STOCK IDENTIFICATION METHODS WORKING GROUP (SIMWG)

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Contents

i Executive summary

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

In 2021, SIMWG continued providing 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.

The key activity of SIMWG is to address requests by ICES working groups for technical advice on issues of stock identity. In 2021, SIMWG reviewed the report of a project on herring stock structure upon request by the ICES Herring Assessment Working Group (HAWG).

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 annual reviews on advances in stock identification methods keep 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 is coping 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	2/3
Chair(s)	Christoph Stransky, Germany
Meeting venue(s) and dates	By correspondence in 2020
	By correspondence in 2021, online meeting, 17 June 2021

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) Interdisciplinary approaches
j) Emerging issues

SIMWG annual reviews on advances in stock identification methods keep 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 annual reviews of advances in stock identification methods are summarized in Annex 4.

2 Technical reviews and expert opinion on matters of stock identification

SIMWG provides ICES expert groups and working groups expert feedback on questions of stock structure for ICES stocks. In 2021, SIMWG has contributed to ICES advisory needs by providing expert feedback on the status of stock structure of several species.
SIMWG received a request from the Herring Assessment Working Group (HAWG) on reviewing and commenting a recent project report on stock structure of herring *(Clupea harengus)* west of the British Isles. The details of the review are summarized in Annex 3.

The second request, received from the Working Group for the Bay of Biscay and the Iberian Waters Ecoregion (WGBIE) could not be considered in due time, as it was also addressed to the Working Group on Application of Genetics in Fisheries and Aquaculture (WGAGFA) and the SIMWG tasks were not defined clearly, which could not be clarified before SIMWG report submission.

In addition, the SIMWG chair participated in the preparation of the Benchmark Workshop for Barents Sea and Faroese Stocks (WKBarFar 2021) and provided information on stock discrimination of Norwegian coastal cod and Northeast Arctic cod.

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

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

There has been no notable contribution of SIMWG on this ToR during the current reporting year. It is expected that this ToR will be dealt with in detail during the next physical meeting of SIMWG.

Annex 1: List of participants

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Annex 2: SIMWG Resolution

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	17 June & by correspondence	Online meeting		
Year 2022	tbc		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 fulfill requests.
Linkages to other organizations	There are no obvious direct linkages, beyond the SIMWG members’ affiliation and commitment to their own employers.

Annex 3: Responses to requests from ICES working groups

HAWG request

SIMWG received the following request from the Herring Assessment Working Group (HAWG):

An EASME funded project to assess the stock identity of herring in Divisions 6.a, 7.bc through genetic and morphometric analysis was completed in December 2020. The genetic assignments developed during the EASME project will be used as the basis for splitting survey indices into the different populations. It is recommended that before the results and conclusions from the project are incorporated into the assessment and management of 6a, 7bc herring that the report should undergo peer review. Herring in 6a,7bc will undergo a benchmark in January 2022 with a data meeting in November 2021. HAWG recommends that the methods and results of this project are reviewed by the Stock Identification Methods Working Group and feedback provided before the end of August 2021.

The project report (Farrell *et al.* 2021) is available for download here: https://op.europa.eu/en/publication-detail/-/publication/5cb3c320-a702-11eb-9585-01aa75ed71a1

The SIMWG had the opportunity to the review the results of the EASME project, recently presented to HAWG in order to clarify the stock structure of herring spawning and inhabiting the shelves between ICES subareas 6a and 7b-c.

The work carried out was an impressive collaborative effort, embodying much of what should be expected by modern applied fisheries stock identification science, by sampling thousands of individuals over multiple years and striving to select spawning fish to represent population baselines. The study should also be commended for the judicious approach of obtaining opportunistic samples from multiple sources, including recent historical specimens from previous projects (i.e. WESTHER), and exhibiting remarkable collegiate spirit in liaising with concurrent herring genomics projects (i.e. GENSINC) towards selecting the most appropriate genetic markers for the task at hand. In this context, this study should serve as an example of good practice for optimal use of existing resources and result reproducibility.

SIMWG felt that the methodology is rigorous throughout. Every step of the work is illustrated thoroughly, with a high amount of detail, especially regarding the two assignment approaches. These were mostly appropriate, though perhaps somewhat redundant. One limitation of the study is that only three groups were included in the baseline, even though the second approach suggested highest discrimination with k=5 clusters. These clusters were again combined in the next step, ending up with three major groups. The results achieved with the MSHAS samples did not appear to differ majorly between approaches. Should this toolkit become more practically employed in an operational environment, it may be useful to produce a simpler, shorter, “standard operating procedure” to facilitate intake and use by less technical operators. However, such an approach should potentially be implemented in the ICES Transparent Assessment Framework (TAF) system to achieve the best transparent outcome. This would also allow others to apply a similar method or to reproduce the outcome. A detailed comparison between the two assignment approaches is missing, it would, however, have been of interest why particular individuals would have been assigned differently. It may be worth comparing these assignment approaches with *Paetkau et al.*'s (2004) established “exclusion test”, as this might ground the approach in long-proven practice and potentially offer an additional level of verification.

There was some discussion about the choice of the 0.67 threshold (which can be viewed as representing the level at which a specimen is at least twice as more likely to belong to baseline X than baseline Y), which may well serve the purpose of examining mixed catches, but would not represent a defensible forensic tool in the context of traceability. This is also something to consider in view of translating this technology into applied operational settings. SIMWG suggests to conduct some sensitivity test on the threshold, also taking into account the potential existence of additional components not included in the baseline.

There is no doubt in SIMWG that the approaches presented can be used to:

1. Distinguish the 6aS late winter spawners from the 6aN autumn spawners;
2. Distinguish, more subtly, the spring-spawning contingent in 6aN from 6aS (even though the relatedness between these two is high);
3. Confirm essentially the 'North Sea nature' of the 6aN autumn spawners;
4. Assess the mixed MSHAS catches (which appear primarily composed of 6aS fish, with the proportion of autumn-spawning fish increasing as one moves north-east towards Cape Wrath and the Orkneys).

It may be expected that HAWG will want to flag the evidence above for consideration for advice revisions and reappraisal of current stock structure perceptions.

While the current approach appears fit for routine scientific assessment of catches, it is clear that should these markers be employed for market product traceability, the assignment thresholds would have to become more stringent and the computational procedures made simpler.

Regarding the morphometric approach, including body morphology and otolith shape analysis, SIMWG felt that the effort required would not be worth pursuing further in this context, given the poor stock resolution achieved by the method (which also appeared not to employ state-of-the-art tools) and the likely substantial sources of bias/noise introduced along the procedure. In terms of the body morphometrics, the used landmark analysis could have been replaced with a more appropriate method such as outline-based geometric morphometrics. However, SIMWG has some doubts that this would have increased the low assignment rates. Otherwise, also this section of the study is thorough, even though the same critique with regard to the assignment approach applies.

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

Advances in Stock Identification Methods in 2021

In 2021 (review period mid-2020 to mid-2021), 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, Florian Berg and Stefano Mariani)

Our annual monitoring of the usage patterns 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 2021 is not complete at this time (June 2021). However, while microsatellite studies are slightly declining, the number of papers with SNPs have doubled in 2020.

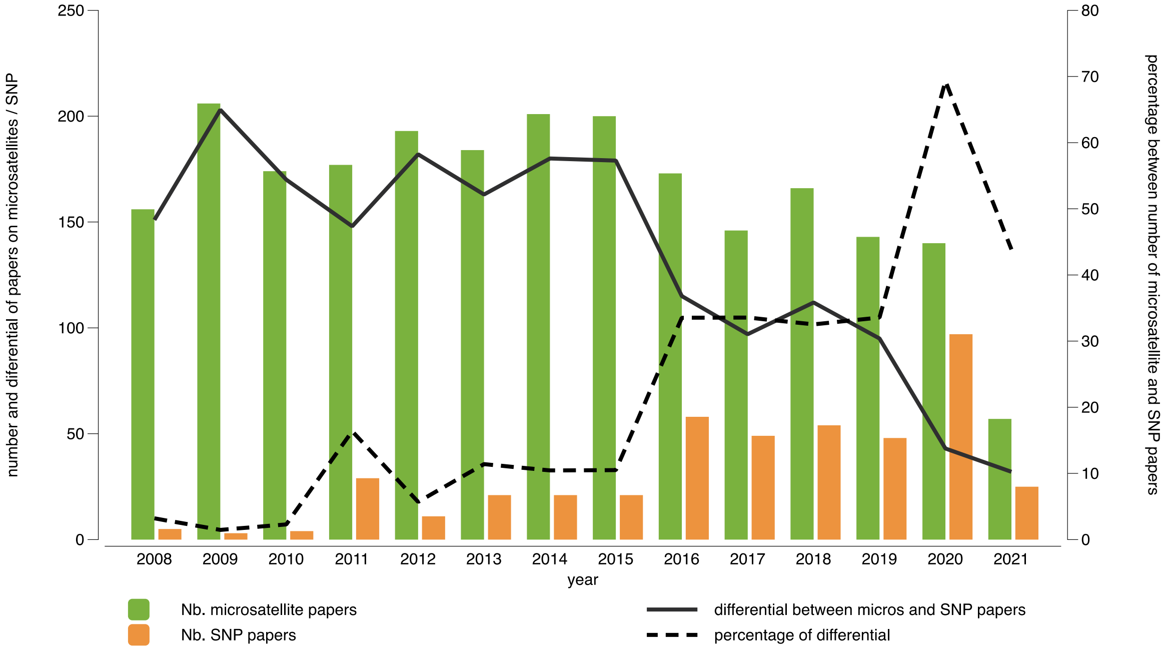

Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (green bars) and SNPs (orange bars), as listed in the Clarivate Analytics Web-of-Science. The search criteria were: “fish* AND gene* AND (population OR stock) AND ‘molecular marker*’,” where ‘molecular 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 (June 2021).

The use of genetic markers has contributed during the last year to numerous and significant advances towards marine stock structure and identification. A review by Papa *et al.* (2021) provides a detailed summary of the population genetic studies of New Zealand fish species (with a particular focus on hoki, orange roughy, snapper, ling, and blue cod), while highlighting still the lack of genetic data for many other commercial fish species.

The studies chosen contribute explicitly to demonstrate the relevance of molecular techniques in determining population structure in commercial species where previous, more traditional methods have failed. With the new methods even small-scale population structure among highly migratory species can be revealed.

Han *et al.* (2020) reported hundreds of loci underlying ecological adaptation to different geographical areas and spawning conditions in Atlantic herring (*Clupea harengus*), which could further be linked to several stocks managed within ICES waters. They applied a comprehensive analysis of whole-genome sequence data from 53 population samples spread across the entire species distribution. This paper is also a key contribution to study review by SIMWG requested by HAWG.

The population structure of another highly mobile species, haddock (*Melanogrammus aeglefinus*) was revealed by Berg *et al.* (2021). They investigated 138 SNPs in more than 1000 individuals from 19 locations across the North Atlantic. Their findings suggesting three main genetic clusters contrast with the current management regime as they found structure within some management areas.

For diadromous species, such as sea trout (*Salmo trutta*), where population dynamics are affected by processes occurring in both freshwater and marine habitats, knowing the population structure is of particular importance for their management. Bekkevold *et al.* (2021) genotyped 189 SNPs and assigned 916 migratory sea trout along the British North Sea coast showing different migratory behaviour among genetic populations. Their findings illustrate the scope for genetic stock identification to monitor population-specific migration behaviours in species where stock assessment has not traditionally incorporated marine phase dynamics.

Vandamme *et al.* (2021) explored whether the management of commercial flatfish, sole (*Solea solea*), brill (*Scophthalmus rhombus*) and turbot (*Scophthalmus maximus*), could benefit from population-specific information, namely in the form of seascape genetics. By using information such as geographical location, sampling year, water column dynamics, combined with genetic information in a redundancy analysis, authors show correlations between stock composition and depth of the pycnocline (turbot), average annual stratification and spatial factors (brill) and temporal factors (sole). The study concludes that the management of fish stocks has to consider species-specific genetic structures and may profit from the documentation of the genetic seascape and life-history traits.

In contrast, genetic studies can also reveal lack of population structure where fish are managed separately. McKeown *et al.* (2020) used SNPs to explore population structure of European sprat (*Sprattus sprattus*) and to inform about their alignment with current management units. They demonstrated lack of structure among the Northeast Atlantic samples indicating connectivity across current management boundaries. Furthermore, they found high genetic divergence of a Baltic population which permits diagnostic assignment of individuals between the NE Atlantic and Baltic populations. Another study involved a comprehensive analysis of the white anglerfish (*Lophius piscatorius*) in the Northeast Atlantic and found that the species is most possibly panmictic, which is in contrast with the current management of three stocks (Aguirre-Sarabia *et al.*, 2021). Moreover, two other findings are worth reporting: (1) among the specimens classified as white anglerfish based on morphological characteristics, 11% were are genetically identified as black anglerfish (*L. budegassa*), and 2) up to 20% of hybrids between the two *Lophius* species can be found in certain areas. This is a clear example were fisheries management should consider the genetic component of these species.

Often several studies on a same species do not consider the previously existing genetic data and do not take advantage of earlier sampling of thousands of individuals over multiple years. Modern applied fisheries stock identification science is expected to implement a collaborative effort, but examples are still scarce. The study by Sort *et al.* (2021) provides such an example, building the first standardized global microsatellite database for a shark species, the tiger shark (*Galeocerdo cuvier*). Authors show that global calibration of microsatellite and other genetic datasets can increase the statistical power and resolution of population structure analysis.

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

The number of studies using growth marks in calcified structures to identify stocks has reduced in the last year. From June 2020 to July 2021, no peer-reviewed article, only one report, was published using this method for stock discrimination, despite the increasing numbers in publications using biosclerochronologies.

In the US, Atlantic cod (*Gadus morhua*) are currently managed as two stocks (management unit). However, in the southwestern Gulf of Maine, two sympatric populations (biological units) have been identified by a number of genetic and phenotypic characters. This is an active area of discussion and meetings for an upcoming 'benchmark' assessment of US stocks, because it could require discrimination of mixed-stock fisheries. One method to discriminate these two populations, winter and spring spawners, with patterns in calcified structures was outlined by Dean *et al.* (2019) developing a model using spawning individuals as baseline for the two sympatric populations. They demonstrated that the first two annuli of winter-spawning fish were significantly larger than those of spring-spawning fish in the western Gulf of Maine.

Lefebvre *et al.* (2021) used this method and applied it to samples from the Northeast Fisheries Science Center (NEFSC) archive for two periods: a contemporary (mid-2010) and a historic (mid-1970s) period. Applying the model developed by Dean *et al.* (2019), they were able to successfully discriminate the two populations and calculate their proportions. In general, the length of the first annuli increased from the historic to the contemporary period, as well as that the proportion of spring spawners decreased. However, the trend in decreasing proportions might be interpreted with caution since they have not considered spatial coverage or sampling effort. They also highlighted that changes in annuli length over time would involve adjustment or recalculations of the initial model developed by Dean *et al.* (2019).

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Life history parameters (Contributor: Richard McBride)

Lam *et al.* (2021) report latitudinal patterns in life history consistent with Bergmann's rule (i.e. lingcod from colder, northern waters were larger-at-age, lived longer, matured at larger sizes, and had lower natural mortality rates than lingcod from warmer, southern waters) as well as size-specific sexual dimorphism (Females were larger, older, and matured as larger sizes). Lingcod, of both commercial and recreational importance, range across 28° of latitude along the US west coast, from southeast Alaska (60°N) to southern California (32°N), requiring large numbers of fish (2189 fish) from numerous locations (24 ports). Analyses of these life history data indicated a stock boundary near central Oregon, whereas a companion analysis of genetic data indicated a stock boundary to the south, near central California. The genetic study was published separately but included many of the same individual fish. The authors consider that the mismatch between the life history and genetic results arises from the inherent difference in scales between ecological versus evolutionary processes. The current boundary used in stock assessment is in between both estimates, at the Oregon-California border, suggesting additional exploration of spatially-based assessments and management options would be helpful.

A "Final Report of Red Hake Stock Structure Working Group" contains new information on stock structure of *Urophycis chuss* (NEFSC, 2020), a commercially important groundfish. Although the Working Groups objective was to consider data from all disciplines available, no genetic or tagging information exists, so the report was limited to analyses of otolith morphology, age and growth, otolith microchemistry, and early life history. Red hake has been managed as two stocks, a northern and southern component, and this was set as the null model. The age and growth data consistently supported the two stock model, even in the face of a decline in growth over time in each stock area. Consistent with a general ecophenotypic pattern with respect to latitude, fish in the southern stock area grew faster but reached a shorter length at older age than individuals in the northern stock area, where the waters are colder. The early life history data offered hints that stock structure could be more complicated, but the limits of all available data held back rejecting the null model of a two-stock fishery.

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Morphometrics/meristics (Contributor: Emma White)

Wardiatno *et al.* (2021) investigated the difference between *Rastrelliger* spp. from three locations off Indonesia using standard morphometric methods and truss network analysis. These mackerel species are ecologically and economically important and the possible population mixing between three mackerel species within this area requires the correct form of management. The discriminant analysis and cluster analysis used in this study based on body morphometrics and truss network showed that there is an overlap between mackerel collected from Ketapang and Bangka. Mackerel from Bintan showed separation from the other two samples. It was noted by the researchers that mackerel populations from Ketapang and Bangka inhabit areas closer to the beach, whereas the Bintan mackerel tend to be further from the shore, which may indicate morphometric adaptations to their environment.

In order to improve the knowledge of species diversity and stock structure of mud crab populations along the Bangladesh coast, Asaduzzaman *et al.* (2021) collected morphometric length measurements and morphometric ratios from three coastal regions of Bangladesh. This study identified two mud crab species from the samples with high classification rates (>99%) using a Linear Discriminant Function Analysis (LDFA). It was also recorded that one stock is much larger than the other, which will have important implications for the management of these species in this area.

Morphometrics was used to discriminate between seven species of prawns from the genus *Metapenaeus* which inhabit Indian waters (Chennuri, *et al.*, 2020). A total of 40 morphometric measurements were collected and use of a correlation matrix showed that 14 of those measurements proved to be important in distinguishing between the different species. 100% classification accuracy was calculated for six of the species, and >87% accuracy for *M. kutchensis*. A simple identification key has been proposed for species of *Metapenaeus* as a result of this study.

El qendouci *et al.* (2021) investigated the variation in body shape of a species of European anchovy (*Engraulis encrasicolus*) in order to understand its stock structure off the North Atlantic and Mediterranean coasts of Morocco. Discriminant Analyses, based on Mahalanobis distances, were applied to 12 body morphometric measurements recorded from each fish. A distinction between the two groups was found with a classification accuracy of 71.9%. The results of this work can be used to develop new fisheries management strategies.

The difference in meristic, morphometric characters and length-weight relationship were used to estimate the variability between river prawns, *Macrobrachium nipponense*, caught in the Caspian Sea, the Anzali Lagoon and a sample taken from an aquaculture farm (Tizkar *et al.*, 2020). Ten measurements were taken from each individual and the data was analysed using cluster analysis and discriminant analysis. This study found there are two morphologically distinct populations of the river prawns.

Mallik *et al.* (2020) applied three stock identification methods; meristics, morphometric and otolith shape analysis, to distinguish between *Priacanthus hamrur* caught in two areas on the east and two areas on the west coast of India. The study used 14 body morphometric traits to perform a stepwise Discriminant Analysis. Body morphometric measurements showed a difference between all four areas, with the largest difference between areas from the east and west of the country.

Ramya *et al.* (2021) conducted a stock structure study on the endemic species of fish, *Barbodes carnaticus*, caught in two Indian rivers. Four stocks in total were investigated; three wild river stocks and one farm-reared stock. A total of 27 morphometric, 9 meristic and 30 truss measurements were collected from each fish. The study applied principle component analysis (PCA), factor analysis (FA), discriminant function analysis (DFA) and cluster analysis (CA) to both conventional morphometric measurements and truss network variables to compare the variation detected by the two methods. The different measurements and analysis techniques showed differences between the four stocks but there were some conflicting results between conventional and truss variables. The paper has suggested genetics as a way to better understand the stock structure of this species.

Morphometrics was used to identify different strains of *Oreochromis niloticus* being farmed in Lake Kariba, Zambia (Makeche *et al.*, 2020). 22 body measurements were collected from each fish and analysed using a dendogram. The study detected eight different strains of *O. niloticus* being farmed at one of the fisheries in Lake Kariba.

Vicente *et al.* (2020) studied *Engraulidae* fishing stocks from an estuary in northeast Brazil using traditional taxonomy, geometric morphometrics and molecular systematics in order to identify the number of species in the *Engraulidae* family that are being commercially exploited in this area. Meristic data were collected for taxonomic analysis and 10 landmarks across the body were chosen for geometric morphometric analysis. Traditional taxonomy identified four fish to species level and two taxa could be identified to genus level. A new identification key was drawn up using morphological features and photographs as a result of the taxonomic analysis. Canonical Variation Analysis (CVA) applied to the geometric morphometric data was in agreement with the outcome of the traditional taxonomic analysis. The results of this research are expected to improve the management of these fish stocks.

Using morphometric relationships, Bodin *et al.* (2020) studied 39 marine species in order to collect appropriate survey data and improve fisheries research management of reef fish in the Seychelles. Two length measurements and three weight measurements were used to explore length-weight, length-length and weight-weight relationships. The length-weight relationship parameters estimated were compared with values published in Fishbase for the same species from different areas. Also, the morphometric relationships of five commercially important species fished in four areas around the Seychelle Islands were recorded in order to identify any spatial differences. These morphometric relationships can contribute to the improvement of fish stock assessments and fisheries research management.

Outside of stock identification and stock discrimination, morphometric and meristic methods have been used to answer various research questions:

Gilby *et al.* (2020) investigated the impact of human pressures on giant mud crabs (*Scylla serrata*) from estuaries in Queensland, Australia. Body morphometric measurements were used to analyse how fishing and urbanisation has affected the body size and functional traits of the giant mud crab. Correlations were found between estuary landscape and body size; larger crabs were found in bigger inlets. Fishing pressure and human population size were found to be negatively correlated with chelipeds size. Using morphometrics, the study showed that human impacts can negatively affect the body size and functional traits of the giant mud crab.

With a focus on climate change, Fang *et al.* (2021) used body size and beak morphology of squid species, *Ommastrephes bartramii*, in the North Pacific Ocean to investigate annual morphological changes under different scales of climate events. Environmentally induced abundance fluctuation was reported by another study, so to investigate this further, geometric morphometrics were used by Fang *et al.*, (2020) to detect any changes in beak morphology and statistically compared the interannual body size change from different climatic years. The study found that both body size and beak shape of *O. bartramii* changed under differing environmental conditions and they concluded the phenotypic plasticity of *O. bartramii* could be used as a response to environmental change.

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Tagging (Contributors: Karin Hüssy and Douglas Zemeckis)

Introduction

This review covers 23 studies published since the last report in 2020. These studies are based on a range of tagging techniques from conventional to acoustic and satellite pop-up tags:

- Conventional tags: 4 studies (Bi *et al.*, 2020; Kneebone *et al.*, 2020; Santos *et al.*, 2020; Randon *et al.*, 2021)
- Electronic data storage tags: 1 study (Aalbers *et al.*, 2021), plus two geolocation methodology validation studies (Gatti *et al.*, 2021; Haase *et al.*, 2021)
- Satellite pop-up tags: 6 studies (Armstrong *et al.*, 2020; Gatti *et al.*, 2020; Griffiths, 2020; James *et al.*, 2020; Kneebone *et al.*, 2020; Rohner *et al.*, 2020)
- Acoustic tags and telemetry: 9 studies (Gahagan and Bailey, 2020; Gargan *et al.*, 2021; Hessenauer *et al.*, 2021; Lédée *et al.*, 2021; Mack *et al.*, 2021; Minett *et al.*, 2021; Secor *et al.*, 2020a,b; Stratton *et al.*, 2021)

The main objectives addressed by the studies were uncertainty in connectivity and spatial population structure in general (Armstrong *et al.*, 2020; Aalbers *et al.*, 2021; Gargan *et al.*, 2021; Mack *et al.*, 2021; Randon *et al.*, 2021; Secor *et al.*, 2020a,b) or in relation to management areas (Gatti *et al.*, 2020; Santos *et al.*, 2020; Aalbers *et al.*, 2021; Hessenauer *et al.*, 2021) and the need to improve stock assessment in presumably overexploited stocks (Griffiths *et al.*, 2010; Kneebone *et al.*, 2020).

Information from tagging data are increasingly combined with other data sources such as abundance and biological indices from fisheries-independent surveys (Santos *et al.*, 2020; Randon *et al.*, 2021), genetics (Lédée *et al.*, 2021; Minett *et al.*, 2021; Randon *et al.*, 2021), otolith shape (Randon *et al.*, 2021), and even photographic-identification database collected by researchers and citizen scientists (Armstrong *et al.*, 2020). As a direct consequence of one tagging study, conservation measures were introduced for ferox trout in western Ireland (Gargan *et al.*, 2021).

The results of several other studies highlighted the need for spatial management to conserve species and stock components (Armstrong *et al.*, 2020; Griffiths, 2020; James *et al.*, 2020; Kneebone *et al.*, 2020; Minett *et al.*, 2021; Randon *et al.*, 2021; Stratton *et al.*, 2021) and even the need for transnational (Aalbers *et al.*, 2021) or national trans-jurisdictional fisheries policies (Hessenauer *et al.*, 2021). Also, recent studies have worked to evaluate and improve the accuracy of geolocation methods for inferring movements and stock structure of demersal groundfish (Gatti *et al.*, 2021; Haase *et al.*, 2020).

In the following, we provide a short summary of objectives, methods, and main results for each of these recent tagging studies with relevance to stock identification.

Identification of stocks and stock components

Santos *et al.* (2020) aimed at providing empirical information to support analytical assessment of blackbelly rosefish (*Helicolenus dactylopterus*) in the Azores archipelago using a combination of catch data, fishery-independent survey indices, and data from 221 fish tagged with T-bar anchor tags from 2000-2016. Despite being distributed across multiple management units in the Azores region, blackbelly rosefish exhibit a strongly sedentary behaviour and an intraregional separation among populations.

Randon *et al.* (2021) also used multiple population- and individual-based approaches, including data from conventional tag-recapture programs carried out in 1970-2018 to improve the understanding of the role of adults in population connectivity and spatial structure of common sole (*Solea solea*) in the Eastern English Channel. Limited migratory exchange was observed between three stock components within the main management area. This misalignment of the current stock definition with the underlying biological metapopulation now requires the improvement of the assessment-management to ensure its sustainable exploitation.

Aalbers *et al.* (2021) used 24 white seabass (*Atractoscion nobilis*) tagged with electronic data storage tags to study movements of fish tagged off Baja California, Mexico. White seabass exhibited seasonal site fidelity to specific geographic areas in Baja California, Mexico and also in California, USA. But, movements between these areas supports a transboundary nature of the stock and suggests that future management would benefit from international fishery policies.

Griffiths (2020) studied the movements and habitat specificity of longtail tuna (*Thunnus tonggol*) off the eastern coast of Australia to provide more knowledge of the species ecology for science-based conservation and management in the wake of stock assessment suggesting overexploitation of stocks. Longtail tuna in that area occupy coastal waters but move large distances associated with the spawning season suggesting metapopulation.

Kneebone *et al.* (2020) aimed to better understand the extent to which population structure, environmental conditions, and movement ecology may play a role in decreasing abundance and range contraction of thorny skate (*Amblyraja radiata*) in the Gulf of Maine using information based on 127 "mark-report" pop-up satellite tags (mrPATs) and 43 conventional tags. Thorny skates exhibited restricted movements without seasonal movements and may represent a single stock/population with metapopulation-like structure. This sedentary behaviour may induce a risk of localized depletion but also facilitates population recovery measures through spatial closures.

Armstrong *et al.* (2020) combined information from 22 satellite pop-up tags with 5146 records in a long-term photographic-identification database collected by researchers and citizen scientists to infer movement patterns of reef manta rays (*Mobula alfredi*) in the Ningaloo Reef World Heritage Area, Australia. Reef manta rays exhibited directional dispersal and connectivity characterized by an emigration-reimmigration pattern between the Ningaloo and another area, the Shark Bay World Heritage Areas, with some individuals exhibiting long-term site affinity to locations. The overlap of core area use with existing UNESCO World Heritage Areas demonstrates the potential for well-positioned marine parks.

Two separate studies addressed movement patterns and spatial distribution of stock components of Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of St. Lawrence (Gatti *et al.*, 2020, James *et al.*, 2020). Based on 62 pop-up satellite archival tags recovered from 2013 to 2018, Gatti *et al.* (2020) found that Atlantic halibut (*Hippoglossus hippoglossus*) showed summer site fidelity with all fish converging in the Gulf's deep channels to overwinter and spawn. According to these authors, this suggests strong mixing during the spawning period and thus a single reproductive population within the Gulf of St. Lawrence. Contrary to this, James *et al.* (2020) suggested that a study based on 20 halibut tagged with pop-up satellite archival tags and 123 with Floy conventional tags, that halibut move along distinct routes from feeding to two separate spawning areas in the deep channel. These authors thus suggest that this is evidence of the occurrence of two subpopulations in the southern Gulf of St. Lawrence, indicating a need to reconsider the current management of Gulf of St. Lawrence Atlantic halibut as one continuous population.

Identification of (spawning) migration patterns

Rohner *et al.* (2020) aimed to close gaps in the ecological understanding of striped marlin (*Kajikia audax*), hampering the efforts of sustainable fisheries management. There were 49 striped marlin tagged with pop-up archival satellite-linked tags off the Kenyan coast from 2015 to 2019 which exhibited long distance movements off the Kenyan coast with shifting seasonal activity hotspots indicative of migrations between feeding and spawning areas, where individuals seasonally moved between two major fishing areas.

Gargan *et al.* (2021) identified movement patterns of 58 radio-tagged ferox trout in two separate rivers in western Ireland to identify spawning locations and stock structure of the highly prized angler trophy species. Ferox from two different catchment areas/lakes showed that the majority of spawning occurred within a single river, highlighting the vulnerability of the ferox population. As a result of this study, conservation measures were introduced.

Stratton *et al.* (2021) aimed at identifying stock structure of Coho salmon (*Oncorhynchus kisutch*) in a coastal watershed on Kodiak, Alaska that supports vital subsistence and recreational fisheries and is currently managed as a single stock. The authors identified movement patterns using 348 radio-tagged adult salmon across three spawning season (2015-2017). Distinct patterns in areas used prior to and during spawning were identified highlighting the need for spatial management planning for conservation of the species.

Minett *et al.* (2021) studied the distribution patterns and range expansion of invasive brown trout (*Salmo trutta*) in the Falkland Islands using a combination of single nucleotide polymorphisms and acoustic tagging from three potential source populations. Low genetic diversity between streams and frequent movement of individuals between areas suggest that brown trout are a highly mobile species without strong stock structuring, and that without containment measures brown trout may invade most waterways in the area endangering native fauna.

Two studies addressed upstream spawning migrations by American shad (*Alosa sapidissima*) using acoustic telemetry. Mack *et al.* (2021) tested the hypothesis that the widely distributed American shad (*Alosa sapidissima*) perform return migrations to the same river systems for spawning. Of the 62 acoustically tagged American shad in the Albemarle Sound, USA, the majority used the same river for spawning, highlighting the need for spatial management to conserve the species. This innate pattern of return migrations is hampered by artificial obstructions such as dams and locks as demonstrated for the Charles river system by Gahagan and Bailey (2020). These authors documented impeded upstream migrations and delayed postspawn emigration based on 98 acoustically tagged fish.

Hessenauer *et al.* (2021) aimed at describing patterns of movement and spatial distribution of Great Lakes muskellunge (*Esox masquinongy*) in the St. Clair-Detroit River System in order to inform management decisions using 58 acoustically tagged fish in two rivers in 2016. Individual fish exhibited different patterns of residency and seasonal movements between areas, thereby crossing jurisdictional and waterbody boundaries.

Two studies used acoustic telemetry to investigate the stock structure of striped bass (*Morone saxatilis*) off the northeast USA coast (Secor *et al.*, 2020a,b). Secor *et al.* (2020a) investigated differential migration (increased migration propensity with increasing individual size) and its consequences to survival and reproductive patterns. Their findings confirmed expectations for a threshold size of striped bass emigrating from the Chesapeake Bay estuary and different mortality rates in resident and migratory population contingents, thereby supporting the central premise of the current stock assessment and management framework of a two-contingent population. Secor *et al.* (2020b) studied the spawning phenology of striped bass tagged in the Hudson River Estuary. Results demonstrated that each of two river reaches where tagging occurred was associated with separate contingents. The two contingents exhibited similar Atlantic shelf migration patterns, but with some differences in timing of migrations, and this presence of multiple spawning units can lead to differential demographic outcomes (e.g., exposure to fishing pressure) and potentially stabilize population dynamics.

Implementation of tagging data in stock assessment

Despite the fact that it is common knowledge that the spatial structure of fish populations is often highly complex and is not necessarily covered by existing management units, the underlying processes for the spatial patterns are often ignored in fish stock assessments. To promote progress towards approaches that do incorporate these spatial aspects, a workshop on "Spatial Stock Assessment Models" was hosted by the Center for the Advancement of Population Assessment Methodology (CAPAM) (Cadrin *et al.*, 2020). The full workshop report is available here: https://www.sciencedirect.com/science/article/pii/S0165783620301259.

Evaluation of different aspects of tagging studies and their relevance for stock identification

Lédée *et al.* (2021) assessed the applicability of a continental-scale array of acoustic receivers to study the stock structure and connectivity of seven teleost and seven shark species by comparison of patterns from this approach with those from genetic and conventional tagging. The authors' main conclusion was that "*Network analysis revealed previously unknown population connections in some species, and in others bolstered support for existing stock discrimination by identifying nodes and routes important for connectivity. Our study shows the power of continental-scale acoustic telemetry networks to detect movements among fishery jurisdictions*."

Bi *et al.* (2020) used 322 yellow perch tagged and recaptured with PIT tags from 2009 to 2015 to study different model setup for assessing movement patterns. Stock components of yellow perch exhibited relatively strong site fidelity in some areas of Lake Erie, Ontario, USA, while perch in other areas of the lake are more migratory, but without exchange between these areas. Some variation in movements across the lake and age classes were observed, highlighting the need for careful tagging design and data evaluation.

Geolocation enables inferences of fish movement tracks from recorded environmental variables from archival tagging data. This information on movements presents useful insights into stock structure for stock identification investigations, but the inherent uncertainty in geolocation necessitates continued advancement and improvement of geolocation methods for acquiring reliable movement information from environmental data. Gatti *et al.* (2021) reviewed validation methods and implementations of geolocation Hidden Markov Models (HMMs) to adapt to regional oceanography, fish species, and tag data, and also evaluated each evaluation approach. Their results showed that model performance can be improved using simple assumptions when pre-processing tag data and accelerometer data show potential for further parameterizing geolocation models. Haase *et al.* (2021) conducted five validation experiments in the southern Baltic

Sea to compare true and modelled positions for quantifying model performance in tagging studies with Atlantic cod (*Gadus morhua*). All five of the tested methods were found to be reliable as a geolocation tool for cod in the Eastern Baltic when an uncertainty of <20 km from the true position is acceptable in movement studies with application to stock identification.

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

From July 2020 to July 2021, there were 10 papers dedicated to otolith shape with one study reviewing the use of otolith shape outline analysis against otolith shape indices for stock discrimination. Another study investigated directional bilateral asymmetry in otolith shape (between right and left otoliths) as a new potential tool for stock identification. Four studies focused on the difference among species (*Booops boops, Istigobius ornatus, Merluccius capensis, Sardina pilchardus*) with only otolith shape as descriptor of stock identification. Additionally, there were 4 other studies using otolith shape in combination with another descriptor (otolith chemistry, genetic and body shape) for stock identification of several species (*Channa striata, Scomber colias, Solea solea, Saurida tumbil*).

Methodology and significant factors which drive otolith shape

Tuset *et al.* (2021) reviewed the literature searching for conceptual and statistical limitations in the use of shape indices and wavelets (contour analysis). They were being specially worrying in the first case due to the widespread routine use of shape indices. In the present study, 42 species were classified using otolith shape indices and wavelets and applying traditional and machine learning classifiers and performance measures. The results were conclusive; wavelets were a more adequate option for the classification of species than shape indices, independently of classifiers and performance measures considered. The artificial neural network and support vector machine provided the highest values for all performance measures using wavelets. In all cases, the measures of sensitivity and precision pointed out a higher confusion between some otolith patterns using shape indices. Therefore, they strongly discourage the routine use of shape indices for the identification of species.

Mahé *et al.* (2021) used the directional bilateral asymmetry in otolith shape between right and left otoliths. Often, studies have directly used the shape asymmetry between the right and left otoliths. They tested the magnitude of directional asymmetry between the sagittal otoliths (left vs. right) of 2991 individuals according to their catch locations, and they selected species to evaluate whether directional asymmetry may itself be a tool to evaluate stock boundaries. Elliptical Fourier descriptors were used to describe the otolith shape. They used a flatfish, the common sole (*Solea solea*, n = 2431), from the eastern English Channel and the southern North Sea as well as a roundfish, the bogue (*Boops boops*, n = 560), from the Mediterranean Sea. Both species showed significant levels of directional asymmetry between the testing locations. The bogue otoliths showed significant asymmetry for only 5 out of 11 locations, with substantial separation between two large areas: the Algerian coast and the western part of the Italian coast. The sole otoliths showed significant asymmetry in the shape analysis (3.84%–6.57%), suggesting a substantial separation between two large areas: the English and French parts of the English Channel and the southern North Sea. Consequently, directional bilateral asymmetry in otolith shape is a potential new method for stock identification.

Otolith shape as tool to stock identification

Ben Labidi *et al.* (2020) investigated for the first time the discrimination of the stock structure of B. boops samples collected from two sampling sites at the marine stations of Monastir and Zarzis located in Tunisia using the otolith shape descriptors analysis. A total of 183 adult samples of *B. boops* were collected between January and August 2019 from two sampling sites at the Monastir and Zarzis marine stations. The outlines of sagittal otolith pairs from fish samples collected from the two sites were digitized and analyzed for shape variation by elliptical Fourier analysis (EFA). Discriminant Function Analysis (DFA) showed statistically significant differences in otolith shape within and between fish samples in the two sites, i.e., there was an asymmetry. This asymmetry was found between the left and right otoliths within each site, as well as between the same sides (left–left) and (right–right) otoliths between the Monastir and Zarzis stations. Fish stock samples at the two stations represent two groups or populations of the Tunisian bogue stock and should be managed separately. In addition, the asymmetry in the otolith shape between fish samples from the two stations can be attributed to differences in the rate of growth resulting from local environmental factors such as water temperature, salinity, habitat, and diet. However, the inter-individual or even the intrapopulation asymmetry between the right and left otoliths can be explained by the possibility of having intra-individual stress that led to abnormalities in the development of the individuals or by the presence of poor living conditions for the larvae, resulting from unfavorable environments.

Neves *et al.* (2021) aimed to contribute to the knowledge on the population structure of the European sardine (*Sardina pilchardus*) using shape analysis, based on samples from 14 locations in the Northeast Atlantic and the Mediterranean Sea, covering nearly the entire distribution range of the species. A combination of elliptic Fourier descriptors and otolith size parameters were explored by multivariate statistical methods. Five distinct groups were identified: (1) the Cantabrian Sea and the English Channel; (2) the North and Southwestern Portuguese coast; (3) the Mediterranean and the Gulf of Cadiz; (4) Madeira and Azores islands; and (5) Northwest African and South Portugal coasts. Moreover, connectivity between Cantabrian/Galicia and western Portugal was suggested, as well as through the Gibraltar Strait. The results were directly compared with those from previous genetic and morphometric studies conducted on the same individuals, being generally consistent with areas of otolith shape change.

Sadeghi *et al.* (2020) analysed otolith shape variation in the Ornate goby, *Istigobius ornatus* (Teleostei: Gobiidae), collected along the intertidal coasts of the Persian Gulf and Oman Sea, using Wavelet transform technique in the ShapeR package to determine population differentiation and structure. There were significant differences ($P < 0.001$, ANOVA) among geographically distant populations based on the variation in the anterior and posterior otolith rims. However, otolith shapes of neighbouring populations were more similar to each other ($P > 0.01$). Mantel test showed a positive correlation between the Euclidean distance of otolith shape and geographical distances among populations ($r = 0.93$, $P < 0.002$). This indicates that levels in otolith shape resemblance between populations are dependent on geographic distance. Different scenarios are discussed to explain the pattern of otolith shape variation and population structure. Among possible key mechanisms responsible for population differentiations are isolation by distance, Late Pleistocene sea level fluctuations, and ecological and geographical differences between the studied locations. This study highlights otolith shape efficiency as an exceptionally convenient morphological marker to study intraspecific-level evolutionary and contemporary phenomena in marine fish.

Shoopala *et al.* (2021) investigated the use of otolith shape analysis for purposes of stock-structure analysis of *Merluccius capensis*. The fishing industry is an important economic sector in Namibia and South Africa, with the shallow-water hake *Merluccius capensis* being an important target species. Recent genetic studies of M. capensis found two stocks in the Benguela Current Large Marine Ecosystem, one in the north (17–29° S) and one in the south (29–36° S), and a proposed mixed stock in the Orange River area (around 29° S). *Merluccius capensis* otolith samples were collected during demersal-trawl surveys along the Benguela, for the years 1992, 2004 and 2005. Different years were selected to investigate temporal stability in otolith shape in the northern Benguela. A total of 1 628 otolith images were analysed using the shapeR library in R. Otolith shape was analysed using wavelet transformation, and ANOVA-like permutation tests indicated no significant differences between the northern (17°31′–25°29′ S) and central (25°30′–29°05′ S) Benguela for all years but showed significant differences between the northern and southern (29°05′–35°50′ S) Benguela. This study therefore demonstrated that otolith shape could be used for stock discrimination of *M. capensis*. It confirmed one stock of *M. capensis* in the northern and central Benguela and another in the southern Benguela, which supports the current, separate management approach for this species. It also showed some differences in otolith shape from the 1990s to the 2000s, which could be explained by increased movement of the southern Benguela stock to the northern Benguela and increased hybridisation in the later years.

Otolith shape with another descriptor for stock identification

Khan *et al.* (2021) used both elemental composition and otolith shape to stock identification. Typical studies also have a large number of elemental compositions and shape measures relative to the number of otolith samples, with these measures exhibiting strong mean– variance relationships. These properties make otolith composition and shape data highly suitable for use within a multivariate generalised linear model (MGLM) framework, yet MGLMs have never been applied to otolith data. Here we apply both a traditional distance based permutational multivariate analysis of variance (PERMANOVA) and MGLMs to a case study of striped snakehead (*Channa striata*) in India. We also introduce the Tweedie and gamma distributions as suitable error structures for the MGLMs, drawing similarities to the properties of Biomass data. We demonstrate that otolith elemental data and combined otolith elemental and shape data violate the assumption of homogeneity of variance of PERMANOVA and may give misleading results, while the assumptions of the MGLM with Tweedie and gamma distributions are shown to be satisfied and are appropriate for both otolith shape and elemental composition data. Consistent differences between three groups of *C. striata* were identified using otolith shape, otolith chemistry and a combined otolith shape and chemistry dataset. This suggests that future research should be conducted into whether there are demographic differences between these groups which may influence management considerations. The MGLM method is widely applicable and could be applied to any multivariate otolith shape or elemental composition dataset.

Muniz *et al.* (2020) studied the Atlantic chub mackerel (*Scomber colias*) which is an important commercial fish species of the North-East Atlantic. Two-year old individuals collected 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 analysed 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.

Randon *et al.* (2020) assessed and compared the discriminatory power of genetic markers and otolith shape to reveal the population structure on evolutionary and ecological time scales of the common sole (*Solea solea*), living in the Eastern English Channel (EEC) stock off France and the UK. First, we genotyped fish with Single Nucleotide Polymorphisms to assess population structure at an evolutionary scale. Then, we tested for spatial segregation of the subunits using otolith shape as an integrative tracer of life history. Finally, a supervised machine learning framework was applied to genotypes and otolith phenotypes to probabilistically assign adults to subunits and assess the discriminatory power of each approach. Low but significant genetic differentiation was found among subunits. Moreover, otolith shape appeared to vary spatially, suggesting spatial population structure at fine spatial scale. However, results of the supervised discriminant analyses failed to discriminate among subunits, especially for otolith shape. We suggest that the degree of population segregation may not be strong enough to allow for robust fish assignments. Finally, this study revealed a weak yet existing metapopulation structure of common sole at the fine spatial scale of the EEC based on genotypes and otolith shape, with one subunit being more isolated. Our study argues for the use of complementary tracers to investigate marine population structure.

SriHari *et al.* (2021) used the morphology of fish, otolith shape, meristic traits and mtDNA D-loop region to delineate the stocks of Greater Lizardfish, *Saurida tumbil*, collected from the west coast of India. The information regarding the stock structure of this species is scarce. Samples were collected between October to November 2018 from three major fish landing centres namely Mumbai, Mormugao and Kochi. Truss network analysis and otolith shape indices revealed the morphological divergence for body and otolith shape among the sampling regions. However, meristic traits and D-loop sequences of mitochondrial DNA could not show variation among the stocks, suggesting the existence of a single panmictic population of *S. tumbil*. The results of the present study are useful to formulate the stock-specific management measures for *S. tumbil* along the west coast of India.

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Otolith chemistry (Contributors: Lisa Kerr, Susanne Tanner and Zach Whitener)

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

Burns *et al.* 2020 developed a continuous-surface of otolith microchemistry in UK waters based on age-0 juvenile whiting and applied this for the purpose of geolocation of whiting (*Merlangius merlangus*). This method provided a way to link specific fishing grounds to the nursery areas that produced the fish. This analysis demonstrated high connectivity across existing stock boundaries and identified the importance of the Firth of Clyde as a nursery area for whiting.

Using Bayesian modelling, Macdonald *et al.* (2021) derived quantitative rules for assessing the spatial and temporal scales of otolith chemical variation in Icelandic Summer Spawning (ISS) Atlantic herring (*Clupea harengus*). Otoliths from across the full range of ISS fish were analyzed against these rules from three years of sampling to assess nursery connectivity, fidelity and contributions to the fishery using Bayesian multivariate linear models based on differences in elemental Li, Mg, Mn, Zn, Sr, Ba and the stable isotopes δ13C and δ18O. Baselines for nursery areas were created from age-1 and -2 that were nursery residents. Their study showed that there is 1) strong evidence for nursery site fidelity between age-1 and age-2, and 2) that multiple nurseries contribute to the fished age-3 population. The authors recognized that more sampling is needed to bolster their findings but expect that their methods and "rules" should be easily adapted other fisheries with stock identification and discrimination needs.

Nazir and Khan (2021) reviewed the current status of otolith science for stock discrimination, including the use of otolith chemistry, structure, shape, and combinations of these techniques. They reviewed some of the underlying biology of why and how the environment and growth of fishes influence the characteristics of otoliths, while also highlighting areas that need more study, including: in-situ validation of environmental effects on chemistry across the reproductive cycle of fish, the relations between calcium polymorphs and the rate of elemental uptake, and the building of multi-year databases of otolith and water chemistry. They note that otolith chemistry and shape have become more popular methods in recent years due to the advancement of statistical analyses and software, further emphasizing the importance of validation efforts.

Moura *et al.* (2020) studied the stock structure of Atlantic mackerel Scomber scombrus using otolith shape and chemistry. Fish were collected from 6 representative spawning areas from both the North-West Atlantic (NWA) and North-East Atlantic (NEA) stocks, including Canadian waters, US waters, North Sea, Western component, Southern component, and Bay of Biscay. The success of combined otolith signatures use for discrimination between NEA and NWA was 100%, while discrimination among smaller scale spawning components within the broader stocks was 100% for the NWA and 68% for within the NEA. The authors argue that these results should be taken into consideration for management that the NWA stock should be split in two, while the mixed results in the NEA confirm the complex metapopulation structure there and the need for more and continuous evaluation for proper management.

Redding *et al.* (2020) tested hypotheses on natal origin and contingent mixing by analysing natal otolith δ18O values of the Northwest Atlantic mackerel (*Scomber scombrus*) population (comprised of northern and southern contingents) and comparing them to the Northeast Atlantic population. As expected, otolith δ18O values varied between the Northeast (higher) and the Northwest (lower) Atlantic basins, and between contingents within the Northwest Atlantic stock, although contingent differences varied between years. Most adult mackerel sampled from US waters (southern contingent) represented the northern contingent (Canadian spawning site). The confirmation of the seasonal mixing of older and larger fish between the two contingents provides support and justification for the development of bi-national (United States–Canada) assessment and management of Northwest Atlantic mackerel.

The otolith elemental composition of Gilthead sea bream (*Sparus aurata*) were analyzed by Vrdoljak *et al.* (2020) to discriminate between nursery areas exposed to varying levels of pollution. Using La-ICP-MS, Pb/Ca, Zn/Ca, Mg/Ca, Ba/Ca, and Sr/Ca ratios were investigated, and multivariate analysis found clear separation between sample sites and elements with Zn/Ca and Pb/Ca being particularly important. They found that Zn accumulated continually and Pb only in discrete portions of the otoliths, particularly in the area associated with the first winter of growth. The authors explored site differences, but did not conduct a full test of classifying individuals back to natal origin based on their findings.

Atlantic chub mackerel (*Scomber colias*) are managed as a single stock in the North-East Atlantic, but with growing fishing pressure, there has been more interest in gaining a more nuanced understanding of the population. Correia *et al.* (2021) investigated the otoliths from fish collected off of the Portuguese mainland, the Azores, Madeira, and the Canaries with a suite of elemental ratios and isotopic ratios. They were able to correctly classify 80% of fish back to the place of capture, as well as 100% classification of fish from the island samples (i.e., correct classification among islands and no misclassification of island fish to the mainland). Regional differences were driven by Sr:Ca, Na:Ca, Ba:Ca, Mg:Ca, Li:Ca, Mn:Ca, δ13C, and δ18O. The authors conclude that this is strong evidence for managing the species in European waters with regional management units.

Andrade *et al.* (2020) used otolith trace element composition of Atlantic cod (*Gadus morhua*) collected in five locations in northern Norway and western Svalbard to identify natal sources, broad-scale migration patterns, and to determine if cod currently reside in Arctic fjords. Results suggest that cod from all locations mainly recruited from the Barents Sea, conforming to the Northeast Arctic cod ecotype. The degree of chemical overlap between a fjord in northern Norway and one in Svalbard varied with fish age, suggesting individual movements consistent with the Norwegian coastal cod ecotype. Also, otolith chemical composition of mature fish from two fjords in Svalbard suggest that cod from the Barents Sea might have recently established residency in these fjords.

Fink-Jensen *et al.* (2021) determined concentration of 14 elements in otolith edges of the small pelagic fish caplin (*Mallotus villosus*) collected from 18 locations along the Greenland coast. Their study provides a chemical baseline for investigations of migration and population structure of capelin and potentially other marine organisms in Greenlandic waters, using chemical tracers. Geographic variations were demonstrated for 8 elements (Li, Ba, Sr, Pb, Mg, P, Zn and Mn) and otolith chemical composition identified three regions along the coastline. The west coast contains two chemically distinct zones – north and south of ~68 ◦N. The results demonstrate the applicability of otolith chemistry as a tracer of physicochemical variation in an Arctic marine environment and may contribute to better understanding population structure and spatial dynamics of capelin, a key prey species in the Arctic marine food web.

Recently, the applicability of otolith chemistry as a novel method to estimate and validate age and growth rates in fish species with unclear seasonal otolith growth bands has been explored.

Heimbrand *et al.* (2020) tested for the first time a new age estimation method based on seasonal patterns in trace elemental otolith incorporation and compared it with the traditional method of visually counting growth zones, using otoliths of cod (*Gadus morhua*) from the Baltic and North seas. Mg:Ca and P:Ca, both proxies for growth and metabolic activity, showed greatest seasonality and therefore have the best potential to be used as chemical clocks. Overall, the chemical (novel) method had an overall greater precision and percentage agreement among readers than the visual (traditional) method. The authors conclude that otolith chemistry is a promising alternative ageing method for fish populations difficult to age, such as the Eastern Baltic cod.

Hüssy *et al.* (2020) conducted a review aimed at summarizing the knowledge on otolith composition and biophysical drivers of biomineralization, present hypotheses on how biomineralization should affect element incorporation. The review suggests that biomineralization has a controlling effect on otolith element concentrations for elements that are linked with somatic growth, but not for elements that substitute for Ca in the crystal lattice. The review recommends that interpretation of the ecological significance of patterns from field samples therefore needs to consider the impact of the underlying biomineralization processes of the element in question as well as physiological processes regulating the availability of ions for inclusion in the growing crystal lattice.

Hüssy *et al.* (2021) validated the periodicity of recurrent patterns in ^{25}Mg, ^{31}P, ^{34}K, ^{55}Mn, ^{63}Cu, ^{64}Zn, ^{66}Zn, ^{85}Rb, ^{88}Sr, ^{138}Ba, and ^{208}Pb in Baltic cod (*Gadus morhua*) otoliths from tag–recapture and known-age samples. Otolith P concentrations showed the highest consistency in seasonality over the years, with minima co-occurring with otolith winter zones in the known-age otoliths and in late winter – early spring when water temperatures are coldest in tagged cod. The timing of seasonal minima and maxima was stock specific (western and eastern stocks) and the amplitude in P was larger in faster-growing western compared with eastern Baltic cod. Seasonal patterns with minima in winter – late spring were also evident in Mg and Mn, but less consistent over time and fish size than P. Authors conclude that otolith P, and to a lesser extent Mg and Mn, may have the potential to supplement traditional age estimation or to guide the visual identification of translucent and opaque otolith patterns used in traditional age estimation.

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Parasites (Contributor: Ken Mackenzie)

Eight publications dealing with the use of parasites as biological tags for population studies of marine vertebrates were published in the year from June 2020 to July 2021. The target hosts ranged from anadromous and pelagic teleosts to cetaceans. The study regions included the Southwest Atlantic Ocean, the Northwest Pacific Ocean, the Mediterranean Sea and the Bay of Bengal. Nematodes of the genus *Anisakis* were the parasites most frequently mentioned. The continuing and increasing use of molecular methods for parasite identification was apparent.

A regular feature of these reports in recent years has been the number 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 assemblage of parasites. Four more studies from this region were published in the past year.

Braicovich *et al.* (2021) investigated changes in the structure and composition of the parasite assemblages of Brazilian flathead *Percophis brasiliensis* in the Argentine Sea during a 13-year period (2005–2018) between samples during which protective fishery closure methods had been applied. The aim of the study was to evaluate how parasite communities of *P. brasiliensis* had changed in response to these protective measures, and also to test the hypothesis that a different stock of *P. brasiliensis* existed in southern Magellanic waters, which had not been sampled in 2005. Differences between infra-communities of long-lived parasites were investigated by non-metric multidimensional scaling (nMDS) and canonical analysis of principal coordinates (CAP). These analyses provided evidence of a discrete stock of the host species in southern Patagonian (Magellanic) waters.

Canel *et al.* (2021) investigated how differences in migratory behaviour between different age groups of fish can affect the use of parasites as biological tags for studying seasonal migratory patterns. The subject host of this study was the Argentine croaker *Umbrina canosai* in the Southwest Atlantic off northern Argentina and Uruguay. This fish shows asynchrony between adult males, females and juveniles in migratory timings, which makes it a good model to assess how such discrepancies can be reflected in the structure of its parasite assemblages, and how these differences can affect the interpretations of migratory patterns when parasites are used as biological tags. A total of 254 host specimens from eight samples with differences in mean length were examined for metazoan parasites. Only long-lived parasites were used for comparisons between samples. A strong influence of fish length on the structure and composition of the parasite assemblages was observed across samples, demonstrating the importance of ontogenetic changes on parasite assemblages. This study highlights the importance of taking into account differences between fish length and age classes when using parasites as biological tags.

Irigoitia *et al.* (2021) described the genetic and morphological identifications of adult *Anisakis* nematodes collected from cetaceans stranded on the coast of Buenos Aires Province, Argentina. *Anisakis pegreffii* and *A. berlandi* were detected in two orcas, and *A. typica* and *A. pegreffii* were detected in one franciscana. These represent the first records of *A. pegreffii* in both host species, and of *A. berlandi* in orcas. The results provide valuable information on the host ranges and geographical distributions of these parasites in this region, thereby contributing to the use of *Anisakis* spp. larvae as indicators of different water masses and the fish stocks associated with them.

Levy *et al.* (2021). The subject host of this study was the euryhaline species silverside *Odontesthes argentinensis*. The study area was a coastal lagoon system in the northern Argentine Sea, where substantial genetic differences had been observed between estuarine and adjacent marine populations of silverside, despite the lack of geographical barriers separating them. The aims of this study were to determine if the structure and composition of parasite assemblages indicated (1) isolation between populations and (2) evidence of incipient processes of colonisation of freshwater habitats by the estuarine population. Analyses of parasite assemblage structure were restricted to larval helminths with long life spans in the subject host. These analyses showed a homogeneity in parasite assemblages in the freshwater and estuarine populations, but significant qualitative and quantitative differences in parasite assemblages between the freshwater-estuarine and marine populations. This high degree of differentiation proves the utility of parasite assemblages as indicators of host population structure and its ongoing incipient speciation process in this lagoon.

Two studies from the **Northwest Pacific** region were published in the past year, one on parasites of skipjack tuna and the other on parasites of baleen and toothed whales.

Takano *et al.* (2021) used the species composition and infection levels of larval nematodes of the genus *Anisakis* to identify stocks of skipjack tuna *Katsuwonus pelamis* in the Northwest Pacific and adjacent seas. A total of 112 skipjack were examined and 5 sibling species of *Anisakis* were found: *A. berlandi, A. pegreffii, A. simplex* (s.s.), *A. typica* and *A. physeteris. Anisakis* species composition varied between Northeast Japan, the Sea of Japan and other areas, which was largely concordant with previous stock discrimination results, but molecular phylogenetic analysis revealed two intraspecific groups in *A. simplex* (s.s.), one of which occurred almost exclusively in Northeast Japan. Fish from Northeast Japan were also characterized by a remarkable variety in the intensity of *A. simplex* (s.s.), suggesting a mingling of individuals with different migration patterns. Two genetically distinct groups of *A. physeteris* (s.l.) were also identified. It is suggested that these nematodes, together with other parasites, could be used to provide more insights into stock structure of skipjack in the Northeast Pacific.

The study of Gomes *et al.* (2021) was based on the molecular study of *Anisakis* nematodes from two species of dolphin and two species of baleen whales from the seas around Japan. Three species of *Anisakis* were found in these cetaceans: *A. simplex s.s., A. typica* and *A. pegreffii.* Most of the common minke whales predominantly harbouring *A. pegreffii* adults belonged to the Yellow Sea – East China Sea stock, which migrates through the Sea of Japan, whereas most of those parasitized by *A. simplex* (*s.s*) adults were from the Okhotsk Sea – West Pacific stock. The results suggest that these *Anisakis* sibling species may be used as biological tags to further differentiate whale stocks, and it is suggested that molecular analysis of *Anisakis* eggs in minke whale stools could be used as a less invasive method of nematode identification.

In the **Bay of Bengal**, a study by Bhuiyan and Zhinu (2020) used parasites to study the stock structure of Hilsa shad *Tenualosa ilisha* In Bangladeshi waters. Three different stocks or types of *T. ilisha* have been recognised in this region: fluvial, potamodromous and marine. This study investigated the stock composition of these fish using parasites found in the viscera as biological tags. A total of 2667 fish were caught in 3 different habitats: freshwater, estuarine (brackish) and marine, from which 11 parasite taxa were collected. Parasites that satisfied established selection criteria and showed statistically significant differences in prevalence between habitats were the cestode plerocercoid *Ilisha parthenogentica* and two species of juvenile acanthocephalans of the genus *Acanthosentis.* The higher prevalence of *I. parthenogenetica* in brackish water indicated that the fish had become infected while feeding in this habitat, while the higher prevalence of *Acanthosentis* spp. indicated recruitment in freshwater. The similar prevalences of short-lived parasites, such as adult trematodes, in all three habitats and the significantly higher prevalences of *I. parthenogenetica* and *Acanthosentis* spp. in specific habitats suggests that all shad populations in Bangladesh are largely anadromous and provided no evidence of different stocks.

In the **Mediterranean Sea**, Santoro *et al.* (2020) reported the results of the parasitological examination of a single juvenile sunfish *Mola mola* caught in the central Tyrrhenian Sea. Ten parasite species were found, two of which were identified as potentially useful biological tags for stock identification and migratory routes of *M. mola.* The parasites selected were the plerocercoid of the trypanorhynch cestode *Gymnorhynchus isuri* and the larval nematode *Anisakis simplex* (s.s.). There is no previous record of *G. isuri* from any *Mola* spp. or from the Mediterranean Sea, but it does occur throughout the Atlantic Ocean. *Anisakis simplex* (s.s.) has never been recorded from the Mediterranean except for the Alboran Sea, a transitional zone between the Atlantic and the Mediterranean; the southern limit of its distribution in the Northeast Atlantic lies along the Spanish-Portuguese Atlantic coast. From this information, a possible scenario suggested here is that the sunfish examined had migrated into the Mediterranean from the Atlantic.

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Interdisciplinary approaches (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 and becoming a regular approach. In addition, there is also an increasing effort towards an effective implementation of the information of population spatial structure into management and assessment tools, some of these studies are also here included. In addition, some multidisciplinary reviews have been published. We synthetize below reviews and integrated approaches published in 2020 and 2021 and that were not included in the review published by the WG last year.

Given the increasing availability of information off different tools for many species, some integrative reviews have been published. Lucena-Frédou *et al.* (2021) review existing life history, fishery, and stock assessment information for this group, including aspects of stock structure. Stock structure literature findings are reviewed for little tunny (evidence of two groups off Africa), wahoo (panmictic structure), blackfin tuna (structure between Gulf of Mexico and W. Atlantic), Atlantic bonito (stock structure within the Mediterranean), and king mackerel (structure within the Gulf of Mexico). Molecular approaches were most common among reviewed studies. The authors conclude that ICCAT management units do not align well with current stock structure information for small tunas.

The development of highly multidisciplinary projects have increased the possibility of developing publications of studies integrating the results on stock identification using many contrasting techniques. In a comprehensive integrated approach to stock structure of Pacific sardine (*Sardinops sajax*) off South Australia, Izzo *et al.* (2021) develop a structured semi-quantitative approach for considering 14 stock discrimination elements. The elements are combined for pairwise comparisons of 13 regions (78 pairs) where DV (difference value) = 0 where no difference occurs; else DV=1. A Stock Discrimination Index is computed for each pair as SDI = Σ DV/count DV. The approach was successfully tested against otolith shape/chemistry analysis for a subset of regions. The approach lends itself well to directing sources of information from the literature and group deliberations into an auditing system. Still, weighting of DVs are equal in SDI estimates, which includes a sweep of evolutionary, phenotypic, and fishery variables, which may not be reasonable. Small tunas (e.g., blackfin and bullet tunas, bonitos, king and Spanish mackerels, wahoo) present assessment challenges given their dispersed Atlantic-Mediterranean distribution and lack of focused research. Randon *et al.* (2021) also apply the SDI approach to all the information on stock identity through five population- and individual-based approaches gathering information on stock common sole (*Solea solea*) of the Eastern English Channel. Overall, the SDI index suggested evidence of spatial structure for this species and region. The authors conclude that the misalignment of the current stock definition with the underlying biological metapopulation now requires the improvement of the assessment-management to ensure its sustainable exploitation.

The combination of genetic markers and otolith information (shape and microchemistry) was one of the first integrative stock identification approaches that emerged in the bibliography, and it is still a very common approach while some limitation can emerge when the temporal length of the samples is not adequate for the life span of the studied species. Brophy *et al.* (2021) build on past otolith stable isotope discrimination work on Atlantic bluefin tuna by integrating SNP genetic analysis, showing moderate increased discrimination by including both markers, albeit delta-18O retains a dominant contribution. A new otolith chemistry baseline is built for the recent decade from adult spawning region samples and is compared to those of the multi-decadal historical juvenile baseline. The adult baseline showed better discrimination, which the authors suggests is caused by juvenile trans-Atlantic migrations and strong adult homing. While genetic, otolith chemistry and integrated baselines supported the current two stock premise, unknown samples were classified inconsistently with genetic and otolith chemistry random forest assignments, leading to curtailed classification success of the integrated approach. A key limitation in this and the recent SNPs genetic study (Rodriguez-Ezpeleta *et al.* 2019) are very small genetic baseline samples for the Gulf of Mexico (n=45 collected over four years) and Mediterranean (n=105 over 3 years), which is inadequate for a long-lived species with high probability of cohort variation in SNP markers. Indeed, the otolith chemistry approach also combines years, which is increasingly problematic given the likely interannual changes in oceanography underlying Western Atlantic and Mediterranean isoscapes. Random *et al.* (2020) also assessed and compared the discriminatory power of genetic markers and otolith shape as an integrative tracer of life history to reveal the population structure on evolutionary and ecological time scales of the common sole (*Solea solea*) of the Eastern English Channel. These authors used a supervised machine learning framework applied to genotypes and otolith phenotypes to probabilistically assign adults to subunits and assess the discriminatory power of each approach. Their results of the supervised discriminant analyses failed to discriminate among subunits, especially for otolith shape, suggesting that the degree of population segregation may not be strong enough to allow for robust fish assignments. The authors conclude that the results revealed a weak yet existing metapopulation structure with subunits operating at a fine scale. Few studies also combine genetics with body morphometrics, Nikolic *et al.* (2020) apply this interdisciplinary approach to Albacore tuna (*Thunnus alalunga*) in the southwest Indian (SWIO) and southeast Atlantic (SEAO). The authors also combine these techniques with species' dispersal potential by modelling particle drift through major oceanographic features. The study suggests genetic differentiation between the southeast Atlantic and southwest Indian Oceans, supporting their demographic independence, while the other techniques also reveal potential dispersal potential of early life stages from SWIO to SEAO and adult or sub-adult migration from SEAO to SWIO. Finally, Wright *et al.* (2021) combine genotypic screening and phenotypic traits to define the scale of population structuring in Atlantic cod inhabiting the northern North Sea and Scottish west coast. While their genetics results indicated an isolation by distance pattern with a fine scale structuring, spatial variation in phenotypic traits reflected genetic variation with cod maturing later and at a larger size in some areas. The authors stress that the mismatch between stock divisions and population units is leading to a misunderstanding about stock recovery of the species.

Increasing tagging information, particularly in many large pelagic species, is allowing to develop numerous integrative studies of migration patterns and stock structure in combinations with different techniques, or with different populations simulations or models. Senina *et al.* (2020) implement the tagging data of the skipjack tuna (*Katsuwonus pelamis*) in the Pacific Ocean to the SEAPODYM model, which simulates age-structured population dynamics using advection-diffusion-reaction equations describing movement, recruitment, and natural and fishing mortality. Authors argue that tagging data improve estimates of species habitat parameters and movement rates, providing stock sizes close to those presented by the stock assessment models. Santos *et al.* (2020) combine tagging information of Blackbelly rosefish, *Helicolenus dactylopterus*, with depth and temporal distribution, size composition, sex, abundance indices from scientific surveys and commercial catches of several local management units of Azores archipelago (NE Atlantic Ocean). Authors argued that tagging results indicated a strongly sedentary behavior and an intraregional separation among populations, justifying that analytical assessment should be performed under the assumption of local management units. Finally, Aalto *et al.* (2021) combine tagging data of Atlantic bluefin tuna (*Thunnus thynnus*) and adjacent waters to create monthly distribution maps for these two major stocks, that were then used to separate the overall catch records into stock-specific catch time series. The authors showed that the increase in the past in the proportion of catch estimated to come from the eastern stock can be attributable to a decrease in catches in regions dominated by the western stock.

The combination of otolith information with meristic or body morphometrics has been an integrative approaches also observed this year in the literature. Moura *et al.* (2020) applied otolith shape and bulk otolith chemistry of combined year-classes for Atlantic mackerel, *Scomber scombrus*, which is currently considered to comprise two stocks: the North-West Atlantic (NWA) and the North-East Atlantic (NEA). Data were collected in different sampling areas at each stock and the results supported that the NWA stock should be regard as two distinct population units for fisheries management purposes, supporting more detailed otolith chemistry analysis by Redding *et al.* (2000) and Arai *et al.* (2000), which used natal otolith chemistry from archived samples over two recent decades. These latter two studies found strong year-class effects on the ability to discriminate the two Northern and Southern NWA contingents, first described in Sette's classic work (Sette 1950). They further found that US fisheries relied heavily on fish originating in Canadian waters (the Northern Contingent). Moura *et al.* (2020) suggested that complex metapopulational structure occurs for the NEA stock. Sri Hari *et al.* (2021) uses body and otolith shape was used to elucidate the stock structure of Randall's threadfin bream (*Nemipterus randalli*) in the Indian coast. Analyses developed in 5 mayor fishing regions provide differences of different phenotypic stocks. Muniz *et al.* (2021) uses the same approach, otolith shape and body morphometrics, to assess population structure of Atlantic chub mackerel (*Scomber colias*) is the Northeast Atlantic (three islands, Azores, Madeira, Canaries, and three location in mainland Portugal). Regional differences regarding the otolith-shape analyses suggested a non-homogenous single stock, while body morphometrics showed a more detailed separation in two main groups. Joint analyses of the two techniques gave a more comprehensive scenario, showing the existence of three main groups. Authors recommend fisheries management at a finer spatial scale that needs to be better clarified.

Shackell *et al.* (2021) integrated information from genomics, life history traits and tagging to reconsider the spatial ecology of Atlantic halibut (*Hippoglossus hippoglossus*). Genomic patterns identify two populations in the four management areas of the northwest Atlantic, and other approaches suggest non-genetic spatial structure within each stock. Seasonal habitats, conventional tags and electronic tags suggest a diversity of spawning migration patterns that are influenced by season, fish size, maturity, and distance between summer-feeding and over-wintering habitats.

Finally, new and improved simulation, modeling and fisheries assessment frameworks incorporating the spatial dimension are increasingly provided every year. Thorson *et al.* (2021) develop a movement model applied to Pacific cod (*Gadus macrocephalus*) in the Bering Sea able to incorporate different type of movement indicators (experiments, tagging, flux through movement gates (e.g. acoustic arrays), fishery catch-per-unit effort, resource surveys and genetic/chemical markers). The authors specially consider a movement model involving diffusion (random movement), taxis (movement towards preferred habitat) and advection (passive drift following ocean currents) to eventually fitted to data estimating non-linear habitat preferences using environmental information. Goethel *et al.* (2020) apply integrated population models (IPMs) to assess the relevance of ontogenetic and climate-induced movement under different population structures and complexity. The authors stress that the continued development of spatially stratified modelling approaches should allow harvested resources to be better utilized without increased risk.

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Emerging issues: Impact of Offshore Wind Farms on Population Structure (Contributor: David Secor)

Offshore wind turbine sub-foundations result in increased structure, fouling, and other local changes in bottom substrate and biogenic features. This so-called reef effect results in increased concentrations of fishes, well documented for flatfishes and other demersal species (Degraer *et al.* 2020). In their study, Barbut *et al.* (2021) evaluate how offshore wind farms (OWF) can cause regional impacts to patterns of flatfish connectivity and recruitment in the North Sea. Employing a particle-tracking model, they evaluate how overlap of OWFs and spawning and nursery regions might differentially benefit species of flatfish. Findings suggest that species utilizing deeper nursery areas such as European plaice and common dab may experience differential benefits owing to the offshore siting of OWFs. Although population structure was not a focus of the paper, inshore-offshore contingents (phenotypic stocks) of flatfish and other fishes are well known, and might show similar differential reef effect benefits associated with OWF siting and regional impacts.

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