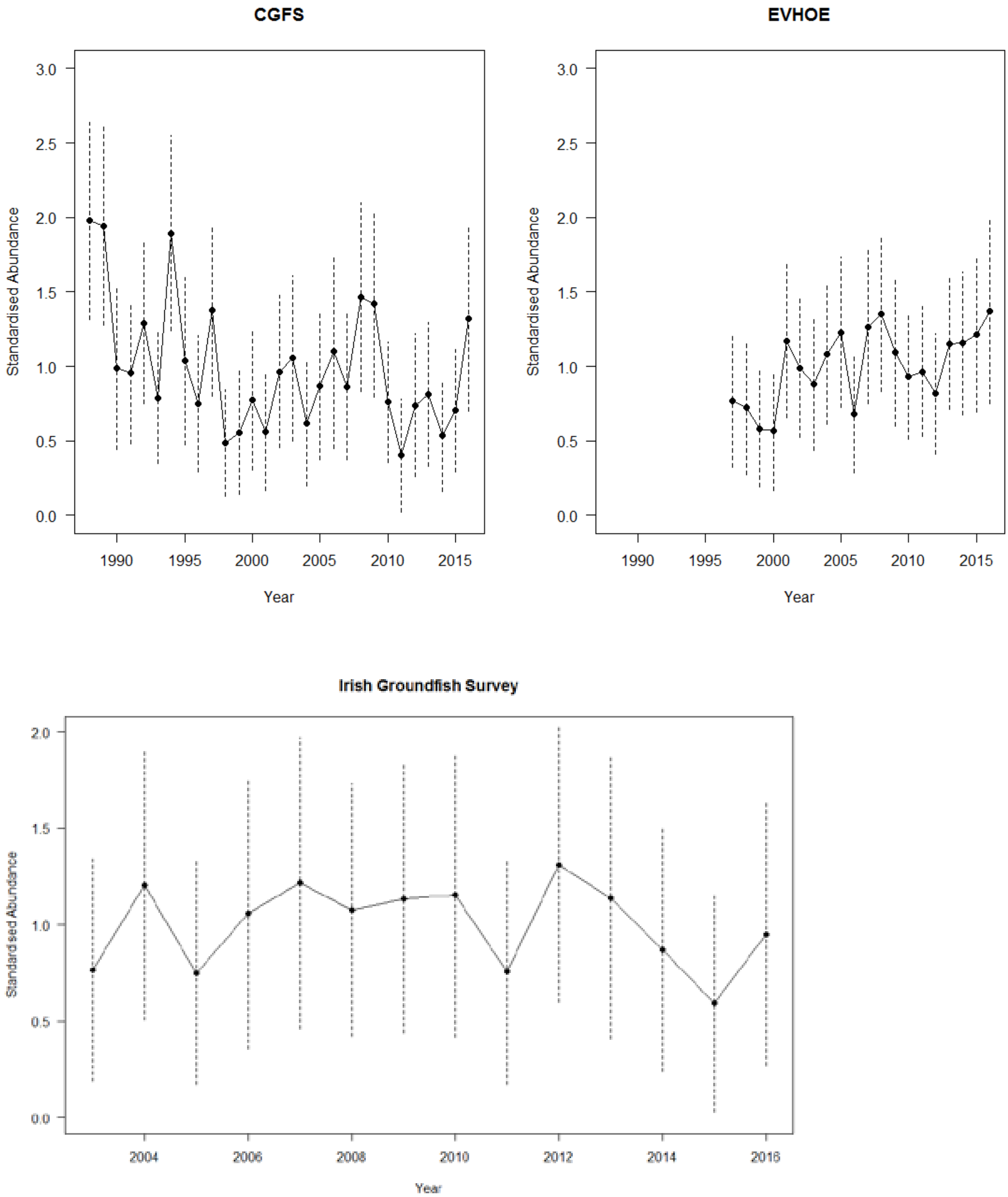
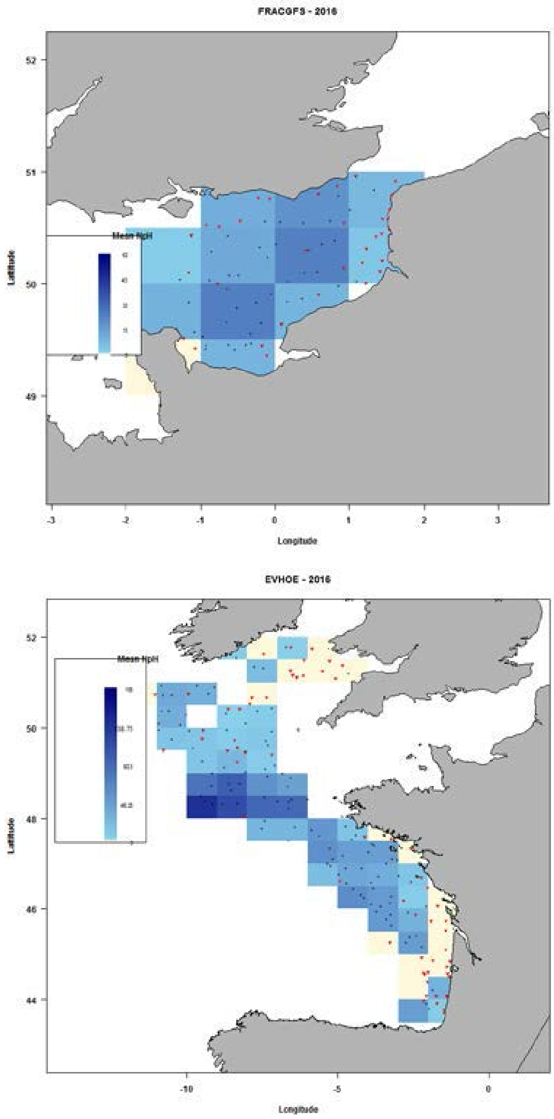


Figure 3. Standardized abundances of red gurnard from CGFS, EVHOE, and Irish GFS series (Neil Campbell, Marine Science Scotland).

Survey Distributions

The red gurnard is a widely-distributed species and as such one of the main issues with available data is that there is no single survey which captures the extent of the distribution of red gurnards, making comparisons across geographic range difficult. However, an examination of the spatial patterns in survey series does not provide evidence for stock structuring, rather only suggests areas differing relative abundance (Figure 4). Standardization and integration of data across surveys would provide a more comprehensive picture of the distribution of red gurnard biomass.



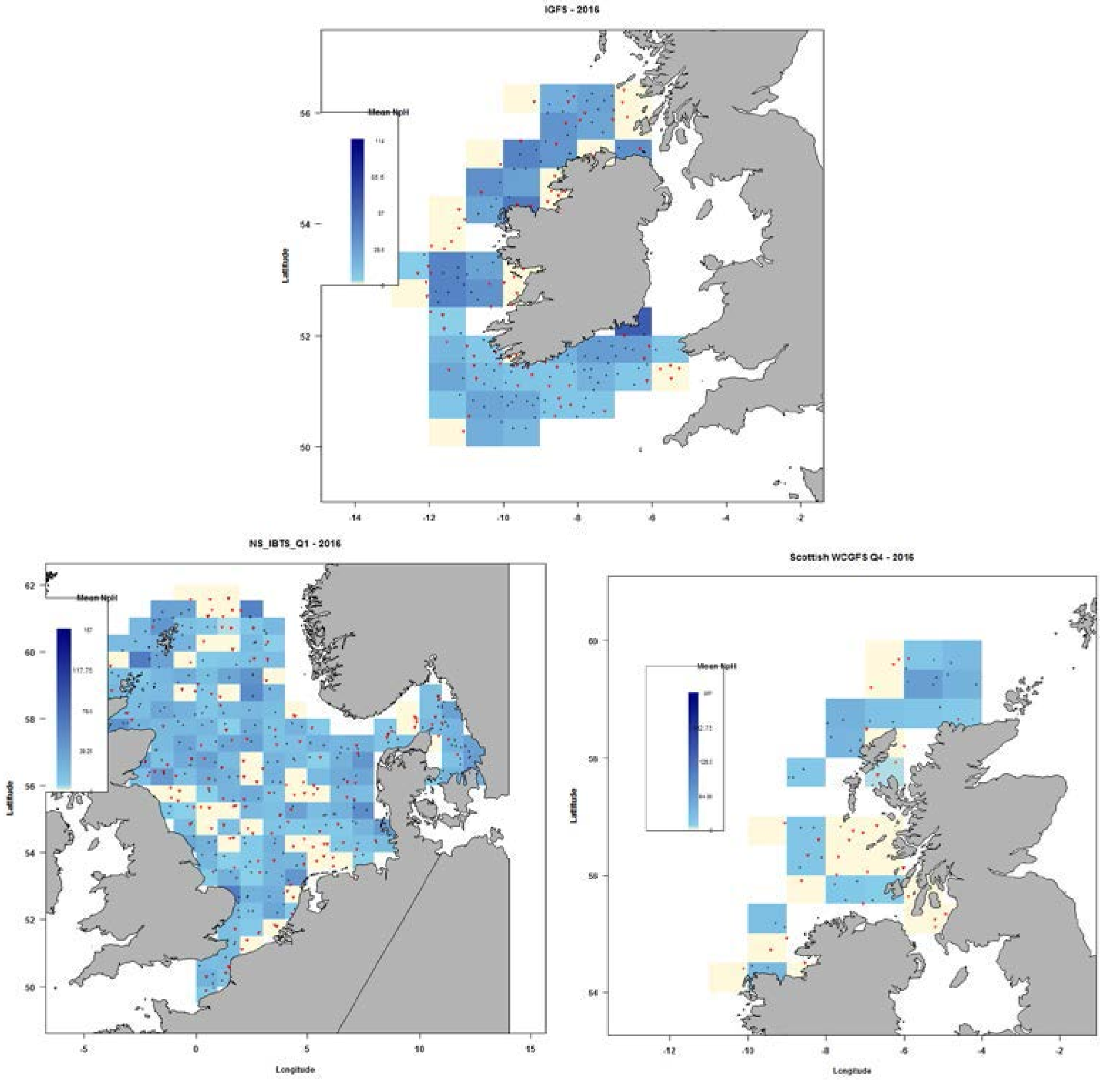


Figure 4. Distributions of red gurnards in CGFS, EVHOE, IGFS, NS-IBTS, and SCOWCGFS surveys in 2016 (Neil Campbell, Marine Science Scotland).

North Sea Seasonal or Vertical Migration

The distribution of red gurnard in the North Sea appears to have expanded with increasing abundance up to 2013. A feature of the data which was presented to WGWIDE in 2018 is the stark difference seen between Q1 and Q3 distributions, with red gurnard only being recorded regularly in Q3 surveys in hauls along the shelf edge around Shetland. Red gurnard are only seen in a handful of other tows at this time of year, in contrast to its widespread occurrence in the North Sea Q1 survey (Figure 5). This would seem to represent a very large-scale migration for all ages of a short-lived species to undertake. There is evidence that triglids migrate onshore-offshore within season on the US northeast shelf (Figure 2 in https://www.st.nmfs.noaa.gov/spo/FishBull/962/mcbride.pdf) suggesting it may be plausible that they seasonally migrate. In addition, there is anecdotal evidence of occasional bycatches of gurnards in acoustic summer surveys of the North Sea for herring, leading to the possibility that they adopt a more pelagic role at this time of year and become unavailable to the bottom trawls used in the IBTS survey (Neil Campbell, personal communication).

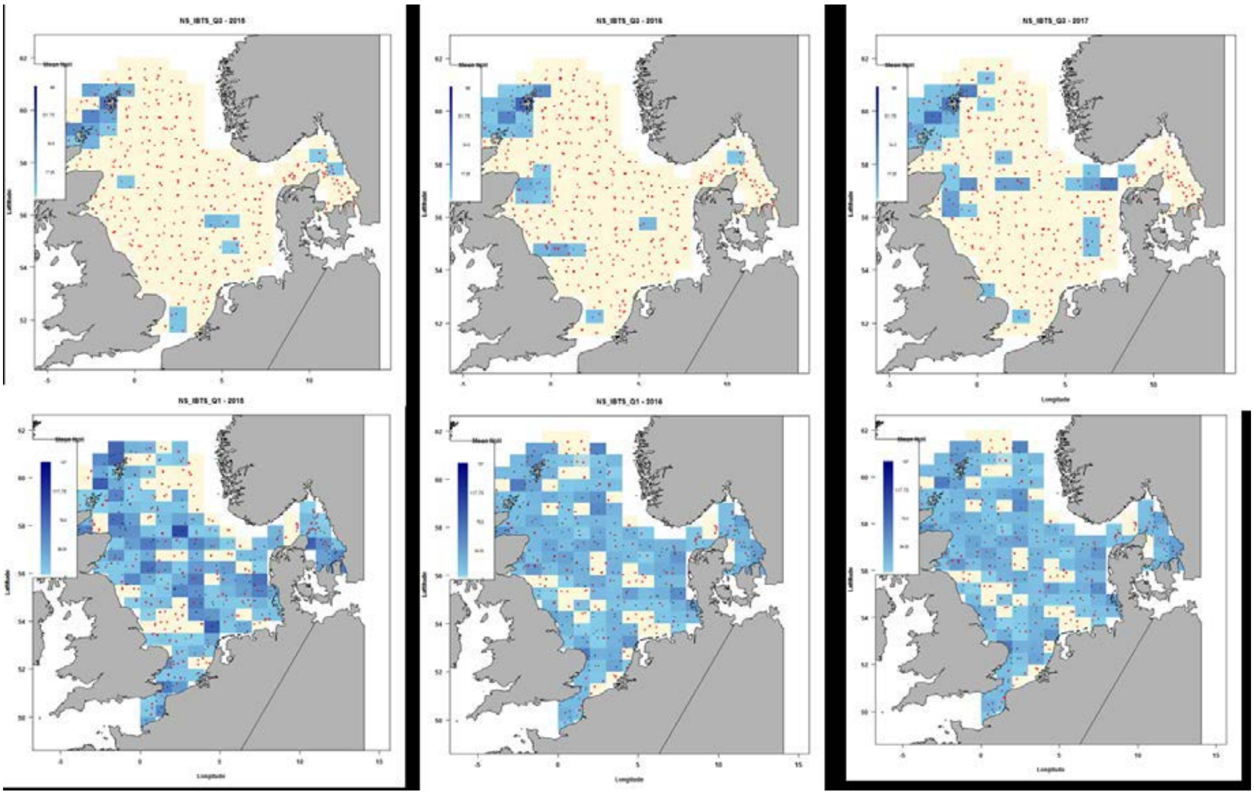


Figure 5.Abundances of red gurnard in the North Sea IBTS hauls in 2015, 2016, and 2017, Q3 (upper panels) and Q1 (lower panels) (Neil Campbell, Marine Science Scotland).

Conclusions and Recommendations

The working document provided by WGWIDE (Neil Campbell, Marine Science Scotland) provides a review of the available information that might be relevant to stock structure of red gurnard. The SIMWG does not find evidence for splitting the stock into two stock areas (North Sea/west of Scotland and Celtic Seas/Biscay) at this time. Although there is evidence of different trends in abundance between the areas across surveys, without additional information this evidence is insufficient to support a conclusion regarding stock structure. The North Sea survey shows strong seasonal changes in distribution which may be attributable to seasonal migration. Alternatively, issues of catchability due to vertical migration are raised in the working document that may explain some of the seasonal differences in distribution. Furthermore, understanding more about seasonal and ontogenetic movements of this species would be helpful in interpreting distribution information. There is no biological data for assessing potential differences in stock identity (e.g. genetic or phenotypic markers) between areas. We recommend that more granularity be required in fishery dependent data collection (i.e., identification to species), a comparison in gurnard catchability among the various surveys in this region, and starting basic biological data collection for accurate stock identification for the data poor species before any spatial management changes should be considered or stocks delineated.

References

Heessen, Henk JL, Niels Daan, and Jim R. Ellis, eds. Fish atlas of the Celtic Sea, North Sea and Baltic Sea: Based on international research-vessel surveys. Wageningen, Netherlands: Wageningen Academic Publishers, 2015.

Pawson, Micheal G. Biogeographical identification of English Channel fish and shellfish stocks. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, 1995.