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Interim Report of the Stock Identification Methods Working Group (SIMWG)

7-8 August 2018

Portland, USA

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

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Executive summary

Over the past year, the Stock Identification Methods Working Group (SIMWG) made progress toward addressing our multi-year terms of reference and has contributed to ICES Science Plan priorities. The working group was chaired by Lisa Kerr (USA) during this period and SIMWG held an in-person meeting in Portland, Maine, USA, 7–8 August 2018 with some members working by correspondence in 2018.

SIMWG has continued to provide annual updates on recent applications of stock identification methods to ICES species and on advances in stock identification methods. SIMWG's annual reviews on advances in stock identification methods keep ICES members abreast of best practices in this field of study.

SIMWG continues to work on resolving issues of stock identification as requested by ICES working groups. Over the past year, we have received three requests to address questions on issues of stock structure: 1) stock identity of European sardine (*Sardina pilchardus*) from participants in the Workshop on Atlantic Sardine (WKSAR); 2) beaked redfish (*Sebastes mentella*) stock affiliation on the East Greenland slope from the North Western Working Group (NWWG); and 3) proposed stock identification of the cod in ICES area 6a.

SIMWG also continues to work on reviewing and reporting on advances in mixed stock analysis. This work is relevant to resolving mixed stock composition issues in assessment and management and will continue over the next year of our three year cycle.

1 Administrative details

Working Group name

Stock Identification Methods Working Group (SIMWG)

Year of Appointment within current cycle

2017

Reporting year within current cycle (1, 2 or 3)

2

Chair(s)

Lisa Kerr, USA

Meeting dates

7–8 August 2018

Meeting venue

Portland, Maine, USA

2 Terms of Reference

a) Review recent advances in stock identification methods;

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

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

3 Summary of Work plan

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

4 List of Outcomes and Achievements of the WG in this delivery period

- SIMWG provided annual updates on recent applications of stock identification methods to ICES species and on advances in stock identification methods.

- SIMWG planned and held and in-person group meeting in Portland, Maine, USA (7–8 August 2018).
- SIMWG responded to a request on three issues of stock structure: 1) stock identity of European sardine (*Sardina pilchardus*) from participants in the Workshop on Atlantic Sardine (WKSAR); 2) beaked redfish (*S. mentella*) stock affiliation on the East Greenland slope from the North Western Working Group (NWWG); and 3) a proposal on proposed stock identification of the cod (*Gadus morhua*) in ICES area 6a.
- SIMWG continues to consider advances in mixed stock analysis and plans to dedicate effort during the coming year to outline a paper relevant to resolving mixed stock composition issues in assessment and management.

5 Progress report on ToRs and workplan

5.1 ToR a) Review recent advances in stock identification methods

In the last year, there was a proliferation of applications of stock identification methods to ICES stocks, as well as several notable advances in stock identification methods with many results relevant to ICES science and advice. SIMWG experts summarized new applications and advances with a focus on recent research in the focal areas listed below (see Annex 3 for details of review).

a) Genetics (Contributor: Stefano Mariani)

b) Growth marks in calcified structures (Contributor: Rich McBride)

c) Life history parameters (Contributor: Rich McBride)

d) Morphometrics/meristics (Contributor: Steve Cadrin, Christoph Stransky)

e) Tagging (Contributor: Steve Cadrin)

f) Otolith shape (Contributor: Kelig Mahe, Christoph Stransky)

g) Otolith chemistry (Contributors: Lisa Kerr and Zachary Whitener)

h) Parasites (Contributor: Ken Mackenzie)

i) Simulation approaches (Contributor: Lisa Kerr)

j) Interdisciplinary approaches (Contributor: Stefano Mariani, Lisa Kerr, Steve Cadrin, Dave Secor, Christoph Stransky)

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

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

SIMWG received three requests for review of stock identification issues (see Annex 3 for full details of review).

SIMWG received a request from the participants of the Workshop on Atlantic Sardine (WKSAR). Participants from WKSAR requested a review of stock identity information on Atlantic sardine. The group summarized available stock structure information in the

WKSAR report, and requested feedback from SIMWG on the document and input on the specific question of the appropriateness of the stock structure scenario they adopted in the most recent benchmark assessment process (2017).

SIMWG received a request from the North Western Working Group (NWWG) to review beaked redfish (*Sebastes mentella*) stock affiliation on the East Greenland slope. In 2009, ICES reviewed the stock structure of beaked redfish, *S. mentella* in the Irminger Sea and adjacent waters (WKREDS). They recognised that there are three biological stocks of *S. mentella* in the Irminger Sea and adjacent waters: 'Deep Pelagic'; 'Shallow Pelagic'; and 'Icelandic Slope'. This separation of the stocks did not include *S. mentella* on the Greenland continental slope. ICES decided that NWWG should conduct a separate assessment for *S. mentella* in subarea 14.b (Irminger sea, 14b1; and east Greenland continental Shelf, 14.b2) until further information was available to assign stock origin. Since 2009, further studies on stock structure and species separation have been conducted. Based on this new information NWWG recommended that the separation of *S. mentella* on the Icelandic and Greenlandic slopes be revised and the possibility of a joint assessment of *S. mentella* on the Icelandic and Greenlandic slopes be evaluated. NWWG requested SIMWG review this issue of stock identification.

The North Western Waters Advisory Council (NWWAC) is exploring options for a genetic study, financed mainly by the industry, on cod and whiting in the West of Scotland – North Sea area to determine the genetic association of the stocks in these areas. NWWAC requested the support of ICES and relevant scientists for this project as the results could provide a direct input to the assessments, which could require an update, as a result. ICES welcomed the proposed work on genetic identification of stocks and recommended that the NWWAC could engage with SIMWG. SIMWG reviewed an initial project proposal on the identification of the cod population structure in area 6.a.

5.3 ToR c) Review and report on advances in mixed stock analysis, and assess their potential role in improving precision of stock assessment

SIMWG continues to consider advances in mixed stock analysis and plans to dedicate effort during the coming year to outline a possible paper that would be a focus of work at our upcoming in-person meeting planned for next year. The aim would be to develop a paper that is relevant to resolving mixed stock composition issues in assessment and management.

6 Revisions to the work plan and justification

SIMWG revised its work plan for the coming year to include planning for an in-person meeting in 2019 to take place in Reykjavik, Iceland.

7 Next meetings

We are planning to hold our 2019 ICES SIMWG meeting at the University of Iceland, Reykjavik, Iceland.

Annex 1: List of participants

Name	Institute	Country (of institute)	Email
Lisa Kerr (Chair)	Gulf of Maine Research Institute, 350 Commercial St. Portland, ME 04101	USA	lkerr@gmri.org
Steve Cadrin	School for Marine Science & Technology 836 South Rodney French Boulevard New Bedford MA 02744	USA	scadrin@umassd.edu
Stefano Mariani	Ecosystems & Environment Research Centre – University of Salford, M5 4WT	UK	s.mariani@salford.ac.uk
Zachary Whitener	Gulf of Maine Research Institute, 350 Commercial St. Portland, ME 04101	USA	zwhitener@gmri.org
David Secor	University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, PO Box 38, Solomons, Maryland	USA	secor@umces.edu
Richard McBride	Northeast Fisheries Science Center National Marine Fisheries Service 166 Water Street, Woods Hole, MA 02543	USA	Richard.McBride@noaa.gov
Kelig Mahe	IFREMER, Sclero-chronology centre, 150 quai Gambetta, BP 699, 62321 Bou-logne-sur-Mer, France.	France	Kelig.Mahe@ifremer.fr
Ken Mackenzie	School of Biological Sciences, University of Aberdeen, St. Machar Drive, Cruickshank Bd., Aberdeen, AB24 3UU, United Kingdom	UK	k.mackenzie@abdn.ac.uk

Christoph Stransky	Thünen Institute of Sea Fisherieries Herwigstr. 31 27572 Bremerhaven, Germany	Germany	christoph.stransky@thuenen.de

Annex 2: Recommendations

Recommendation	Adressed to
1. SIMWG does not find sufficient evidence to support the recent change in stock structure of European sardine adopted in the 2017 benchmark. Furthermore, SIMWG is not certain that the previous stock structure (north, south) is well supported. Ongoing genetics may help to resolve this issue and SIMWG recommends the review of this new research prior to the next benchmark for a decision on this topic.	WGHANSA
2. SIMWG does not recommend a combined assessment of beaked redfish along the east Greenland slope with the Icelandic slope. Furthermore, more precautionary management should be considered in managing the mixed fishery	NWWG
3. SIMWG's review of a proposed cod genetics study in ICES area 6a is well developed, with a strong problem statement, a concise but relatively comprehensive literature review, clearly stated objectives, a technically sound approach, a well-qualified team of scientists, and a promising partnership with the fishing industry. SIMWG offers some recommendations for consideration by the principal investigators.	NWWAC

Annex 2: ToR a) Review recent advances in stock identification methods

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

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

Genetics (Contributor: Stefano Mariani)

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

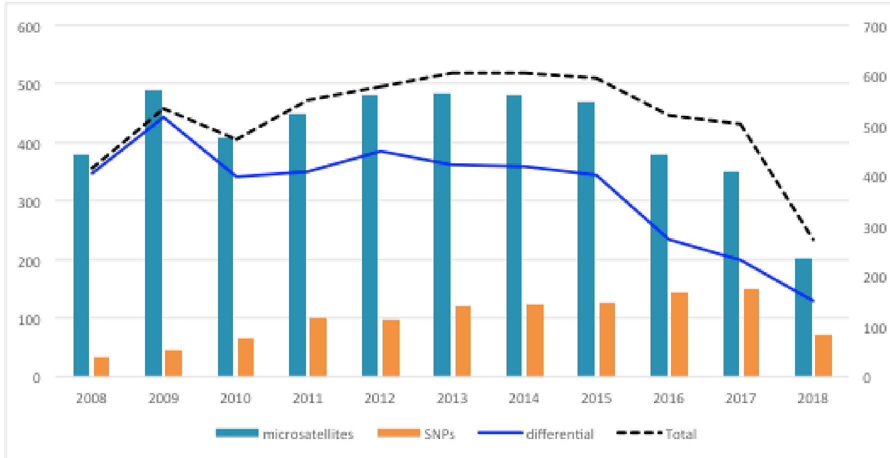

Figure 1. Scientific publishing trend since 2008, comparing outputs of studies using microsatellites (blue bars) and SNPs (orange bars), as listed in the Clarivate Analytics Web-of-Science. The search criteria were: "fish* AND gene* AND (population OR stock) AND 'molecular marker*'," where 'molecular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

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

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

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

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

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

References

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

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

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

Growth marks in calcified structures (Contributor: Rich McBride)

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

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

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

Life history parameters (Contributor: Rich McBride)

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

References

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

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

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

- Berg *et al.* (2018) confirmed previous studies that found high heritability of meristic, morphometric and growth traits. They investigated both genetic factors and salinity gradients on phenotypic plasticity of Atlantic herring from the Atlantic Ocean into the Baltic Sea using breeding experiments. They concluded that otolith shape and vertebral counts have a significant genetic component and are therefore useful for stock identification.
- Jakubavičiūtė *et al.* (2018) studied morphological variation and differentiation of three-spined stickleback (*Gasterosteus aculeatus*) from two major genetic clusters inhabiting coastal Baltic Sea areas, using geometric morphometrics, body plate numbers and otolith shape. Their results show that fish from one area (Curonian Lagoon) representing one of the clusters had a significantly higher number of body plates, potentially indicating a response to higher predation pressure compared to the other areas studied. Body shape also significantly differed among locations with deeper bodied fish in the Curonian Lagoon. The

most conservative and least plastic trait studied, otolith shape, did, however, not show any divergence among the areas studied. The results suggest morphological divergence in plastic traits like body plates and body shape in response to local environmental conditions. The lack of divergence in otolith shape further suggests that the degree of population differentiation is weak or rather recent, as also highlighted in earlier studies using molecular markers or synchrony in population abundances. Overall, this study shows that at least the number of body plates can serve as an effective stock delineator among genetic clusters of three-spined sticklebacks in the Baltic Sea.

- Rawat *et al.* (2017) provide a review of truss morphometrics for stock identification. They provide twelve case studies from India and conclude that truss networks are effective for measuring shape and discriminating stocks.
- Geladakis *et al.* (2017) used landmark morphometrics to compare putative stocks of sardine from seven locations in the eastern Mediterranean. The found that body condition was strongly related to principal coordinate scores. Despite the confounding effect of body condition, discrimination of different morphotypes from the Aegean and Ionian Sea was significant and supported 81% correct classifications.
- Canty *et al.* (2018) evaluated geographic variation of yellowtail snapper from three locations off Honduras in an attempt to enforce area-based management. Their analysis included genotyping, otolith microchemistry and morphometrics to identify geographic origin and found that morphometric analysis supported 80% classification accuracy, otolith microchemistry supported 54% accuracy and genetic analyses supported 52% accuracy. Although the authors make conclusions about the most appropriate approach to discriminating capture location, better understanding of stock identity (e.g., distribution patterns, connectivity, reproductive isolation, environmental patterns) would provide better guidance on the most appropriate scale of spatial management and approach for stock discrimination.
- Perez-Quinonez *et al.* (2017) discriminated three species of thread herrings in the Gulf of California using meristic, morphometric and mtDNA characters. They counted gill rakers, quantified geometric morphometrics of body shape, and analyzed Cytochrome Oxidase Subunit I of mtDNA. Three distinct morphotypes were genetically different.
- Kocabaş *et al.* (2017) investigated phenotypic variation in three trout species and found differences in spotting pattern, color pattern or fin pigmentation traits.
- Pazhayamadom *et al.* (2017) found significant morphometric differences between the Red Sea and the Mediterranean Sea associated with swimming and visibility.
- Vikas *et al.* (2018) correctly classified orangefin labeo from five locations with 50–80% accuracy based on morphometrics.
- Purushothaman *et al.* (2018) used a morphometric truss network to investigate stock structure of Arabian red shrimp from five locations off India and found significant geographic variation.

- Sreekanth *et al.* (2017) studied stock structure of Japanese threadfin bream from four locations off India using truss network analysis with 69–79% classification accuracy.

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

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

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

Methods

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

Case Studies

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

- Arregui *et al.* (2018) overwintering of juvenile bluefin tuna and fidelity to the Bay of Biscay using internal and satellite archival tags. They found high concentration in the Bay of Biscay during summer, when bluefin tuna inhabit in the mixed layer, and substantial geographic dispersion from autumn to spring. Half of the fish overwintered in the mid-Atlantic, near the Azores or Madeira Islands, while three made trans-Atlantic round trips, and one individual travelled to and remained off the eastern coast of the United States. A high percentage of tagged fish returned the next year, suggesting a strong fidelity to the area. One third of tagged fish overwintered in the Bay of Biscay and surrounding areas. These findings appear to contradict assumptions about seasonality and annual movement patterns of bluefin tuna in the Bay of Biscay.
- Arrizabalaga *et al.* (2018) reviewed the subpopulation structure of Atlantic bluefin tuna of Mediterranean origin based on electronic tagging and genetic studies to revise some life history and movement paradigms. Although is somewhat equivocal to test several hypotheses, they conclude that it seems more likely that bluefin tuna spawned in the western Mediterranean use the Atlantic more intensively than those spawned in the eastern Mediterranean. Schaefer *et al.* (2015) studied movement patterns and mixing of bigeye tuna in the central Pacific Ocean using over 31 thousand tag deployments. Linear movements from conventional tags and most probable tracks from archival tags suggest some regional fidelity and substantial mixing of bigeye tuna between release longitudes. Mixing is greatest among adjacent areas.
- Skomal *et al.* (2017) studied broad-scale movements of the white shark in the western North Atlantic using satellite-based tags. They found that white sharks are more broadly distributed than previously believed. Young fish were located in near-coastal and shelf-oriented habitat but ontogentically shifted to pelagic habitat with frequent excursions to mesopelagic depths.
- Braun *et al.* (2018b) studied basking shark movements in the western Atlantic using archival tag data and an oceanographic model. Many individuals spent several months at meso- and bathy-pelagic depths where accurate light-level geolocation was impossible during fall, winter and spring. Integration of archival tag data analysis with three-dimensional depth-temperature profile data indicated that basking sharks moved over 17 000 km from Massachusetts to Brazil, and most demonstrated seasonal fidelity to Cape Cod and the Gulf of Maine.
- Mansfield *et al.* (2017) documented seasonal variation in trans-equatorial movement of South Atlantic yearling loggerhead turtles using satellite tags. Yearling loggerhead turtles from Brazilian rookeries transited south with strong southward currents. When currents flowed in the opposite direction late in the hatching season, turtles moved northwards across the Equator. Swimming helps to maintain position within frontal zones seaward of the continental shelf.
- Curtis *et al.* (2018) investigated movements of young white sharks in the western North Atlantic. Satellite and acoustic tag data indicated that young white sharks remained resident in New York Bight waters through summer, suggesting that the region is a nursery area. Southward movements were observed

during fall, with overwintering habitat identified off North and South Carolina shelf waters. Return migrations toward the New York Bight were observed in some individuals the following spring.

- Schaefer *et al.* (2011) investigated movement patterns of yellowfin tuna off Baja California using from archival tag data. Analyses indicated four distinct behaviours: 1) diving less than 50 m at night and greater than about 100 m during the day; 2) ten or more dives greater than 150 m during the day; 3) surface-oriented behaviour; and 4) deep-diving behaviour exceeding 1000 m.
- Secor *et al.* (2017) used a mark-recapture experiment to evaluate larval retention of striped basin Chesapeake Bay. More than 25 million larvae were released with chemically marked otoliths. They conclude that increased nursery volume reduces variance in water quality and enhances retention of larvae within the nursery.
- Gaube *et al.* (2018) found that mesoscale eddies influence the movements of mature female white sharks in the Gulf Stream and Sargasso Sea using satellite and archival tags. Two mature female white sharks inhabited the interiors of anticyclonic eddies, characterized by warm temperature anomalies. One shark with an archival tag made frequent dives to 1,000 m in anticyclones, where it was presumably foraging on mesopelagic prey. Prey may be more accessible in warm temperature anomalies in anticyclones.

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

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

Afanasyeva *et al.* (2017) applied geometric morphometrics and elliptical Fourier analysis to otolith samples to analyze species identification and population structure of seven *Sebastes* species. *Sebastes* are notoriously difficult to distinguish using body morphology.

So, the discrimination of species based on otolith shape is promising for stock identification.

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

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

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

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

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

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

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

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

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

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

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

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Otolith Chemistry (Contributors: Lisa Kerr and Zachary Whitener)

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

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

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

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

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

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

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

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

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

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Parasites (Contributor: Ken Mackenzie)

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

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

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

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

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

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

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

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

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

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

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

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

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

Gwilliam *et al.* (2018) report the first integrated genetic [mitochondrial (mt)DNA and nuclear microsatellite] and morphological (morphometric, meristic and colouration) study to assess patterns of divergence between populations of *Diplodus* species in the

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

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

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

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

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

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Simulation approaches (Contributor: Lisa Kerr)

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

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

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

Intent, motivation and audience

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

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

Coverage

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

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

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

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

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

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

Connections to the work of ICES and the SIMWG

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

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

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

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

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Annex 3: ToR b) Provide technical reviews and expert opinions on matters of stock identification, as requested by specific Working Groups and SCICOM

1. Evaluation of European Sardine Stock Identity

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

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

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

Background

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

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

Previous ICES stock units (2017):

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

Revised ICES stock units:

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

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

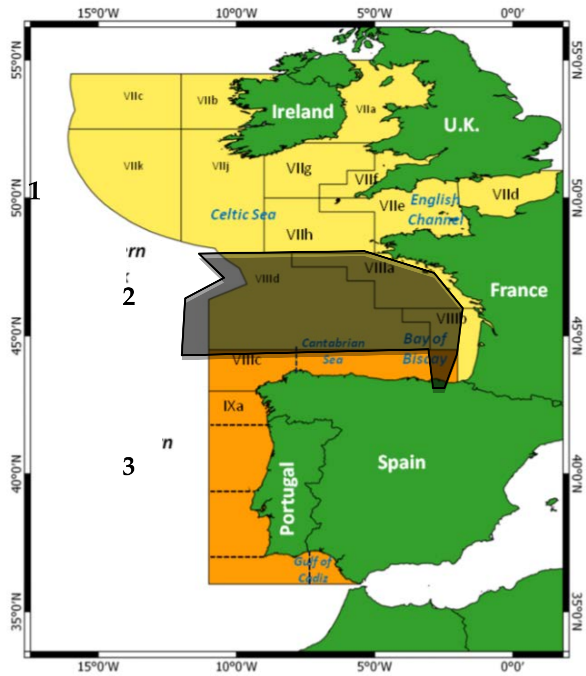

Figure 1. Revised ICES stock units: 1) European sardine in subarea 7 (Southern Celtic Seas, English Channel), 2) European sardine in divisions 8.a–b and 8.d (Bay of Biscay), 3) European sardine in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters).

Genetics

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

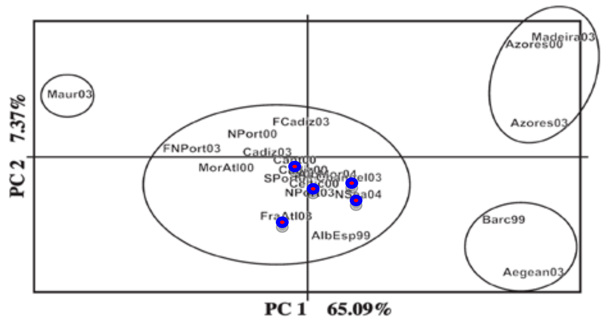

Figure 2. Figure from Kasapidis er al. (2012) illustrating results of p*rincipal component analysis of all 21 samples of sardine* used in study for 5 polymorphic microsatellite loci. Groupings refer to the inferred stocks of sardine.

Growth

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

Body Morphometrics

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

Otolith Morphometrics

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

Otolith Microchemistry

Castro (2007) applied otolith chemistry to understand sardine stock structure with sampling focused within the southern stock areas (Bay of Biscay, northern Iberian Peninsula, and Gulf of Cadiz) and found differentiation among areas for fish of the smallest size classes and that discrimination between areas decreased with increasing size groups .The results are interpreted in terms of a net balance of migration of large sardine from Northern Portugal to towards Bay of Biscay and Gulf of Cádiz. This study suggests sardine movements are significant in terms of population numbers, the existence of a single sardine stock in Atlanto-Iberian waters would be supported.

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

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

Oceanographic life cycle retention

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

Catch Trajectories

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

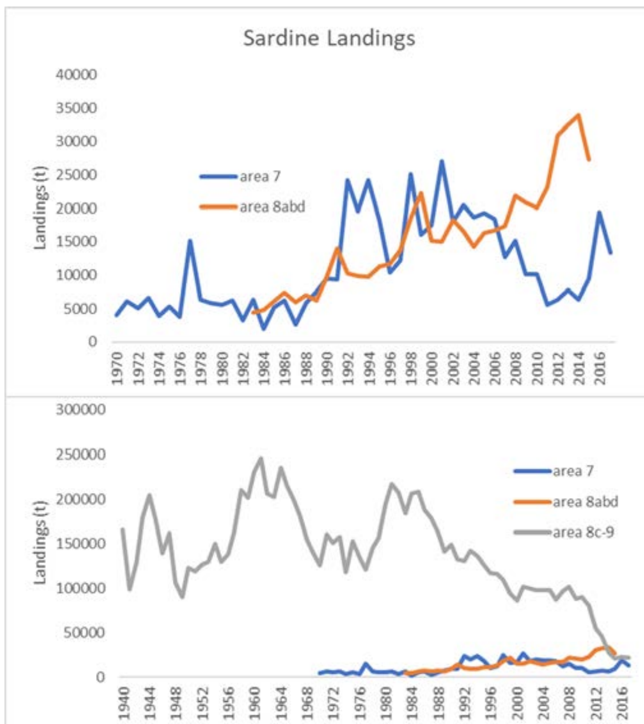

Figure 2. Sardine landings from the Celtic Seas and English Channel (area 7), from the Bay of Biscay (area 8abd) and from Iberian waters (area 8c-9).

Conclusions and Recommendations

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

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

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List of participants

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

2. Evaluation of Beaked redfish stock affiliation on the East Greenland slope

ECOREGIONS: Greenland Sea and Icelandic Waters

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

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

Background

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

Review of new genetic information

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

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

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

Conclusions and Recommendations

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

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

Reference

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

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

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

SIMWG reviewed a proposal titled "Atlantic Cod (*Gadus morhua*) Stock identification In ICES area 6a" by Edward Farrell and Peter Wright.

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

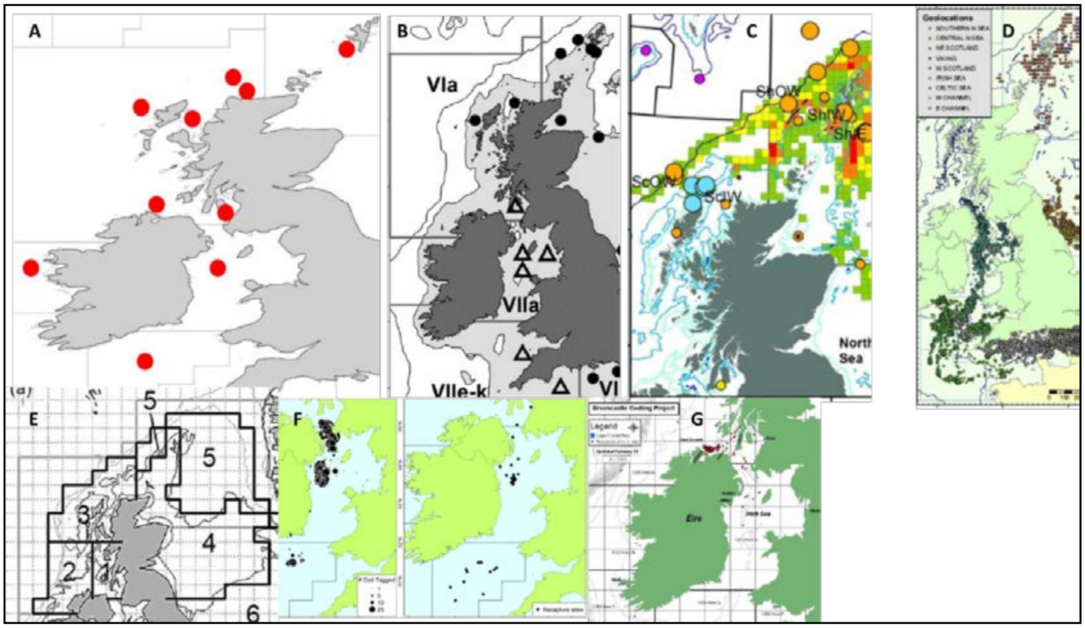
1) The proposed research is appropriately focused on stock identity of cod west of Scotland (ICES Area Via) but also considers and connectivity with the North Sea, Irish Sea, Celtic Sea and west of Ireland. Therefore, we suggest that the title should be revised to "Atlantic Cod (*Gadus morhua*) Stock identification In ICES area 6a <u>and adjacent areas</u>".

2) SIMWG agrees with the problem statement that "Whilst delineation by management area may be more convenient for management and regulation purposes, accurately assessing the status, biomass and sustainable exploitation rates of mixed 'stocks' is inherently difficult if not impossible as they do not correspond to biological units." Furthermore, we suggest that understanding population structure is essential for managing the recovery of cod stocks and fisheries.

3) The proposed research is expected to address the first three 'key questions' (Are there multiple biological populations within 6a? Can they be discriminated genetically? Are they different from adjoining areas?). The fourth 'key question' (Do the stock boundaries between 4a and 6a and between 7a and 6a reflect population boundaries?) may not be definitively addressed with the proposed research, but the proposed research will be an important step toward answering the question and determining what information is needed to do so.

4) In the Golden Age of interdisciplinary stock identification, the EC made substantial investments in multi-organizational research projects (e.g., HOMSIR, REDFISH, HERGEN, WESTHER, METACOD, SARDYN, …) to address questions like the ones posed in the proposal. Those investments produced practical information for fishery management as well as advances in methodological approaches and scientific contributions. We appreciate the support from industry to fund a stock identity study, and recommend that government institutes should consider providing matching funds to allow a broader, interdisciplinary and multi-organizational approach to this project. Collecting other information (length, sex, maturity stage, otolith sample) would help to provide supporting information from other approaches.

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



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

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

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

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