STOCK IDENTIFICATION METHODS WORKING GROUP (SIMWG)

VOLUME 2 | ISSUE 94

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

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ISSN number: 2618-1371 I

ICES Scientific Reports

Volume 2 | Issue 94

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Recommended format for purpose of citation:

ICES. 2020. Stock Identification Methods Working Group (SIMWG).
ICES Scientific Reports. 2:94. 32 pp. http://doi.org/10.17895/ices.pub.7485

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i Executive summary

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

The identification of the spatial boundaries of exploited stocks is a fundamental requirement before any stock assessment or modelling can be contemplated, and therefore lies at the heart of resource management.

SIMWG continues to provide annual updates on recent applications of stock identification methods to species assessed by ICES and on advances in stock identification methods. Based on the wide expertise of SIMWG members, the group provides reviews of recent literature on genetics, growth marks in calcified structures, life history parameters, morphometrics/ meristics, tagging, otolith shape, otolith chemistry, parasites and interdisciplinary approaches. A key activity of SIMWG is to address requests by ICES working groups for technical advice on issues of stock identity. In 2020, the working group reviewed the outcome of the Workshop on Stock Identification of North Sea Cod (WKNSCodID).

SIMWG contributes to the general understanding of the biological features of the north Atlantic ecosystem through its work to describe fish population structure. Additionally, SIMWG's annual reviews on advances in stock identification methods keeps ICES members abreast of best practices in this field of study. SIMWG expert reviews on questions of stock structure for particular ICES species are directly relevant to the appropriate definition of stock and contribute to the accuracy of stock assessment and effectiveness of management actions. 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. 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	2020
Reporting year in cycle	1/3
Chair	Christoph Stransky, Germany
Meeting venue and dates	By correspondence in 2020 (14 participants)

1 Review recent advances in stock identification methods

Over the past year, there has been a wide use 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:

a) Genetics
b) Growth marks in calcified structures
c) Life history parameters
d) Morphometrics/meristics
e) Tagging
f) Otolith shape
g) Otolith chemistry
h) Parasites
i) Simulation approaches / Interdisciplinary approaches

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 two 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 feedback to ICES expert groups on questions of stock structure for ICES stocks. In 2020, SIMWG contributed to ICES advisory needs by providing expert feedback on the status of stock structure of several species.

The request was put forward by the Benchmark Workshop on Greater Silver Smelt (WKGSS).

SIMWG provided expert advice on the following species:

1. Greater silver smelt (*Argentina silus*) in the North Atlantic;
2. Atlantic cod (*Gadus morhua*) in the North Sea.

The details of the reviews are summarized in Annex 3.

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 advice has been well received by the groups who put forward requests. There is currently a growing number of requests from various groups which showcases the valuable contribution of SIMWG to the ICES community. SIMWG's expertise should be continuously used to address 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.

Annex 1: List of participants

Name	Institute	Country (of institute)	Email
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Annex 2: SIMWG Resolution

2019/FT/HAPISG10 The **Stock Identification Methods Working Group** (SIMWG), chaired by Christoph Stransky, Germany, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2020	By correspondence			
Year 2021	tbc	tbc		
Year 2022	By correspondence		Final report by 1 August to SCICOM	

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 Relevant to all ICES species	1.4, 5.1, 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	1.4, 5.1, 5.2	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	Relevant to resolving mixed stock composition issues in assessment and management.	1.4, 5.2, 5.4	3 years	EG report and contribution to ICES ASC; methodological paper in international journal

Summary of the Work Plan

Year 1	Address terms of reference through work by correspondence in 2020
Year 2	Organise a physical meeting for SIMWG for summer 2021.
Year 3	Address terms of reference through work by correspondence in 2022

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.
Participants	The Group is normally attended by some 10–15 members and guests.
Secretariat facilities	Standard support
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 fulfil requests.
Linkages to other organizations	There are no obvious direct linkages, beyond the SIMWG members' affiliation and commitment to their own employers.

Annex 3: Response to requests from ICES working groups

Greater silver smelt

SIMWG contributed to the ICES Benchmark Workshop on Greater Silver Smelt (WKGSS) in February 2020 by providing expertise on the review of genetic strock structure. Based on a Working Document to WKGSS by Seljestad *et al.* (2020), SIMWG made the following comment:

Sample sizes are adequate and cover a large extent of the distribution range. The only limitations pertain to the lack of temporal replication for some locations (including some key ones, such as Iceland, Shetland and Skagerrak, which also include a smaller amount of individuals), and the fact that the samples from different areas are representative of inconsistent life-history (age and reproduction) trait distributions. The set of markers have not been explored in depth, especially in terms of neutral vs adaptive variation. This can have a significant bearing on the patterns observed (especially when the degree of divergence is low, as it is the case here). The effect of life history stage has also not been tested so far. Overall, there seems to be a general indication that the Icelandic group (which seems to show affinity to the Faroese one) and the Skagerrak contingent, may represent two slightly divergent groups, with the rest of the samples conforming to a fairly homogeneous grouping. Given the afore-mentioned caveats, it would not be prudent to base on this evidence drastic conclusions as to the stock structure of this species. However, since the general pattern identified does not appear to refute the current perception of the Greater argentine's stock structure, it seems reasonable to use this in support of the current assessment status. Further, in-depth analysis of these genetic data is warranted, as they may either strengthen or revise the current perception.

North Sea cod

SIMWG contributed to the planning of the ICES Workshop on Stock Identification of North Sea Cod (WKNSCodID), chaired by Steve Cadrin, 3–6 August 2020, and reviewed its outcome. The comments by SIMWG members were incorporated into the WKNSCodID report.

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

Advances in Stock Identification Methods in 2020

In 2020, 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.

Genetics (Contributors: Rita Castilho, Christophe Pampoulie, Stefano Mariani)

Our annual monitoring of the patterns of usage of molecular markers in fisheries stock identification continues to detect a decrease in the total number of studies regressing to the 2017 publication levels and affecting both microsatellites and SNP papers (Figure 1). The proportional change between microsatellites and SNP studies continues to be not significant (chi-square: 0.0, p-value: 0.99). Note that the data for 2020 is not complete at this time (July 2020).

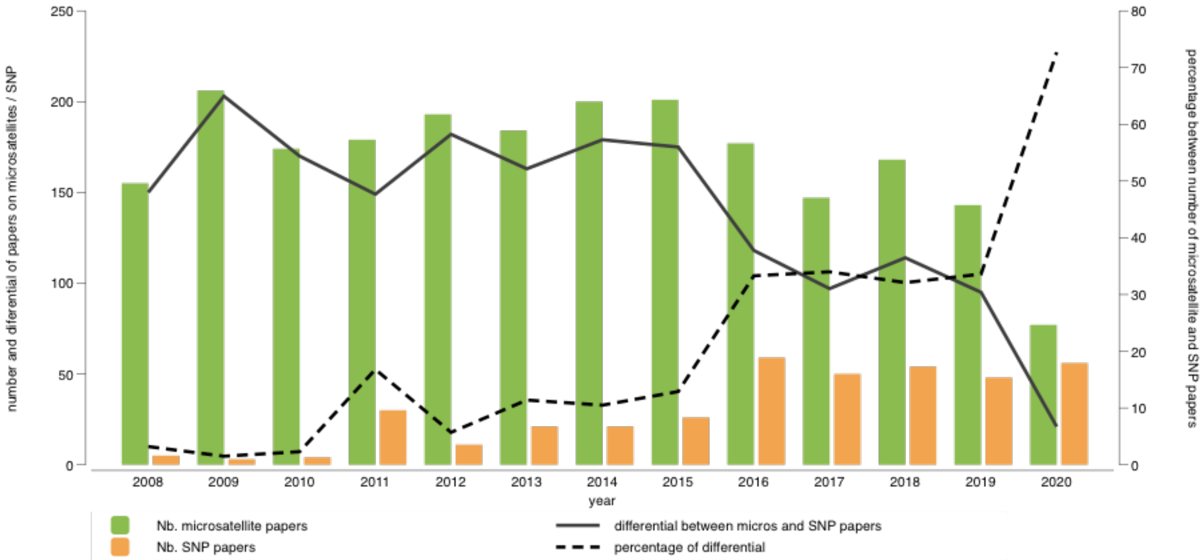

Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (green bars) and SNPs (orange bars), as listed in the Clarivate Analytics Web-of-Science. The search criteria were: "fish* AND gene* AND (population OR stock) AND 'molecular marker*'," where 'molecular 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 2020 only represent papers published through to the present date (July 2020).

The genetics area continues to produce studies that contribute to explicitly show the relevance of molecular genetics data in determining population structure in valuable commercial species to contribute to improved management practices. However, while microsatellite studies are in decline, the number of papers with SNPs are increasing ever so slowly.

Pedraza-Marrón *et al.* (2019) based on morphological and genomic congruency (SNPs) reset the existence of two distinct entities of red snapper, *Lutjanus campechanus* (northern red snapper) and

Lutjanus purpureus (southern red-snapper), which carries implications for the red snapper fisheries management.

The European hake (*Merluccius merluccius*), a valuable commercial resource, is currently managed based on two stocks, the northern and southern stock, with the boundary located at Capbreton Canyon in the Bay of Biscay. Leone *et al.* (2019) also found two stocks but with a different geographic delineation: the northern stock composed of hakes from the Norwegian Sea, while the southern stock encompasses the other southern locations including the Bay of Biscay sites that were previously in different management units. Despite a sampling design of the study that does not allow the placement of the stock boundary, the molecular data (SNPs) prompts for the need of collating different lines of evidence from multiple SNP studies, towards the adjustment of the management units for this important species.

Petrou *et al.* (2019) showed that inter-individual contamination in spawning aggregations could affect genotype calling and introduce noise in species (like Clupeids) with already subtle genetic structure. This result calls for careful consideration in evaluating the risk of contamination on a case-by-case basis.

The sandeel *Ammodytes marinus* displays no significant spatial substructure in ICES areas; however, the study based only on 13 SNPs was able to reveal three main groups, which reflects some degree of reproductive substructuring (Jiménez-Mena *et al.*, 2019).

The Atlantic mackerel (*Scomber scombrus*) has been managed as a single stock since 1995, but its genetic structure has been under debate for decades. Gíslason *et al.* (2020) investigated the genetic structure of Atlantic mackerel using 14 microsatellite loci and spawning as well as feeding samples covering the distribution range of the species (n=1231). Their study supports the current management and only revealed significant differentiation among the northeast and northwest stocks. In addition, assignment of the feeding aggregations samples showed that all the samples collected in the Central North Atlantic (Icelandic waters, Faroese Islands, Greenland and the Norwegian Sea) originated from the northeast Atlantic population.

Besides SNPs (Single Nucleotide Polymorphisms) that represent point mutations, another level of variants (SVs - Structural Variants) can be detected when there are different genomic arrangements such as deletions, duplications, insertions, inversion or translocations. Dorant *et al.* (2020) showed that a subset of SVs called Copy Number Variants (CNVs), involving insertions, deletions and duplications of 'chunks' of DNA sequences across the genome, perform significantly better than SNPs in detecting higher genetic differentiation in the American lobster (*Homarus americanus*). This result is relevant because it can drive the population genetics field into yet another class of markers.

The utilisation of environmental DNA (eDNA) for assessing population-genetic information

Environmental DNA, DNA extracted from water samples, has recently been shown to be useful for assessing the genetic structure of aquatic organisms. eDNA approaches often rely on single-marker of mitochondrial DNA, and eDNA haplotype distribution can then be used to infer population structure in certain cases. Sigsgaard *et al.* (2020) present a brief overview of the eDNA-based population genetics performed so far and described standards for future developments in the field. Currently, four types of genetic markers have been used to derive population-genetic information from eDNA: D-loop, Cytochrome B, cytochrome oxidase I and 16S rRNA, and Sigsgaard *et al.* (2020) present an overview of these studies in their Table 1 (see below). The size of the fragment used varied from 106 to 493 bp. The use of eDNA to infer population-genetics information can be relevant for elusive species and species at risk since eDNA is a non-invasive non-lethal technique. Sigsgaard *et al.* (2020) also made recommendations for assessing the usefulness of eDNA approaches to infer population-genetic information in different research settings. While very few studies have taken this angle when using eDNA, there is in the future a potential to obtain population-genetic information from the large eDNA surveys which are currently taking place in several oceanic regions.

Table 1. Summary table of eDNA studies which obtained population-level information presented in Sigsgaard *et al.*, 2020.

Reference	Environment	Target taxon/taxa	Variant detection approach	MItochondrial target gene(s)/region(s)	Length of marker(s) (bp)
Uchii *et al.* (2016)	Freshwater	*Cyprinus corpio* (com-moncarp)	qPCR	D-loop	240
Sigsgaard *et al.* (2016)	Marine	*Rhincodon* typus (whale shark)	Species-level metabarcoding	D-loop	412-493
Goriki *et al.* (2017)	Freshwater	Proteus *onguinus* (olm)	qPCR	D-loop,cytochrome b, and 16S rRNA	106-157
Stat *et al.* (2017)	Marine	Fishes	Multispecies metabarcoding	16S rRNA	178-228
Parsons *et al.* (2018)	Marine	*Phocoeno* phocoeno (harbour porpoise)	Species·level metabarcoding	Cytochrome b	160
Baker *et al.* (2018)	Marine	*Orcinus orco* (killer whale)	ddPCR	D-loop	139-246
Marshall and Stepien (2019)	Freshwater	*Oreisseno polymorpho* and *D. rostriformis* (Eurasian zebra and Quagga mussels)	Multispecies metabarcoding	Cytochrome oxidase I	169-175
Stepien *et al.* (2019)	Freshwater	*Hypophtholmichthys molitrix* (silver carp)	Multispecies metabarcoding	Cytochrome b	135
Turon *et al.* (2019)	Marine	Eukaryotes	Multispecies metabarcoding	Cytochrome oxidase I	313

Note: The type of aquatic environment, taxa and genetlc region(s) targeted , as weil as the technique applied for detection of genetic variation, and the size of the targeted markers are given.

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Growth marks in calcified structures (Contributors: Richard McBride and Florian Berg)

Atlantic herring (*Clupea harengus*) is managed as a metapopulation on both sides of the Atlantic Ocean. A metapopulation is an aggregate of local populations – with limited connectivity among themselves – exhibiting local dynamics of growth and mortality. We are often interested in the rates of straying between local populations, which creates mixed stocks. Two well-established mixed-stock methods for separating spring- versus autumn-spawning herring groups are to either evaluate: 1) their gonad for spawning readiness, or 2) the growth microstructure in otoliths. Especially the later method is currently applied to identify and separate mixed catches for the assessment and management of two stocks in the greater North Sea ecoregion, the Western Baltic spring spawning herring (WBSS) and North Sea autumn spawning herring (NSAS). Berg *et al.* (2020) employ both methods, along with genetic markers, and reported only about 77% accordance between all three methods. In cases of discrepancy, in about 8% the genetic and otolith assignments did not match with the gonad method. Further, about 7% of the otolith microstructure assignments did not correspond with the genetic and gonad assignment. These mismatches represent individuals potentially straying or reuniting from their natal spawning season, respectively. The choice from these different methods used for the splitting of stocks could have an impact on stock assessment.

Growth marks in calcified structures often differ between localities because of environmental conditions, with or without the added element of genetic differences. Malanski *et al.* (2020) document different feeding conditions (comparing plankton and gut content analysis) and growth rates (otolith microstructure) for capelin (*Mallotus villosus*) at two northern sites of the Atlantic Ocean (64, 69°N). The lower-latitude site had earlier seasonal production of the capelin larvae and their prey but the prey were smaller, so capelin at both sites reached comparable sizes by their first winter. This study reveals the possibility to use otolith microstructure to identify different capelin stocks.

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Life history parameters (Contributor: Richard McBride)

The stock assessment for Atlantic cod in the Kattegat region, between Denmark and Sweden, has been confounded by 'mortality,' not attributed to fishing or natural causes. Hemmer-Hansen *et al.* (2020) considered an alternative explanation: a migration of at least some of the assessed fishery stock. They analyzed single nucleotide polymorphisms, a set of genetic markers, to show this region is composed of fish originating from two stocks, a mixed stock situation. Spatially, fine scale sampling demonstrated a declining proportion of North Sea Cod from the northern to the southern part of the Kattegat, relative to the local, Kattegat cod. Otolith microchemistry data showed that cod of North Sea origin enter the Kattegat as larvae or juveniles but return to the North Sea at about age-4. In terms of the contributions of a life history approach, spawning fish in the Kattegat were dominated by fish of local origin. This life history framework identifies migration and not mortality of one part of a mixed-stock component as a significant process in this region, and accounting for this in data collection and stock assessment methods should improve the sustainability of these stocks.

Reference

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Morphometrics/meristics (Contributors: Michaël Gras and Emma White)

Morphometrics continue to be used in order to increase our understanding of the life history and population structures of different marine fish species. The phenotypic profile of a fish can be the result of both environmental and genetics influences and can be used to identify subpopulations of species occupying large and small spatial ranges.

Landmark-based geometric morphometrics was used to study blue jack mackerel from 6 different areas in the Northeast Atlantic. Using univariate and multivariate statistical analysis, the study found that the population of blue jack mackerel in the study area is phenotypic heterogeneous. They identified specific morphometric variables on the body that showed the largest difference between sampling areas and they investigated the temporal stability between samples collected in 2016 and 2019, reporting that *T. picturatus* can exhibit phenotypic adaptations to the surrounding environment. The assignment of individuals back to their population of origin was high, at 78% in 2016 and 83% in 2019 (Moreira *et al.*, 2020).

Seth *et al.* (2019) used landmark-based geometric morphometric analysis to investigate the body shape variation in pony fish. 11 species of pony fish were identified along the Odisha coast in India. Inter-specific shape variation was looked at to determine the morphological divergence of shape between the species.

Ressel *et al.* (2020) investigated the possibility of using morphometry to distinguish between capelin populations in Arctic and sub-Arctic ecosystems. Relative warps, which is a geometric morphometric method, along with Procrustes ANOVA, estimates of morphological disparity and canonical variates analysis were used to compare samples between and within geographic regions. Morphological variations found throughout the sampled regions implies interspecific diversity for this species. Differences in sex and biological attributes were also explored in this study.

Hanif *et al.* (2019) used truss network morphometrics to investigate the differences in *A. clupeoides*, a species of sardine found in the Bay of Bengal. After collecting data from four different areas within the bay, one of the areas was found to show significant differences from the other three sites. The study used body morphometrics to identify key characteristics on the body that could distinguish between the areas. This new information regarding the structure of the sardine stock within the Bay of Bengal will have implications for management.

Mounir *et al.* (2019) studied *Sardina pilchardus* that occur off the coast of Morocco using morphometric analysis in order to investigate whether stocks defined by the FAO could include different morphotypes and to compare the morphometric results with newly published genetic data. Truss variables and landmark data were applied to samples collected from 4 different ports on the Moroccan Atlantic coast. Three distinct morphotypes were discovered and corresponded well with the FAO's stock definition. The results from this paper did not match those of the genetic study completely.

Three species of shad found in India have been studied for morphometric relationships using a truss network system. Dwivedi (2019) revealed 13 of the 77 variables that were measured were able to distinguish between the three species. Morphometrics was successfully used as an efficient diagnostic tool to classify the three species correctly.

Little known species of Chinese cavefishes have been described using morphometrics in order to raise awareness of these species and provide a dataset for subsequent comparative analyses with other cavefishes (Lunghi *et al.*, 2019).

The population structure of longfin gurnard, *Chelidonichthys obscurus*, was examined using a combination of 13 morphometric characters and the infection parameters from 7 parasite assemblages (Boudaya *et al.*, 2020). Spatial variation was highlighted by morphometric characters within the study area and three of the measurements collected; body height, pectoral fin length and first dorsal fin length, were found to be the most informative characters. The use of parasites to distinguish between longfin gurnard stocks was deemed uncertain in this case.

Ethin *et al.* (2019) investigated mesristic and morphometric characters, and truss measurements across the body of minor carp in order to differentiate between samples collected from isolated populations of this species. 91% of the individuals were correctly assigned back to their original population and it is assumed that these differences arose from ancestral origin.

Using morphometric and meristics traits, Suman *et al.* (2020) successfully differentiated between two closely related species of sciaenid fish, *Otolithes cuvieri* and *Otolithes ruber*. 98% of the individuals were correctly classified based on five morphometric characters and two of the meristic characters measured were important to distinguish between the species.

Rahman *et al.* (2019) collected measurements of morphometric and meristic characters from the banded gourami, *Trichogaster fasciata*, in Bangladesh. The data collected during this study will be used to identify species and contribute to the stock assessment of the Gajner Beel wetland ecosystem and adjacent ecosystems.

Aisyah and Syarif (2019) used morphometric and meristic characteristics to compare Selangat fish between two different areas of Bangka Island, Indonesia. The study reports that the spatial difference between sampling locations and different environmental conditions at this sites have a significant effect on morphometric and meristic characters of selangat fish.

Morphometric, meristic and molecular characteristics were used by Jang *et al.* (2019) to study the geographic variations of Korean sea raven, *Hemitripterus villosus*, from three locations in the Yellow Sea. The results show there are two distinct populations of Korean sea raven with an admixture zone. This research highlights the need for better management of these two populations.

Bani *et al.* (2019) compared geometric morphometric, meristic and molecular methods to classify the subspecies of *Alosa caspia* in the South Caspian Sea. 30 morphometric and 10 meristic measurements were taken from the samples. Four distinct groups were distinguished based on morphometric and meristic measurements but the molecular analysis did not agree with this. Further genetic studies are required to confirm this.

Research continues to investigate improvements and adaptations to the methods being used in morphometrics. Fruciano *et al.* (2020) explored different preservation techniques and how they may affect the shape of the tissue. Subsequent statistical analysis could, in turn, provide misleading inferences as a result. They discuss the use of fresh, frozen and fish preserved in formalin and ethanol and how mixing preservation techniques should be avoided. This kind of research continually improves the techniques used in the study morphometrics.

Morphometric techniques have also been used to describe the differences between two different schools of sprat in the Pacific Ocean. The study was carried out during the spawning season. Acoustic descriptors included school length, height, perimeter, area and volume. By using these measurements, the study was able to describe the characters of sprat schools inhabiting two areas and differentiate between them (Casarsa *et al.*, 2019).

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Tagging (Contributor: Karin Hüssy)

Introduction

The majority of the reviewed papers focused on answering ecological question, like migration range, temperature preference or essential habitats of a species, and are either based on the use of passive tags (Frisk *et al.*, 2019; Shelton *et al.*, 2019) or by combining archival tag data with oceanographic data (Braun *et al.*, 2019; Crear *et al.*, 2020; Nimit *et al.*, 2020). A few of the reviewed papers have additionally resulted in confirmation of current management areas (Zemeckis *et al.*, 2019; Bird *et al.*, 2020) or in new management recommendations (Barnett *et al.*, 2019; Perkinson *et al.*, 2019; Lecomte *et al.*, 2020).

Most traditional stock assessment models are based on fixed management units that to a larger or smaller extent reflect the spatiotemporal distribution of a given stock. There is growing evidence that the distribution of many stocks is more complex and do not fit into a "simple box" concept. This highlights the need for efforts to design spatially explicit assessment models that can estimate connectivity among population units by incorporating tag-recovery data directly into the assessment – such as the studies by Goethel *et al.* (2019) and Vincent *et al.* (2020).

Patterns of movement and distribution from passive tags

Barnett *et al.* (2019) aimed at identifying whether the coastal habitats that have been declared shark refuge areas (SRAs) along the Tasmanian coast are essential habitats within the distribution range of elephantfish (*Callorhinchus milii*) as well. In the SRAs, a fishery for elephantfish is still permitted. A combination of acoustic tracking, catch data and reproductive information suggests that these SRAs are in fact essential habitats for reproduction and likely important for other purposes, such as foraging. Elephantfish should therefore be included in the current SRAs.

Bird *et al.* (2020) used mark-recapture tagging studies undertaken from 1959–2017 to identify stock units of elasmobranch fish from Northern Ireland, the Irish Sea to the and Bristol Channel. Data were most comprehensive for skates (*Rajidae*), with 22 374 released and 3342 (14.9%) returned. Most data related to thornback ray (*Raja clavata*), blonde ray (*R. brachyura*) and spotted ray (*R. montagui*). Tags were generally returned from areas less than 50 km from their release, and usually from the ICES Division in which they were released, indicating that the current stock units used by ICES are broadly appropriate.

Cameron *et al.* (2019) used a long-term (47 years) mark-recapture data with 9 recaptures to investigate the population structure, spatial distribution and seasonal movements of porbeagles (*Lamnas nasus*) in Irish waters. The limited number of recaptures seems to indicate that porbeagle may sow some seasonal site fidelity, using Irish waters as summer feeding area.

Frisk *et al.* (2019) used passive acoustic telemetry and Floy tags to examine the impact of movement patterns on the exponential increases biomass observed in Winter Skate *Leucoraja ocellata* in Georges Bank and southern New England. This biomass increase cannot be fully explained by internal population dynamics of a population without immigration. Annual movements of 58 Winter Skate captured revealed seasonal long-distance dispersal capabilities exceeding 1000 km with a collectively traveled distance of 17 576.9 km. 51 recaptured Winter Skate from a total of 3416 marked with Floy tags suggested greater offshore movement than was observed in acoustically tagged individuals. This study illustrates that the Winter Skate is a highly mobile species that moves extensively throughout its large geographic range.

Lecomte *et al.* (2020) investigate metapopulation connectivity of the common sole (*Solea solea*) in the Eastern English Channel (EEC), using a state-space mark–recovery model with 4036 recaptures. The common sole stock is currently assessed as a single and spatially homogeneous population. The study was designed to estimate adult connectivity using mark–recapture data from multiple release experiments from 1970 to 2018 across the EEC and adjacent management areas. The study results suggest minimal large-scale adult movements between management areas; minimal movements among spatial units within the EEC, and with even lower levels of immigration from areas adjoining the EEC. Our results support the hypothesis of segregated populations within the EEC, highlighting the need for revising the current one-stuck management.

Perkinson *et al.* (2019) evaluated tag-recapture and population genetics data for cobia (*Rachycentron canadum*) in the south-eastern United States to provide information on population structure and determine the geographic boundary between stocks in the Gulf of Mexico and the Atlantic Ocean. 1750 tag- recapture data combined with 2796 genetic samples of cobia. The results indicate that separate stocks occur from Texas through Hobe Sound on the east coast of Florida and from Savannah, Georgia, to the Chesapeake Bay in Virgina, with distinct genetic groupings within the Atlantic Ocean stock.

Shelton *et al.* (2019) showed that the ocean distribution of Chinook salmon (*Oncorhynchus tshawytscha*) depends strongly on region of origin and varies seasonally in a study of tag-recapture data from California to British Columbia between 1977 and 1990 and using a coastwide state-space model. Survival on the other hand showed regionally varying temporal patterns.

Stewart *et al.* (2020) studied spatial patterns of movement and growth in snapper (*Chrysophrys auratus*) using tag-recapture data of 2117 recaptures covering the entire distribution area of the species. The results indicated population characteristics of partial migration, where the majority (~71%) of fish did not move any detectable distance and a small proportion (~4%) moved between 100 and 1000 km. Specific growth rates were significantly affected by the latitude at tagging, with higher growth rates at lower (more northern) latitudes. The study results suggests that snapper are mainly resident on a sub-decadal time scale and at reasonably small spatial scales.

Zemeckis *et al.* (2019) aimed at identifying the spatial and temporal distribution of cod spawning in order to inform fishery management actions to rebuild the Gulf of Maine stock of Atlantic cod (*Gadus morhua*) using acoustic telemetry and passive acoustic monitoring equipment deployed in fixed-station arrays and mounted on mobile autonomous gliders. Tagged cod exhibited spawning site fidelity and spawning primarily occurred from early November through January with a mid-December peak and some inter-annual variability. The spatial distribution of spawning was generally consistent among years with multiple hotspots in areas >50m depth. Current closures encompass most of spawning, but important areas are recommended for potential modifications to these closures.

Geolocation: Coupling archival- and pop-up tags with oceanographic data

Braun *et al.* (2019) used pop-up satellite archival transmitting tags (PSAT) coupled with a global observation-assimilating ocean model to obtain information on basic biology, including stock boundaries and movement between management zones of broadbill swordfish (*Xiphias gladius*). 20 tags were deployed on juvenile swordfish in the Azores and adults in the northwest Atlantic (NWA). Resulting tracks from 16 individuals averaged 3751 km (range 345–7247 km) over 93 days (range 17–181 days). Juveniles tagged in the Azores made regional movements while adults tagged in the NWA moved between summer foraging grounds near the Grand Banks to winter habitats near the Antillean Arc. Integration of results from our PSAT-based movements with conventional tag and catch-per-unit effort data largely supports current stock boundaries.

Crear *et al.* (2020) developed a depth-integrated habitat suitability model using archival tagging data from cobia (*Rachycentron canadum*) in the Chesapeake Bay and coupled tagging data with high-resolution ocean models to project the contemporary and future distributions of the species under climate change scenarios. The study showed that during the winter months, suitable cobia habitat currently occurs in offshore waters off North Carolina and further south, whereas during the summer months, suitable habitat occurs in waters from Florida to southern New England. In warmer years, the availability of suitable habitat increases in northern latitudes. Under continued climate change over the next 40–80 years, suitable habitat is projected to shift northward and decrease over the shelf.

Nimit *et al.* (2020) studied yellowfin tuna (*Thunnus albacares*) aiming at understanding of how oceanography influences the distribution of the species using pop-up satellite archival tags and remotely sensed oceanographic data from two regions in the northern Indian Ocean. Tagged individuals showed a preference for ambient temperatures of 26–29°C and avoided moving below the relatively shallow oxycline depth, which is indicative of the stratified waters in the study area. Low dissolved oxygen levels are likely a limiting factor for tuna movement given their high oxygen demand.

Modelling: Use of tagging data in stock assessment

Goethel *et al.* (2019) explored the applicability of a spatially explicit simulation-estimation framework that simulates metapopulation dynamics with two populations and time-varying connectivity. The framework was implemented for three life history (i.e., longevity) scenarios to explore the relative utility of tagging data for use in spatial assessment models across a range of tag release designs (e.g., annual, historical, periodic, and opportunistic tagging). Model scenarios also investigated the impacts of not accounting for incomplete tag mixing or assuming all fish were fully selected (i.e., that the age composition of tagged fish was unknown). Results demonstrated that periodic tagging (e.g., releasing tags every five years) may provide the best balance between tag program cost and parameter bias.

Vincent *et al.* (2020) investigated the performance (bias and precision) of a recapture-conditioned integrated tagging catch-at-age analysis (ITCAAN) that assumes yearly natal homing under varying model complexities and intermixing rates and compared the results to those from a release-conditioned ITCAAN. The study also investigated how misspecification of natural mortality, parity in population productivities, tag shedding, and spatially-varying reporting rates affected estimation of model parameters. For most scenarios investigated, estimation by the release-conditioned ITCAAN was less biased and more precise compared to the estimation by the recapture-conditioned ITCAAN presumably as a consequence of the former providing additional information on region-specific survival. However, both models performed poorly in estimating population specific abundances for scenarios with high intermixing rates and when reporting rates varied regionally but were assumed to be regionally constant in the ITCAANs.

Review

Seber and Schofield (2019) reviewed the applicability of a wide variety of tags and markers used for uniquely identifying animals. Examples are various types of attached tags, natural markers on animals (e.g., tiger stripes, tail fins), radio tags, PIT tags that use an integrated circuit chip, water acoustic tags, genetic markers, next-of-kin information, and trace methods without captures using cameras. The study considers in detail models for estimating tag loss using different kinds of tag combinations in both a discrete and instantaneous modelling framework.

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Otolith shape (Contributors: Kélig Mahé, Florian Berg and Christoph Stransky)

From July 2019 to July 2020, there were 32 papers dedicated to otolith shape with one study around the statistical classifiers to discriminate fish stocks based on otolith shape and one study around ontogenetic and sex effects on otolith shape. Eight studies conducted otolith shape analyses as tool to describe the stock structure. Others studies were focused on the difference among species.

Methodology and significant factors which drive otolith shape

Smolinski *et al.* (2020) compared the performance of two traditional and four machine learning classifiers based on Fourier analysis of otolith shape using selected stocks of Atlantic cod (*Gadus morhua*) in the southern Baltic Sea and Atlantic herring (*Clupea harengus*) in the western Norwegian Sea, Skagerrak, and the southern Baltic Sea. Their results showed that the stocks can be successfully discriminated based on their otolith shapes. They observed significant differences in the accuracy obtained by the tested classifiers. For both species, support vector machines (SVM) resulted in the highest classification accuracy. These findings suggest that modern machine learning algorithms, like SVM, can help to improve the accuracy of fish stock discrimination systems based on the otolith shape.

Vaux *et al.* (2019) investigated population structure among fish sampled from two nearshore reefs (Siletz Reef and Seal Rock) and one offshore site (Stonewall Bank) within a <50-km2 area off the Oregon coast. Fish from the three sample sites exhibited small but statistically significant differences based on genetic variation at >15 000 neutral loci, whether analyzed independently or classified into nearshore and offshore groups. Male and females were readily distinguished using genetic data and 92 outlier loci were associated with sex, potentially indicating differential selection between males and females. Morphometric results indicated that there was significant secondary sexual dimorphism in otolith shape, but further sampling is required to disentangle potential confounding influence of age. This study is the first step toward understanding intra-specific variation within the deacon rockfish and the potential management implications. Since differentiation among the three sample sites was small, the authors consider the results suggestive of a single stock. However, future studies should evaluate how the stock is affected by differences in sex, age, and gene flow between the nearshore and offshore environments.

Denechaud *et al.* (2020) investigated the variability of Northeast Arctic (NEA) cod (*Gadus morhua*) otolith shape between 1933 and 2015, using elliptical Fourier descriptors extracted from archived material of 2968 mature fish. Series of hierarchical multivariate models were developed to relate shape to the identified optimal windows of some environmental drivers. Differences between years accounted for <3% of the observed variation and no significant differences were found between the average cohort shapes. The models not only confirmed that fish growth was the strongest driver of shape differences, but also highlighted effects of temperature and biomass-related variables at different life stages. Extrinsic factors described only a small fraction of the observed variance, which indicates that environmental changes over time likely account for less than the natural inter-individual variability in otolith shape. These results suggest that overall shape remains relatively stable through time within NEA cod, which further contributes towards a consensus on the biological interpretation of shape differences.

Otolith shape as tool to stock identification

ICES areas

Schade *et al.* (2019) evaluated a suite of non-molecular stock discrimination techniques (otolith shape analysis, stable isotope analysis on otolith nuclei, otolith readability and diameter of translucent zones [TZs]) on the same set of genetically validated Baltic cod baseline samples from the mixing area (Arkona Basin) and adjacent areas (Belt Sea, Øresund and Bornholm Basin). Otolith shape and stable oxygen isotope analyses showed the highest classification accuracies; between 80 and 84% of cod individuals were correctly assigned to their respective stock of origin. Stable carbon isotope analysis, otolith readability and the diameter of the first 2 TZs yielded classification accuracies of only 52 to 61%. Given the high assignment accuracy and the availability of archived otoliths, otolith shape and stable oxygen isotope analyses on otolith nuclei are powerful separation methods that allow for high-throughput quantification of present and past mixing proportions of Baltic cod stocks. This study provides the most comprehensive approach of genetically validated stock discrimination techniques currently available for Baltic cod, and evaluates the applicability and reliability of otolith-based methods for future research studies and for fisheries management purposes.

Muniz *et al.* (2020) collected chub mackerel (*Scomber colias*) between January and April of 2018 at six sampling locations (45 fish per site) of the NE Atlantic (Azores, Madeira, Canaries and Portugal mainland - Matosinhos, Sesimbra and Portimão) were used for body morphometrics and otolith shape analyses. Data were analyzed by univariate and multivariate statistics. Reclassification success using shape analysis and body morphometrics showed an overall rate of 51% and 74%, respectively. Regional differences regarding the otolith shape analysis suggest a single stock, not necessarily homogenous, with a discrete separation of two main groups (oceanic islands and Portugal mainland). However, body morphometrics show a more detailed separation in two main groups (Canaries and the others, but with a slight differentiation between fish from Azores/Madeira and Portugal mainland). Moreover, joint analyses gave an overall reclassification success of 82% and allowed a more detailed scenario showing the existence of three main groups (Canaries, Azores/Madeira and Portugal mainland). Regional differences are probably related with different oceanographic conditions influencing the feeding regime and fish grow. The hereby data suggest that S. colias caught in the North-East Atlantic are different population-units, and recommend a fishery management at a finer regional scale.

Moura *et al.* (2020) evaluated the stock structure of *Scomber scombrus* using otolith shape and chemical signatures. One hundred and eighty individuals of the same cohort (age 3), caught between January and February of 2018 from six key locations in the North Atlantic, were used.

Individuals were collected from the two spawning components in the NWA stock, the Canadian Northern component (NWA-N) and the US Southern component (NWA-S); and from the three spawning components in the NEA stock, the North Sea (NEA-NS), the Western (NEA-W) and the Southern components (NEA-S), plus, an overlapping area of these last two components, the Bay of Biscay (NEA-BB). Combined otolith signatures fully discriminated the NEA and NWA stocks (100% of reclassification success, indicates distinct population-units) and discriminated the components within each stock with high reclassification percentages (100% and 68% for the overall reclassification of the NWA and NEA components, respectively). These data suggest that NWA stock should be regard as two distinct population units for fisheries management purposes, confirms the complex metapopulational structure of the NEA stock, and calls for the need of continuous evaluation of these complex stocks in order to achieve a sustainable exploitation.

Other areas

Song *et al.* (2020) analyzed and compared variations of the sulcus and otolith outlines of three geographic stocks (Huanghe (Yellow) River estuary (HHE), Jiaozhou Bay (JZB), and Changjiang (Yangtze) River estuary (CJE)) of white croaker Pennahia argentata in northern Chinese coastal waters. The sulcus and otolith outline analyses via elliptical Fourier transform (EFT, i.e. outline analysis) achieved an overall classification rate of 80.4% and 87.2%, respectively. Based on a combination of sulcus and otolith shape indices (SIs) and two derivative ratios, a moderate discriminatory efficiency of 64.7% was obtained. The results indicate that sulcus outline analysis could be used alone to discriminate white croaker stocks, and that both sulcus and otolith outline analyses discriminated the fish stocks at a higher classification rate than the shape indices. The sulcus outline analysis provided complementary information to the whole otolith outline analysis for stock discrimination. Both the sulcus and otolith outline analyses efficiently discriminated between the most geographically separated CJE and HHE stocks, indicating that they could be considered discrete stocks for fishery management.

Hoff *et al.* (2020) studied *Isopisthus parvipinnis*, commonly known as "bigtooth corvina", which is a marine estuarine-dependent fish captured in the southeast and south Brazilian coast as bycatch of the shrimp fishery. This work used the sagittae morphology as a tool to primarily study the population structure of *I. parvipinnis* between Sao Paulo and Santa Catarina states (23°S to 26.9°S) in Brazil. Secondly, it intended to verify the existence of morphological alterations over time, by comparing otoliths of fish captured in 1975 and 2018/2019. Otolith shape analyses were performed in individuals ranging from 66 to 139 mm of total length, obtained from historical (1975) and present catches (2018/2019) in the shallow coastal areas off North of Sao Paulo (NSP), Centre of Sao Paulo (CSP), South of Sao Paulo (SSP), Parana (PR) and Santa Catarina (SC). Otoliths were analyzed using shape indices (SIs), elliptical Fourier descriptors (EFDs) and both tools combined. Morphological variations among locations and between years were tested using uni- and multivariate statistics. Data showed regional differences in the otolith shape analysis over the years. Samples from 1975 presented an overall low reclassification rate (43%), with a high overlap of individuals among locations, suggesting the existence of a single group. Differently, samples from 2018/2019 discriminated four distinct spatial units with a good overall reclassification (74%): group 1 - NSP; group 2 - CSP; group 3 - SSP + PR; and group 4 - SC. The data suggest regional changes at long term in the population dynamics of *I. parvipinnis*, from a single panmictic population in the past to a metapopulation structure in the present days, with consequences for the rational and sustainable management of the fishery. However, once it was the first evaluation of the population structure of *I. parvipinnis*, it is highly recommended to use complimentary phenotypic and/or genetic approaches to corroborate the hereby observed findings.

Pavlov & Shirokova (2020) analyzed Amur sleeper (*Perccottus glenii*) populations from four water bodies of Central Russia: (1) the lake near Maslovka village (Nizhny Novgorod oblast), (2) Sima Pit, (3) Upper Sharapovskii Pit, and (4) Lower Sharapovskii Pit (Moscow oblast). The diameter (along the dorsoventral axis) of the first annual zone is 0.8–1.5 mm. The highest growth rate (29 mm per year on average) and the largest individuals (up to 245 mm TL) are registered in population one. Based on two sagitta shape indices (height to length ratio and ellipticity), a directed bilateral asymmetry is observed in population one. Based on the variation of fluctuated asymmetry, distinct differences between the populations are absent. The elliptic Fourier analysis shows that population 1 differs from populations 2, 3, and 4 in sagitta shape. A small interpopulation variation of sagitta morphology is revealed.

Rashidabadi *et al.* (2020) used simultaneously the scale and otolith morphometry as a potential tool for the identification of Persian brown trout *Salmo trutta* stocks of the Lar Lake and five rivers from Lar Basin, Iran. Fourier coefficients (FC) and circularity, rectangularity, roundness, ellipticity and form factor shape indices (SI) were calculated for otolith and scale. Several SIs were significantly different among sites for both structures. Permutational multivariate analysis of variance revealed significant differences between several pairwise comparisons for otolith and scale (FCs and indices separately). Discriminant analysis showed otolith FCs (cross-classification rates: 25–86%) and SI (20–45%) appear to be a relatively acceptable tool to discriminate between several locations. Comparatively, the scale morphometry showed lower discriminatory power (FC = 3–65%; SI = 15–34%), with the exception of SI for Elarm River (60%), Kamardasht River (56%) and Lar Lake (75%). Cross-classification rates improved up to 100% when discriminate analysis incorporating all variables for otolith and scale was performed. The results showed a potential segregation between some water bodies, suggesting that the otolith and scale morphometry could be a useful tool to delimit *S. trutta* populations in relatively close freshwater environments.

Koeberle *et al.* (2020) evaluated otolith shape variation in Chinook salmon (*Oncorhynchus tshawytscha*) as a potential tool for stock discrimination using wavelet coefficients and Fourier harmonics in three case studies at multiple spatial scales. We adopted a simple Classification Tree model that used otolith shape variation to separate Chinook salmon groups. We found best performance of the model occurring between hemispheres, followed by Oregon basins, within-watershed Elk River, Oregon, and lastly among South American basins. Otolith shape analysis is a promising tool for stock discrimination if used in conjunction with other methods to better understand plasticity of anadromous species that use pan-environmental systems.

Wiff *et al.* (2020) analyzed a total of 253 pairs of sagittal otoliths of *Genypterus blacodes* in the fjords and inner channels of Chilean Patagonia. Their contours were modelled using wavelet analysis as a tool for stock discrimination. Contours were compared using canonical analysis, and classification was performed using linear discriminant and Random Forest analyses. The results indicated that the wavelet method is efficient in modelling otolith contours, and the discriminant analyses showed differences among fishing grounds across the latitudinal gradient, thus confirming the hypothesis that *G. blacodes* conform to at least two separate stock units in Chilean Patagonia. Fishing grounds that were closer in space showed higher levels of misclassification. The discussion focuses on how environmental variables and the geography of fjords shape stock differences and how this information can be used for the sustainable management of *G. blacodes*.

Souza *et al.* (2020) used otoliths from 1800 European perch (*Perca fluviatilis*) individuals from 9 different populations to analyze the ontogenetic and inter-population differences on the otolith shape using six morphometric indices. The relationship between fish and otolith length was fitted using three different regression models (linear, power and logistic) to identify the best allometric relationship. The results show that there are strong ontogenetic and interpopulation differences in *P. fluviatilis* otolith shapes. The authors also show that the relationship between the fish and otolith length follows a logistic curve. The ontogenetic differences on otolith shape might be related to extrinsic factors (diet shift and intra and interspecific competition) in each ecosystem, given that the reservoirs are different and no clear pattern on the otolith shapes can be distinguished among populations. The results imply that the available back-calculation models may not always provide accurate estimates of *P. fluviatilis* length and that a model that takes into account the real allometric relationship for the species can improve the fish length estimations of back-calculated fish lengths for the European perch.

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Otolith chemistry (Contributors: Lisa Kerr and Zach Whitener)

The following is a review of recently published papers regarding stock structure of ICES relevant species and stocks using otolith chemistry.

Atlantic bluefin tuna are managed as two separate management units (east and west) in the North Atlantic, despite observed mixing that occurs across the management boundary. Kerr *et al.* (2020) use otolith stable isotope chemistry (δ13C and δ18O) to identify the stock composition of bluefin landings from the Gulf of Maine that is of particular importance, because approximately 70 % of the U.S. western Atlantic total allowable catch is removed from this region annually. The authors also characterize effects of stock mixing has been identified as a priority for improving the management of Atlantic bluefin tuna. Results indicated that the majority of fish caught in the Gulf of Maine from 2010 to 2013 were eastern origin. They found the highest proportion of eastern origin fish were caught in 2012 and the proportion of eastern origin fish was greater in late summer to fall. Although the majority of fish in small and intermediate size classes were eastern origin, fish in the largest size class (>250 cm) were predominantly western origin. Using these data, they demonstrated an approach for integrating mixed stock composition information into fishery-specific harvest data (U.S. rod and reel catch, catch-at-age, and catch-per-unit-effort). This information can be used to monitor mixed stock composition of the fishery, partition catch to population of origin, and to inform management decisions aimed at controlling population of origin harvest.

Not concerned explicitly with stock identification, but still applicable, Limburg *et al.* (2019) looked at Eastern Baltic cod (*Gadus morhua*) to investigate the relationship between declining fish condition and increased hypoxia in the region. Examining trace element chemistry from otoliths (Mn and Mg), the authors found that individuals with poor body condition showed a higher level of Mn/Mg in their last year of life, leading to the hypothesis that spending time in hypoxic waters were detrimental to fish health. Lifetime exposer to hypoxia was even more correlated to body condition. Findings such as this may be useful for stock identification in future studies.

Macdonald *et al.* (2020) measured otolith elemental (Li, Mg, Ca, Mn, Zn, Sr, Ba) and stable isotopic (δ13C, δ18O) concentrations in the otoliths of juvenile Atlantic herring (*Clupea harengus*) from Iceland nursey areas. They wanted to investigate the contributions of intrinsic (i.e., within individual) and extrinsic (i.e. environmental) processes affect otolith chemistry by building models to isolate ontogenetic influences from environmental influences. Otolith Li:Ca, Mg:Ca, Mn:Ca and Sr:Ca declined with age within sites. Age slopes differed among sites for Li:Ca and Mg:Ca, and Sr:Ca was lower in larger fish within an age-class. Individual-level variation (i.e., within site, within age-class) was high for all markers, our models highlighting the importance of temperature and salinity (or proxies these represent) in explaining population-level δ13C and δ18O trends. Age- and year-specific predictions for each marker, at each site, generally accorded well with empirical observations, providing inference on island-wide heterogeneity in otolith chemistry across the juveniles' full distributional range. Such 'isoscapes', generated from mechanistically-focused models as presented here, might benefit investigations of population structure for other exploited species, particularly where sampling limitations hamper fishery-management efforts. Although this paper does not focus on stock identification per se, it does provide valuable insight to the processes that affect otolith chemistry.

Moura *et al.* (2020) looked at Atlantic mackerel (*Scober scombrus*) and used otoith shape and chemical signatures to determine the spatiotemporal movements of different spawning components in the North Atlantic, namely the North-West Atlantic and North-East Atlantic stocks. Individuals were collected from the two spawning components in the NWA stock, the Canadian Northern component (NWA-N) and the US Southern component (NWA-S); and from the three spawning components in the NEA stock, the North Sea (NEA-NS), the Western (NEA-W) and the Southern components (NEA-S), plus, an overlapping area of these last two components, the Bay of Biscay (NEA-BB). Combined otolith signatures fully discriminated the NEA and NWA stocks (100% of reclassification success, indicates distinct population-units) and discriminated the components within each stock with high reclassification percentages (100% and 68% for the overall reclassification of the NWA and NEA components, respectively). These data suggest that NWA stock should be regard as two distinct population-units for fisheries management purposes, confirms the complex metapopulational structure of the NEA stock, and calls for the need of continuous evaluation of these complex stocks in order to achieve a sustainable exploitation.

Schade *et al.* (2020) is an interdisciplinary paper that evaluates four methods of stock identification of genetically validated baseline samples of Baltic cod. Western Baltic cod and Eastern Baltic cod coexist in the Arkona Basin, despite their genetic separation. The authors tested non-molecular stock discrimination techniques (otolith shape analysis, stable isotope analysis on otolith nuclei, otolith readability and diameter of translucent zones [TZs]) on the same set of fish from the Arkona Basin and adjacent areas (Belt Sea, Øresund and Bornholm Basin). Otolith shape and stable oxygen isotope analyses showed the highest classification accuracies; between 80 and 84% of cod individuals were correctly assigned to their respective stock of origin. Stable carbon isotope analysis, otolith readability and the diameter of the first 2 TZs yielded classification accuracies of only 52 to 61%. Given the high assignment accuracy and the availability of archived otoliths, otolith shape and stable oxygen isotope analyses on otolith nuclei are powerful separation methods that allow for high-throughput quantification of present and past mixing proportions of Baltic cod stocks. This study provides the most comprehensive approach of genetically validated stock discrimination techniques currently available for Baltic cod, and evaluates the applicability and reliability of otolith-based methods for future research studies and for fisheries management purposes.

Although the species and stock of question are outside of the purview of ICES, the 2020 Siskey *et al.* paper about using the otolith chemistry to discriminate stocks of a failed recovery of winter flounder (*Pseudopleuronectes americanus*) is of value to the SIMWG. The southern New England – mid-Atlantic (SNE–MA) stock of winter flounder (Pseudopleuronectes americanus) collapsed in the 1990s, and has not recovered, but the authors posit that a more nuanced understanding of stock structure may be necessary for rebuilding. Using otolith chemistry tracer manganese–calcium ratios (Mn/Ca) to estimate inshore- versus ocean-nursery contributions, they found 77.3%/22.7% in Southern New England–Massachusetts, 15.7%/84.3% in the Gulf of Maine (GOM), and 60.0%/40.0% in Georges Bank (GB). Strontium–calcium ratios (Sr/Ca) were used to estimate migratory- and resident-contingent membership of nursery-classified fish: 30.2% of fish were classified as bay residents, 25.2% as bay migrants, 25.8% as ocean residents, and 18.8% as ocean migrants. Finally, model selection indicated that both nursery-specific and contingent-specific growth models were more appropriate than a common model. Nursery-specific models exhibited increasing deviations in length with age. Contingent-specific model reflected moderate differences at the youngest ages but convergence at older ages. These findings are informative for the population structure and migration ecology of winter flounder; however, simulation is required to determine whether partial migration and substock structure are necessary inputs for sustainable fisheries management.

Tripp *et al.* (2020) use otolith trace elements to identify stock of origin of Newfoundland capelin (*Mallotus villosus*), with the eventual goals to determine the productivity and connectivity contributions of different spawning areas, as well as metapopulation dynamics. They used laser ablation inductively coupled plasma–mass spectrometry (LA ICP–MS) to look at the elemental signatures (including Mg, Mn, Zn, Sr, and Ba) of 1-3 day old larval capelin. Additional sampling was repeated in some regions over multiple years to study interannual variations. Correct classification rates to natal regions overall was 78%, with region specific ranges from 68-100%, even remaining high at 67-76% despite interannual variation.

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Parasites (Contributor: Ken Mackenzie)

Eight publications dealing with the use of parasites as biological tags for population studies of marine fish were published in the year from July 2019 to June 2020. The target host species ranged from shallow-water estuarine fishes to wide-ranging oceanic species. The study regions included the Mediterranean and Baltic Seas, the northeast and southwest Atlantic Oceans, the NE Pacific and the Indian and western Pacific. Seven publications presented new data and one reviewed existing data.

A regular feature of these parasite tag reports in recent years has been the continuing flow of papers from the southwest Atlantic region off the coasts of Argentina, Uruguay and Brazil – a region characterized by different biogeographical zones, each with its own distinctive parasite fauna of generalist parasites. Two more studies from this region were published in the past year. One, by Canel *et al.* (2019), analysed new and earlier published and unpublished data on the occurrence of two species of larval acanthocephalans – *Corynosoma australe* and *C. cetaceum* - both of which have wide fish host ranges. The effect of 6 variables on the abundance of these parasites in different parts of the study area off the coast of Argentina was evaluated using Generalised Linear Mixed Models (GLMMs). Variables were host total length, biogeographic province of origin, trophic level, diet, depth and habitat. Knowledge of these distribution patterns provides useful information for sustainable management of fisheries in the region. The second paper, by

Levy *et al.* (2019), tested the value of parasites as biological tags at different spatial scales by using them to investigate the population biology of a small estuarine and shallow water fish – the silverside *Odontesthes argentinensis* – off the coast of Argentina. Samples, totalling 142 fish, were collected from two close localities (ca. 35 and 16 km apart) from each of two different biogeographical regions. Similarity of samples at the infracommunity level was analysed by calculating Bray-Curtis similarity indices, followed by nonmetric multidimensional scalings (nMDS). To further examine differences between localities, a canonical analysis of principal coordinates was carried out to compare infracommunities. A PERMANOVA with host length as a covariable was also carried out. All sites were significantly different in their infracommunity structure, even those at short distances from one another, but infra- and component community structures showed higher similarities between sites within regions than between regions. The results proved that parasites can be valuable tools to assess fine-scale fish population structure where site fidelity and adaptations to local conditions are important.

Two papers described studies carried out in the Mediterranean Sea. Bottari *et al.* (2020) identified two distinct stocks of the mullets *Mullus barbatus* and *M. surmuletus* from two areas off the coast of Sicily using long-lived larval helminths as tags. Fish were sampled in March and October of the same year and parasite data were analysed using Fisher's exact test and Bootstrap t-test. The parasites that proved most useful as tags for both species of mullet were *Stephanostomum sp. metacercariae (Digenea)*: fish caught in the Strait of Sicily showed high prevalences (26 and 46.8%), while no infected fish was caught in the Southern Tyrrhenian Sea. For *M. surmuletus*, infection data for unidentified trypanorhynch larvae (Cestoda), digenean larvae and *Hysterothylacium* larvae (Nematoda) further supported the *Stephanostomum* evidence. The other study from the Mediterranean, by Boudaya *et al.* (2020), used parasite assemblage data, together with host morphometrics, to investigate the possibility of separate stocks of the gurnard *Chelidonichthys obscurus* in two gulfs off the coast of Tunisia. Infection data on four short-lived adult helminths and two long-lived helminth larvae (*Hysterothylacium aduncum* and trypanorhynch larvae) were analysed using a multivariate discriminant analysis. The long-lived parasites showed no significant variations in prevalence or mean abundance between the gulfs, but three of the short-lived adult helminths showed variations in prevalence and mean abundance that, considered together with the morphometric data, provided evidence of the possible existence of separate stocks of gurnard in the two gulfs. The authors added a caveat that the effectiveness of using the short-lived parasites as tags is uncertain.

Two papers used parasites to trace migrations of tunas. Hermida *et al.* (2019) used parasite tags to identify seasonal migrations of skipjack tuna *Katsuwonus pelamis* in the North Atlantic by examining 128 tuna from the Madeira archipelago sampled in May and October of the same year. Differences in parasite prevalence between seasons were assessed using the Chi-square test and the influence of host and season on parasite abundance was investigated using Generalized Linear Models (GLMs). Several parasites showed variations in abundance with season, host fork length and fat content. Two adult and two larval helminths showed seasonal differences in abundance. The significant increase from May to October in abundance of the larval trypanorhynch cestode *Tentacularia coryphaenae* and the concomitant decrease in the abundance of *Anisakis sp.* larvae (Nematoda) indicated an input of fish from different areas, most likely from tropical regions. This is supported by the occurrence of some other parasites only previously reported from Brazil, which points to a mixing of skipjack tuna populations from both sides of the Atlantic. In the other study, Moore *et al.* (2019) analysed the parasite faunas of juvenile bigeye tuna *Thunnus obesus* and yellowfin tuna *T. albacares* to determine how far they may have moved since metamorphosis and graduation to a piscivorous diet. Their vast study area included ports within 6 fishery management areas in Indonesia, and from 2 outlier areas (Maldives and Solomon Islands) for contrast. Gills and viscera from 767 *T. obesus* and 1198 *T. albacares* were collected and examined, and both morphological and molecular methods were used for parasite identification. Statistical analyses were by univariate analysis of abundance data (one-way permutational analyses of variance) for each individual parasite taxon, and multivariate analysis of abundance data (a series of linear discriminant analyses (LDA)) for parasite community assemblages. Fish from the two outlier areas harboured parasite faunas distinct from adjacent Indonesian areas. Within Indonesia, results indicated that few juvenile tuna moved west from the Pacific Ocean into the archipelago and few moved west from the archipelago into the eastern Indian Ocean. The results provide a necessary first step in examining structuring of the two tuna spp. in Indonesia and indicate that juveniles of both spp. may have more restricted movement than is recognized in current management arrangements.

In the northeast Pacific, Jacobsen *et al.* (2019) investigated migration patterns of the northern population of Pacific sardine *Sardinops sagax* using parasites as biological tags. Samples from 5 regions were collected from March through November 2005-2008. Fourteen parasite taxa were recorded from 1388 fish examined. To quantitatively evaluate variation in parasite communities, parasite data were modelled for main effects using a 3-way PERMANOVA based on Bray-Curtis similarities. Canonical analysis of principal coordinates (CAP) based on abundance data was used to further examine differences among parasite communities. The results indicated significant differences in parasite communities among all size classes of sardine caught off Vancouver Island compared with those caught off Washington and Oregon and regions off California. The results support a high degree of residency in all size categories of sardines off Vancouver Island during the study period and indicate that individual sardine behaviour is not limited to completing an annual migration between British Columbia or the Pacific Northwest to Southern California. The results indicate that using parasites as tags could help clarify annual migration patterns of individual sardines.

In a chapter from a book devoted to the Baltic Sea ecosystem, Buchmann (2019) reviewed metazoan endoparasites as biological indicators for Atlantic cod, *Gadus morhua*, in the Baltic Sea. Two stocks of cod are recognized in the Baltic Sea: western and eastern. Marked changes in salinity, temperature and oxygen conditions from west to east determine the spatial distribution of different helminth parasites in the Baltic, thus facilitating the use of certain parasites as indicators of different aspects of cod biology, including stock identification and host migrations. This chapter reviews current knowledge of the life cycles and distribution of these helminths in the Baltic, lists the relevant literature, and highlights suitable indicator parasites.

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Interdisciplinary analysis (Contributors: Manuel Hidalgo, David Secor, Steve Cadrin and Lisa Kerr)

The application of interdisciplinary analyses (i.e. the combination of two or more stock identification techniques) have been increasing along the last years. In addition, due to the increasing effort in stock identity research and towards an effective implementation of the information of population spatial structure into management and assessment tools, important and comprehensive reviews have been published along 2019–2020.

As a part of the workshop on 'Spatial Stock Assessment Models' hosted by the Center for the Advancement of Population Assessment Methodology (CAPAM) in La Jolla (United States, October 1-5, 2018), a Special Theme Set has been published in the journal Fisheries Research. A succinct synthesis of the contributions to this workshop reveals that stock assessments require an adequate representation of the spatial scope and structure, while spatially structured stock assessment poses several challenges and still remain rarely applied (Cadrin *et al.* 2020). Within this Theme Set, two main reviews might be considered. Cadrin (2020) reviews population dynamics theory, case studies in management and simulation tests to demonstrate that accounting for spatial structure in stock assessments can improve model performance while ignoring it, tend to lead to failures in fisheries management due to misperceptions of stock status. He emphasizes that an efficient performance of stock assessment relies on both the spatial extent but also the spatial structure of the stock, which includes major patterns of fishing behaviour and population heterogeneity. The review concludes that the development of stock assessment applications should include an evaluation of the most appropriate spatial scope and structure by: interdisciplinary synthesis of all available information, the development of spatial operating models, and testing the performance of estimation models and management strategies. Punt (2020) states that besides the slow but consistent increase in the number of assessments in which space is explicitly represented in the population dynamics model, there is still important challenges associated to the modelling of recruitment and movement. He reviews current available assessments based on spatially-explicit models, identifying the challenges associated with modelling recruitment and related to the increased model and parameter estimation complexity. He provides available solutions and synthetize best practice guidelines. In Punt *et al.* (2020), the authors review which are the challenges for next-generation stock assessment packages, which need to provide a set of extensions needed to assess stocks that do not satisfy the 'well-mixed single-stock' paradigm, being one of them the implementation of the spatial structure.

A second large review of multi-species stock structure occurred for Pacific Ocean tunas, which comprise 70% of the global tuna catch. A large synthesis of existing evidence for different stock structures (Moore *et al.* 2020a) and a prospectus to improve stock structure through directed sampling and research (Moore *et al.* 2020b), were the result of an international workshop held in New Caledonia in 2018. Assessments have assumed eastern vs. stock splits for skipjack *Katsuwonus pelamis*, yellowfin *Thunnus albacares*, bigeye tunas *T. obesus*, and South Pacific albacore *T. alalunga*. Straddling stocks is an enduring issue for the vast management areas of the Western and Central Pacific Fisheries Commission and the Inter-American Tropical Tuna Commission. Evidence for each species is presented as genetic v. non-genetic (tagging data, tissue and otolith analysis, parasites, landings, demographics, and biologically-coupled oceanographic models), and complementary figures provided on current stock structure assumptions, catch data, tagging tracks, and distribution of traveled distances by tagged tunas. Across species, both more continuous yet finer scaled movements than recognized in assessments are featured in the synthesis. Yellowfin conformed better than other species to the East-West split but also showed evidence of regional fidelity. Moore *et al.* (2020a) conclude with six aspects, central in resolving Pacific tuna spatial structures in assessment: 1. Spawning dynamics; 2. Spawning fidelity and localized residency; 3. Provenance of fish, natal homing, and stock contribution levels; 4. Stock connectivity; 5. Effects of climate change; and 6. Sensitivity of stock assessments and climate change models to spatial structure assumptions. In the prospectus (Moore *et al.* 2020b), a series of alternative spatial models are presented as prelude to broader thinking on developing future survey and research initiatives. They include: panmixia, isolation by distance, regional residency, spawning area fidelity, and metapopulation structures.

Interdisciplinary studies combining information from genetics and otolith-based techniques are still a classic interdisciplinary approach in the literature, while improving this interaction by adding other additional techniques, or moving to the application of more sophisticated genomic techniques. Berg *et al.* (2020) apply three different methods to discriminate and understand the dynamics between spring and autumn spawning Atlantic herring (*Clupea harengus*). First, they discriminated herring using maturity development to determine spawning season phenotype. Second, two diagnostic single nucleotide polymorphisms (SNPs) were genotyped and analyzed. And third, otolith microstructure phenotype was also used to discriminate herring of spring or autumn hatching origin. In contrast to the two other methods, the otolith microstructure also provides information of the hatching season of herring. Results revealed certain switching of spawning season behaviours (e.g., recruits from spring spawning, spawn as adults in autumn, and vice versa) that may contribute to gene flow between herring populations, while the viability of the offspring from these individuals still remains unclear. Veax *et al.* (2020) analyzed the genetic variation at >15,000 neutral loci of deacon rockfish (*Sebastes diaconus*) for three locations on the Oregon coast (East Pacific) combined with otolith shape information of the same individuals. They found little differentiation among the three sample sites, and considering the results to be suggestive of a single stock. By contrast, they found a strong sexual dimorphism in the genomic data, also consistent with the otolith shape that displayed a strong ontogenetic pattern. They conclude that future studies should evaluate how the stock is affected by differences in sex, age, and gene flow between the nearshore and offshore environments.

Several studies using genetics to depict spatial structure in the populations also used fishery-independent information to understand the potential ecological mechanisms triggering the differentiation observed. Huret *et al.* (2020) used SNPs to quantify the degree of gene flow between the currently managed fish stocks of European anchovy (*Engraulis encrasicolus*) in the Bay of Biscay and northern areas of its distribution, using as well survey-based CPUE and its seasonal relationship with the environmental variability to support the spatial differences. The genetic analyses revealed clear distinctions between the Bay of Biscay and northernmost populations, with assignment of all English Channel samples to the latter. Fishery-independent information supports this differentiation with anchovies sampled in autumn in the English Channel originating from the summer spawning aggregation in the warm, low saline and plankton rich south-eastern North Sea. This change in the seasonal distribution of the northern population mimics, but in an opposite direction, the one in the Bay of Biscay where anchovy spread towards the north from the spawning habitat into the south-eastern bay. Sakuma *et al.* (2019) combined mitochondrial DNA analyses of Pacific cod (*Gadus macrocephalus*) with spatiotemporal information obtained from surveys to delineate management units of this species over the Japan coast of the Sea of Japan. Based on the consistent results obtained from the two techniques the authors propose a single boundary to be set along the coast of western Honshu Island to divide the area in two management units for this species.

The diverse type of information obtained from otoliths is also one of interdisciplinary avenues to reveal stock boundaries. Schade *et al.* (2019) assessed and contrast four non-molecular stock discrimination techniques based on otoliths (otolith shape analysis, stable isotope analysis on otolith nuclei, otolith readability and diameter of translucent zones) using genetically validated samples (based on SNPs) to assess the assignment of individuals from mixed-stock fisheries of Atlantic cod (*Gadus morhua*) in different areas of the Baltic Sea. The authors concluded that given the high assignment accuracy and the availability of archived otoliths, otolith shape and stable oxygen isotope analyses on otolith nuclei are powerful separation methods that allow for high quantification of present and past mixing proportions of Baltic cod stocks. Authors also provide a comprehensive synthesis of the pros and cons of each technique. Soeth *et al.* (2019) used information of otolith microchemistry and otolith shape of Atlantic spadefish (*Chaetodipterus faber*) sampled in five separated areas of the southeast cost of Brazil. The authors conclude that connectivity between the local population of *C. faber* in the northern population is high while it is limited in the southern populations, suggesting spatially structured semi-discrete groups. Despite the possibility of intermixing *C. faber* populations in the Brazilian Southwest Atlantic coast, authors conclude that local populations should be regarded as different stocks for fisheries management purposes. The same two techniques (otolith microchemistry and otolith shape analyses) were also applied by Biolé *et al.* (2019) to investigate stock identity of fish stocks of Brazilian codling (*Urophycis brasiliensis*) in the Southwestern Atlantic Ocean including samples from Brazil, Uruguay and Argentina. Their results revealed both the presence of at least two fish stocks (Argentina and Brazil), with a third potential stock in Uruguay, but also suggest a strong spatial segregation during ontogeny. Again using otolith microchemistry and otolith shape analyses, Ferreira *et al.* (2019) analyzed the population structure of the tub gurnard *Chelidonichthys lucerna* in Portugal, sampling three locations along the north-central coast. The obtained shape and chemical signatures suggest that *C. lucerna* is apparently a unique single population-unit, although not necessarily homogenous, in this area in Portugal, and that these fish populations should not be managed separately for fisheries purposes. Moura *et al.* (2020) also applied otolith chemical signatures (including microelements and stable isotopes) and otolith shape analyses to investigate potential stock substructure within North-West Atlantic and the North-East Atlantic stocks of Atlantic mackerel (*Scomber scombrus*). Their results indicate a full discrimination within the Northwest Atlantic subcomponents while the authors inferred a complex metapopulational structure in North-East Atlantic. Sakamoto *et al.* (2020) combined otolith $\delta^{18}O$ signatures and microstructure analyses to investigate nursery habitat temperatures and early life growth rates, respectively, of sardine (*Sardinops sagax*) collected from three biogeographic regions around South Africa's coast. The authors test the hypothesis the existence of three, semi-discrete subpopulations, which contrasted to the historically assumed single and panmictic population. Their results indicate that for both summer- and winter-captured adults and summer-captured juveniles, fishes from the west coast grew significantly slower in water that was several degrees cooler than those from the south and east coasts. Their results suggests that mixing between regions is relatively limited, and supports the hypothesis of semi-discrete sub-populations. However, west-south differences does not appear in the winter-captured juveniles, suggesting that differences in early life conditions between regions may change seasonally or most winter-captured juveniles originated from west coast.

Several studies have combined fisheries-dependent information with other stock identification techniques. Kerr *et al.* (2020) applied otolith chemistry techniques ($\delta^{13}C$ and $\delta^{18}O$) to characterize the origin of bluefin tuna (*Thunnus thynnus*) caught in the U.S. rod and reel fishery in the Gulf of Maine and to demonstrate how this information can be applied in fisheries assessment to quantify the effects of stock mixing. Their results indicated that the majority of tuna captured in the Gulf of Maine were from the eastern population originating in the Mediterranean Sea. The authors provided an efficient approach for integrating mixed stock composition information into fishery assessment data including rod and reel catch, catch-at-age, and catch-per-unit-effort. Santos *et al.* (2020) combined information of the spatiotemporal distribution, size composition, sex and movement patterns obtained from tagging experiments of blackbelly rosefish (*Helicolenus dactylopterus*) to assess the stock structure of this deep-sea species in the Azores islands (NE Atlantic). The integration of all this information combined with previous research indicate that the stock of this species around the Azores archipelago is formed by several local management units. Attending to these results, the authors recommend that exploratory analysis for analytical assessment must be performed under the assumption of local management units. Braun *et al.* (2020) combined fisheries-dependent data of broadbill swordfish (*Xiphias gladius*), a recently developed geolocation approach that synthesizes tag data, and a global observation-assimilating ocean model to improve geolocation accuracy of movement information over the north Atlantic and improve the scientific support of the current stock structure. Juvenile swordfish were tagged in the Azores displaying regional movements. Adults were tagged in the northwest Atlantic moving between summer foraging grounds near the Grand Banks to winter habitats near the Antillean Arc. Their results integrating movement information based on pop-up satellite archival transmitting tags with conventional available tagging information, and catch-per-unit effort data, indicates a complex stock structure within the North Atlantic that consistent with current stock structure. Hidalgo *et al.* (2019) used dispersal and connectivity metrics derived from oceanographic models (*i.e.* particle dispersion experiment) to model temporal dynamics of fish recruitment and survival (recruitment/spawning stock biomass) of the complex stock of European hake (*Merluccius merluccius*) in the Western Mediterranean. Their results revealed that inter-annual variability of recruitment is well reproduced by hydroclimatic influences and synthetic connectivity estimates informed levels of self-recruitment over different management areas. These authors show that fisheries management and assessment could be improved by assimilation information of physical oceanography, including observing systems and operational models. Finally, Boudaya *et al.* (2019) examined the population structure of the longfin gurnard (*Chelidonichthys obscurus*) in the Tunisia coast (Central Mediterranean), analyzing morphometry and parasite assemblages on samples obtained in different areas. Morphometric analysis revealed strong spatial variations between the studied zones, providing evidence for the existence of an ecological differentiation along the eastern Tunisian coast. By contrast, the effectiveness of using parasites to study longfin gurnard stocks was uncertain, suggesting the application of complementary approaches to reveal the stock structure of the species in the area.

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