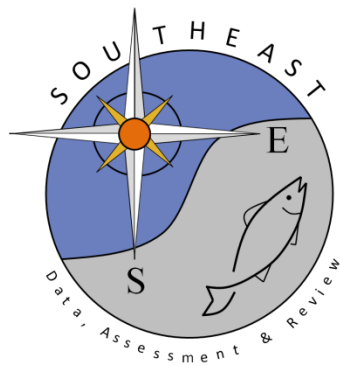


Chapter 22: Interdisciplinary Evaluation of Spatial Population Structure for Definition of Fishery
Management Units (excerpt from Stock Identification Methods – Second Edition)

Stephen X. Cadrin, Lisa A. Kerr, and Stefano Mariani

SEDAR50-RD19

20 May 2016



Interdisciplinary Evaluation of Spatial Population Structure for Definition of Fishery Management Units

Steven X. Cadrin,¹ Lisa A. Kerr,² Stefano Mariani³

¹*School for Marine Science and Technology, University of Massachusetts,
New Bedford, MA, USA*

²*University of Massachusetts, School for Marine Science and Technology,
New Bedford, MA, USA; Gulf of Maine Research Institute, Portland, ME, USA*

³*School of Environment & Life Sciences, University of Salford, Manchester, UK*

CHAPTER OUTLINE

22.1 Introduction.....	536
22.2 A Process for Interdisciplinary Stock Identification.....	537
22.3 Case Studies	539
22.3.1 Winter Flounder (<i>Pseudopleuronectes americanus</i>).....	540
22.3.2 Atlantic Herring (<i>Clupea harengus</i>) off New England	542
22.3.3 Yellowtail Flounder (<i>Limanda ferruginea</i>) off New England	543
22.3.4 Atlantic Cod (<i>Gadus morhua</i>) in New England.....	544
22.3.5 Atlantic Bluefin Tuna (<i>Thunnus thynnus</i>)	545
22.3.6 Beaked Redfish (<i>Sebastes mentella</i>) in the Irminger Sea.....	546
22.3.7 Striped Sea Bream (<i>Lithognathus mormyrus</i>) in the Mediterranean and Adjacent Atlantic Waters	548
22.4 Conclusions	549
Acknowledgments	549
References	549

22.1 INTRODUCTION

As we described in the overview of this volume, stock identification is an important prerequisite for stock assessment and fishery management. The closer management units reflect biological population structure, the better for achieving management objectives such as optimum yield. The challenge we face is that investigation of population structure is a never-ending scientific endeavor that is supported by rapidly advancing technologies and methods; yet, resource conservation and fishery management require the practical definition of spatial management units that are based on the best available science and over time scales that are germane to policy and trade.

Revising spatial definition of management units can pose transition costs for the scientific process (e.g., revised stock assessments), fishery management (e.g., new management plans), and stakeholders (e.g., implications for total allowable catch and individual allocations; see [Aps et al., 2004](#); [Hammer and Zimmermann, 2005](#)). Therefore, a process is needed to consider how new information can be used to reevaluate stock identity and possibly evaluate the implications of existing management boundaries that do not reflect revised perceptions of stock structure.

Information on geographic variation and movement patterns from newly developed and recently applied methods can be reconciled with previous information from more traditional methods for practical definitions. The process for developing inferences of the most likely population structure and recommendations for the most appropriate management units involves: (1) a comprehensive multidisciplinary review of available information, (2) interdisciplinary analysis for synthetic conclusions, and (3) practical considerations of monitoring, assessment, and management.

Like all scientific endeavors, the practice of stock identification has changed over time, taking advantage of new perspectives offered from technological advances and improving our ability to manage fisheries and conserve fishery resources. The earliest definitions of spatial management units reflected fishing grounds (e.g., [Rounsefell, 1948](#); [Royce et al., 1959](#); [Halliday and Pinhorn, 1990](#)). The early stages of fisheries science emphasized demography, and the study of vital rates (e.g., growth maturity, recruitment) led to stock definitions that were based on phenotypic variation (e.g., [Gilbert, 1914](#); [Hjort, 1914](#); [Cadrin and Secor, 2009](#)). A subsequent focus on recruitment dynamics led to investigations of life cycle closure and fish movement patterns, and inferences of movement from conventional tagging studies complemented phenotypic information (e.g., [Jakobsson, 1970](#); [Thorsteinsson, 2002](#); [Hall, 2013](#)). The most profound methodological revolution was the application of genetic techniques to fishery resources, leading to a “stock concept” that was largely based on reproductive isolation (e.g., [Larkin, 1972](#); [Fetterolf, 1981](#)).

Since the early investigations of allozymes for salmonid stocks in the 1970s, the technological revolution promoted advancements in every stock identification approach. Genetic methods advanced from allozymes to a progressively broadening set of DNA markers (e.g., Chapter 13; [Mariani and](#)

Bekkevold, 2013), the development of electronic tags led to much greater understanding of fish movement patterns (e.g., DeCelles and Zemeckis, 2013; Galuardi and Lam, 2013), advances in microchemistry allowed detailed analysis of otoliths (e.g., Kerr and Campana, 2013), imaging improved morphological and parasitological methods as well as geographic information systems, and computer technology facilitated developments in statistical analysis and population modeling (Galuardi and Lam, 2013; Kerr and Goethel, 2013; Schwarz, 2013). As each chapter in this volume demonstrates, stock identification continues to be a rapidly developing field, and the incorporation of new information into fishery management is a challenge.

Although we are compelled to consider new information, it should be interpreted in the context of all available information. Therefore a synthesis of information from multiple stock identification approaches is needed for a comprehensive conclusion. The historical development of information should be recognized as well as the practical limitations for fishery assessment and management.

22.2 A PROCESS FOR INTERDISCIPLINARY STOCK IDENTIFICATION

Conclusions about biological population structure and recommendations for appropriate fishery management units should adhere to principles of best scientific information available (NRC, 2004):

- **Relevance**—The information considered is relevant to the stock being evaluated.
- **Inclusiveness**—All interested scientific parties are included in the review.
- **Objectivity**—Inferences are based on the most likely interpretation of information without bias for a particular outcome.
- **Transparency**—The basis for conclusions should be clearly documented.
- **Timeliness**—Stock identity should be reconsidered when new information becomes available.
- **Verification**—The basis for all previously stated and newly developed inferences should be reviewed in the context of current best practices.
- **Validation**—The data used for all previously stated and newly developed inferences should be reviewed for quality and assurance.
- **Peer review**—Ideally, each component study is published in peer-reviewed literature, and the interdisciplinary synthesis is externally reviewed.

The process we advocate has several sequential stages. At each stage, a consensus summary statement should be developed among all participants. The first step in the process is to clearly define the current spatial management units and their scientific or practical justification. The scientific information that was used to form the current management units should be reviewed in the context of current knowledge and their distinct perspective on stock structure, including explicit objectives, sampling designs, analytical methods, and conclusions from each study.

The next step in the process is to identify all *a priori* hypotheses about population structure, including the paradigm used to justify current management units. All information available should be evaluated with respect to each hypothesis. Some information may not have been sampled to rigorously test hypotheses, but consistency or inconsistency with hypotheses should be considered for each source of information.

The third step in the process is a comprehensive search for information related to the specific fishery resource being evaluated, ideally considering information from throughout the species' geographic range. Information should prioritize research that was explicitly intended and designed to support inferences about stock structure. Secondly, relevant information may be found in other studies that were not intended to be used for stock identification (e.g., fishery descriptions, resource surveys, life history studies). Information from peer-reviewed literature should have more influence on conclusions than that from gray literature, because it has had some peer review from experts in that discipline. Information can be grouped into broad disciplines (e.g., geographic distribution; geographic variation in genetic composition, phenotypic traits, environmental traits; movement patterns), and consensus conclusions within each discipline should be formed.

Cadrin *et al.* (2010) developed five criteria for consensus interpretation of the results from each case study:

1. Was stock identification an explicit objective of the study?
2. Did the samples represent hypothetical stocks (e.g., from a rigorous sampling design)?
3. Was sample size adequate to detect a meaningful difference between groups?
4. Were differences between hypothetical stocks tested statistically?
5. Was the analytical methodology sound (i.e., adequate for the task of determining population structure)? The critiques and protocols described in the first edition of this volume (Cadrin *et al.*, 2005) served as a guide.

Information available within each discipline should be reviewed and interpreted with respect to population structure and the stated hypotheses. Some sources of information may be interpreted in alternative ways, and all viable alternatives should be considered. Final conclusions should be based on information that is objective, parsimonious, and the least equivocal. In summary of all information within a discipline, a general conclusion about stock structure from the perspective of that discipline should be formed.

After the multidisciplinary review is complete, each perception of stock structure should be considered in an interdisciplinary evaluation. Previous syntheses of information should be reviewed at this stage, including the objective and spatial extent of the previous synthesis, and a determination of strengths and weaknesses of the previous conclusions, upon which to contrast the new synthesis. Integrations based on multidisciplinary sampling have distinct advantages for forming interdisciplinary conclusions (see Abaunza *et al.*, 2013). All newly developed conclusions on geographic distribution, geographic

variation, and connectivity should be integrated to obtain a holistic perspective on biological stocks. The unique perspective offered from each discipline along with the sensitivity of specific characters for detecting population structure should be considered to identify congruent results and to reconcile apparent differences.

The final stage of evaluating biological stock structure should involve consideration of each *a priori* hypothesis, identification of information that rigorously tested the hypotheses, and evaluation of whether the information could be used to either reject or support hypotheses. The testing of hypotheses should be based on the most objective information available (i.e., information not subject to alternative or equivocal interpretation). Conclusions on biological stocks should be based on the most robust and parsimonious view of stock structure that is consistent with the best scientific information available.

In recent years there has been an increased recognition of the advantages of conducting stock structure investigations with an interdisciplinary approach from the onset (Abaunza et al., 2008; Higgins et al., 2010). This methodology allows collection of multiple stock descriptors on the same individuals, hence providing the opportunity for a comprehensive quantification of population structure in a common statistical framework, and without the limitations associated with comparisons among different sets of data collected at different times. Presently, uncertainties remain as to the most appropriate way to standardize rather different types of data (e.g., microsatellite genotypes, morphological traits, chemical signatures, parasitic fauna, etc.) and analyze such multivariate matrices. Yet, research is moving toward the optimization of suitable approaches, such as multi-criteria evaluation analysis (MCEA), which has been successfully applied to environmental impact assessment (Janssen, 2001) and which can be integrated in geographic information systems (Carver, 1991) to use spatial features as predictor variables of spatial structure.

Recommendations for practical management units should consider geographic delineations that most accurately reflect the consensus on biological stock structure, as well as practical aspects and the limitations of monitoring fisheries and the resource and managing fisheries (i.e., jurisdictions). Ideally, the implications of new perspectives on stock identity and existing management unit definitions can be evaluated by simulation (see Kerr and Goethel, 2013).

In addition to recommendations for definition of management units, the interdisciplinary analysis can also identify research recommendations, including refinement of fishery and resource monitoring approaches and the optimal sampling design for confirmatory analysis and possibly stock composition analysis for mixed-stock situations.

22.3 CASE STUDIES

The most effective approach to interdisciplinary conclusions about stock structure is a multidisciplinary sampling design (e.g., Abaunza et al., 2013).

However, information from disparate studies can also be integrated to form interdisciplinary conclusions. Examples of interdisciplinary analyses are described from two approaches. Several examples are provided from the Northeast U.S. Stock Assessment Workshop, in which stock structure was reviewed within a stock assessment peer-review process. Other examples are from independent workshops from the stock assessment peer-review process from New England, the International Commission on the Conservation of Atlantic Tuna (ICCAT), and the International Council for the Exploration of the Seas (ICES). Case studies from both approaches demonstrate how information from historical and recent studies can be considered to develop recommendations for fishery management or for further research.

22.3.1 Winter Flounder (*Pseudopleuronectes americanus*)

Stock structure and management units of winter flounder off the United States have been evaluated through the Northeast Regional Stock Assessment Workshop process. Prior to 1996, winter flounder were managed as four stock units in the U.S. waters of the northwest Atlantic: (1) Mid-Atlantic, (2) southern New England, (3) Georges Bank, and (4) Gulf of Maine (Figure 22.1). In 1996 (at the 21st Stock Assessment Workshop), the southern New England and Mid-Atlantic groups were combined to form a single unit for assessment

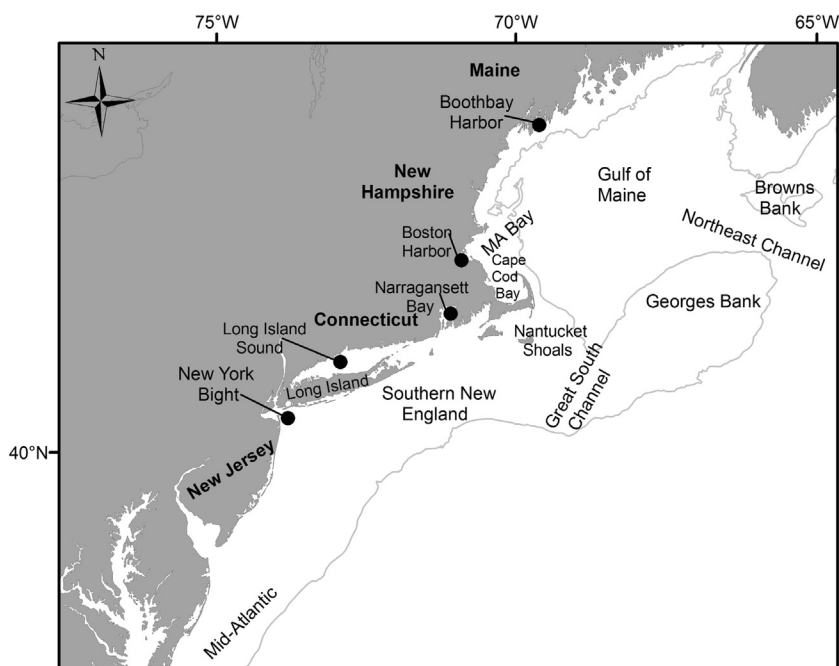


FIGURE 22.1 The northeast United States and continental shelf. Modified from DeCelles and Cadrin (2010).

purposes (Shepherd et al. 1996). The Workshop concluded that there was evidence of localized estuarine populations present in the two areas, but the fisheries in these regions are typically conducted when winter flounder populations are intermixed in coastal offshore waters. These management units were confirmed through a more extensive synthesis that included the species' entire geographic range (DeCelles and Cadrin, 2010), which was peer reviewed through the 52nd Stock Assessment Workshop (NEFSC, 2011).

DeCelles and Cadrin (2010) reviewed information on winter flounder genetics, morphology, meristics, larval dispersal, life history traits, tagging, parasites, and contaminants. Estuarine spawning, which plays an important role in reproductive isolation and population structure, appears to be obligate in southern New England, nonexistent on Georges Bank, and variable in the Gulf of Maine. Behavioral groups (i.e., contingents) are likely present in both the Gulf of Maine and southern New England/Mid-Atlantic stocks. Despite evidence for reproductively isolated estuarine groups, information from tagging, meristic analysis, and life history studies suggest extensive mixing, thereby supporting the current U.S. management units. In Canadian waters, winter flounder are managed as three units: western Scotian Shelf, eastern Scotian Shelf, and the southern Gulf of St. Lawrence (Figure 22.2). Genetic analysis and parasite markers indicate that these Canadian management units are distinct. However, examination of inshore and offshore winter flounder on the western Scotian Shelf suggests that little interchange occurs between these groups. Several separate stocks probably

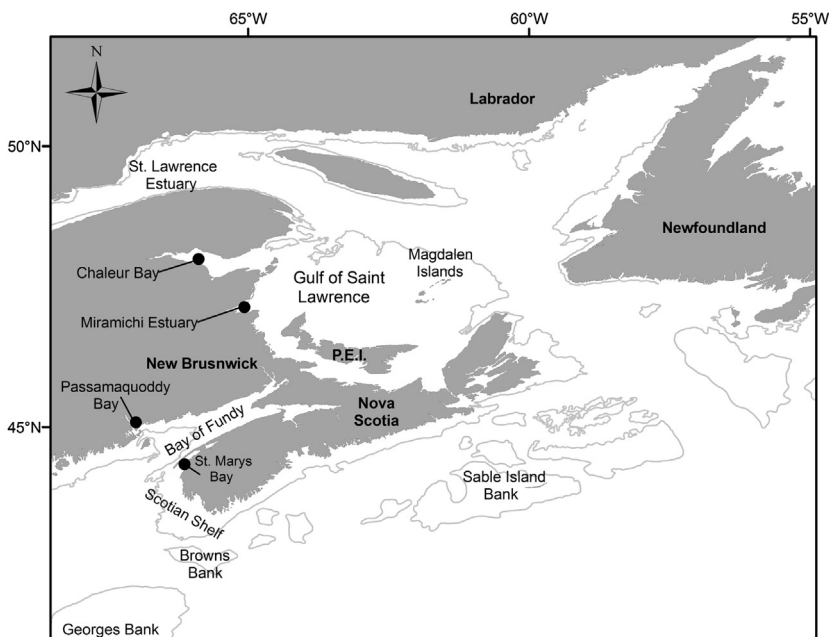


FIGURE 22.2 Atlantic Canada and the northwest Atlantic continental shelf. Modified from DeCelles and Cadrin (2010).

exist within the Gulf of St. Lawrence as well. Stock assessment and fishery management would likely benefit from stock composition analysis of mixed-stock fisheries of both U.S. and Canadian fishery resources.

The three—U.S.—stocks hypothesis was recently tested using analysis of microsatellite DNA from young-of-the-year winter flounder sampled in 27 estuaries from Newfoundland to Delaware and Georges Bank (Wirgin et al., *in press*). They found significant regional genetic stock structure (e.g., Gulf of Maine, southern New England, Georges Bank, Gulf of St. Lawrence, Newfoundland) but little evidence of structure among estuaries within U.S. regions. Research continues on stock composition analysis of mixed-stock fisheries using meristic analysis (DeCelles et al., 2012) and larval dispersal from coastal spawning sites (DeCelles et al., 2010).

22.3.2 Atlantic Herring (*Clupea harengus*) off New England

Stock structure and management units of Atlantic herring off the United States have also been evaluated through the Northeast Regional Stock Assessment Workshop process. The Atlantic herring resource along the East Coast of the United States was originally divided into separate Gulf of Maine and Georges Bank stocks (Figure 22.1), but herring from the Gulf of Maine and Georges Bank components are now combined into a single coastal stock complex, because fisheries and surveys include fish originating from all spawning areas off New England (NEFSC, 2012).

Information available on herring stock structure off New England was reviewed in the context of the current management unit definition. The review included information on the geographic distribution of survey catches and ichthyoplankton collections, geographic variation in genetics, size-at-age and morphology, and movement of early life stages as well as tagged juveniles and adults. The synthesis indicated that three major spawning components from Georges Bank, Nantucket Shoals (Great South Channel area), and the coast of Gulf of Maine are distinct but seasonally mix.

As a result of mixing outside of the spawning season, much of the fishery takes place on mixed aggregations, a situation also typical of some herring stocks in Europe (Ruzzante et al., 2006). Mixing of spawning components in the fishery and during resource surveys precludes separate assessment and management of the components. It is therefore necessary to continue to assess the entire complex, with subsequent consideration of the individual components. Conservation of spawning groups requires more extensive sampling of stock composition from the fishery and surveys as well as monitoring relative abundance of spawning components.

The assessment and management approach for New England herring poses a challenge for the conservation of individual spawning components. Catch limits for the stock complex are allocated to spatial management areas, with the intent of separating spawning areas (inshore Gulf of Maine, area 1A;

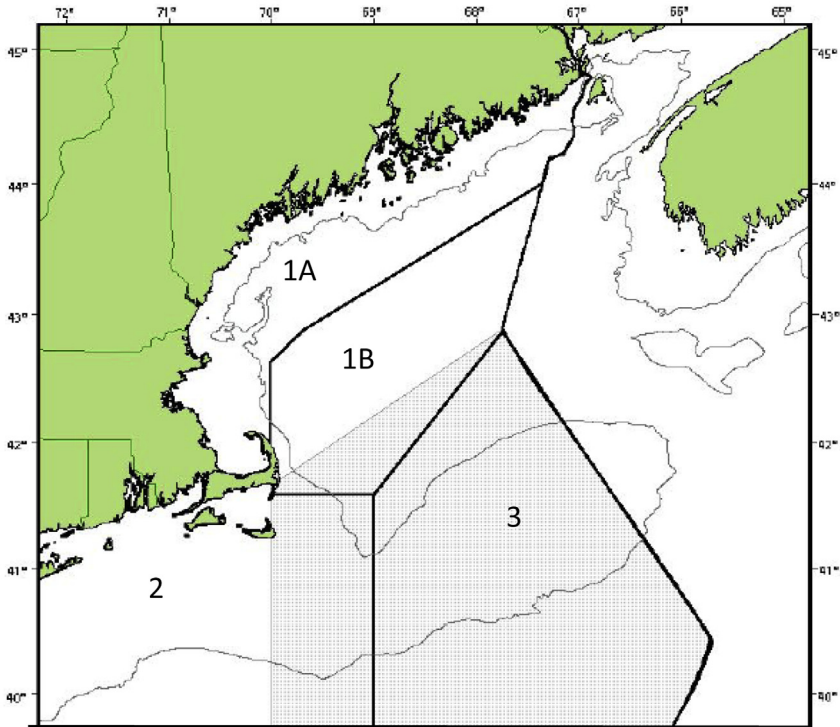


FIGURE 22.3 Management boundaries for Atlantic herring in the Gulf of Maine and on Georges Bank. Lines indicate original boundaries, shaded area indicates 2006 revision to area 3 boundaries. (For color version of this figure, the reader is referred to the online version of this book.) Adapted from NEFSC (2012).

Georges Bank, area 3) from mixing areas (offshore Gulf of Maine, area 1B; southern New England—Mid-Atlantic, area 2; [Figure 22.3](#)), and allocations are based on estimates of stock composition (e.g., from morphometric patterns) and relative biomass among areas. Research continues on acoustic surveys of discrete spawning groups and stock composition of mixed-stock fisheries.

22.3.3 Yellowtail Flounder (*Limanda ferruginea*) off New England

The 36th Stock Assessment Workshop (2003) investigated stock structure of yellowtail flounder resources off the northeastern United States and recommended that the resource should be assessed and managed as three stocks: (1) Georges Bank, (2) Southern New England—Mid-Atlantic, and (3) Cape Cod—Gulf of Maine ([NEFSC, 2003](#), [Figure 22.1](#)). A subsequent and more comprehensive study conducted in 2010 considered geographic patterns of abundance, geographic variation, and movement of yellowtail and came to the same conclusion: yellowtail flounder on the principal U.S. fishing grounds should be managed as three separate stocks despite apparent

homogeneity of genetic variation (Cadrin, 2010). Divergent patterns of abundance and biomass over time suggested two harvest stocks (Georges Bank and Southern New England) of yellowtail flounder with a boundary on southwest Georges Bank. Geographic patterns of growth and maturity indicate two phenotypic stocks of yellowtail flounder, with a boundary on northern Georges Bank (Gulf of Maine and Georges Bank/southern New England). Yellowtail flounder resources off the United States may be a single genetic stock, but significant variation in life history attributes and different patterns of abundance over time suggest that yellowtail flounder off the northeastern United States should be managed as three stocks. Research continues on estimating movement rates among stock areas (Goethel et al., 2009; Wood and Cadrin, 2013).

22.3.4 Atlantic Cod (*Gadus morhua*) in New England

The scientific basis for current management units of cod in New England is described by Serchuk and Wigley (1992), but recent information from genetics and tagging suggests that the current management units should be reconsidered. Unlike the previous three case studies, stock structure of Atlantic cod in the Gulf of Maine region was considered at a workshop that was organized outside of the regional Stock Assessment Workshop process (Annala, 2012). The workshop reviewed existing data, information, and results of analyses relevant to the stock structure of cod in the Scotian Shelf, Georges Bank, Gulf of Maine, and southern New England regions and made recommendations on the most likely biological stock boundaries in these regions (including sub-stock structure). The current management units were considered to be the null hypothesis and other stock structure scenarios as alternative hypotheses. Recommendations were also made for future research required to evaluate these stocks more robustly.

On the issue of fine-scale spatial structure, the workshop concluded that larval retention and multiyear fidelity to local spawning sites suggest fine-scale metapopulation structure. Some traditional spawning groups were depleted (e.g., Ames, 2004) and have not been recolonized by more productive groups. Depletion of historical spawning groups is most apparent in the eastern Gulf of Maine, the Mid-Atlantic, the “Plymouth Grounds,” and recently in Nantucket Shoals.

With respect to broadscale population structure, the workshop concluded that conceptualizing the most likely biological stock structure is essential for the next steps of evaluating alternative management units and their potential to achieve fishery objectives (Annala, 2012). All information from the New England region suggests that there are three genetic stocks: (1) Offshore: eastern Georges Bank (with some connectivity with the Scotian Shelf; see Figure 22.1); (2) Inshore: northern, spring-spawning complex; and (3) Inshore: southern, winter-spawning complex (see Kovach et al., 2010 and references therein). Information from more traditional stock identification

approaches (e.g., tagging, growth, larval dispersal) and larval dispersal studies generally supports the genetic perspective (e.g., [Runge et al., 2010](#)). However, cod in the eastern Gulf of Maine appear to be distinct from other groups. All genetic information available is not entirely congruent with current U.S. management unit boundaries.

The workshop provided compelling evidence that the current management units need to be reconsidered ([Annala, 2012](#)). However, the precise location of boundaries and stock composition of mixed-stock areas remain poorly understood. The workshop identified the need for more detailed review of information from the Scotian Shelf and further consideration of larval dispersal from important spawning grounds. The workshop recommended an evaluation of the advantages and disadvantages of alternative management unit scenarios on stock status and yields from the cod stocks in the region to justify the most appropriate management units. Longer-term research recommendations pointed at stock composition analysis, sampling, and analysis of further genetic data from key areas (e.g., Georges Bank, eastern Gulf of Maine, including archaeological data, and Canadian waters).

22.3.5 Atlantic Bluefin Tuna (*Thunnus thynnus*)

Bluefin tuna is a highly migratory species, with at least two known distinct spawning locations adjacent to the Atlantic Ocean (one in the Mediterranean Sea and one in the Gulf of Mexico) and extensive mixing of spawning groups. In 2001, ICCAT formed a workshop to examine the effects of mixed-stock fisheries for stock assessments and possible management boundaries ([ICCAT, 2001](#)). The goals of the workshop were to evaluate the available information on mixing and movement, examine alternative assessment models that might be used to characterize the biological hypotheses, suggest alternatives for management structures that might be used given the biological and assessment characteristics, and evaluate the information and institutional requirements needed to assess and manage the stocks under alternative management structures.

Based on the available information, the workshop categorized conclusions into what is known, what is likely, and what is unknown ([ICCAT, 2001](#)). In the first category, there is compelling evidence that there are at least two spawning areas, and more fish spend time on the side of the Atlantic where they were tagged than migrate far away. The more likely conclusions were that there is a substantial degree of spawning-site fidelity, the distribution of fish from the two known spawning areas overlaps in some seasons, and some fish of eastern origin are caught in the west Atlantic management area and vice versa. A research program was proposed based on the unknown aspects of bluefin stock structure and mixing. Research continues on Atlantic bluefin tuna tagging, genetics, otolith chemistry, life history, and mixed-stock population modeling to support stock assessment and fishery management (e.g., [Rooker et al., 2007](#); [Taylor et al., 2011](#); [ICCAT, 2012](#)).

In 2013, a workshop was convened to review advances in biological data and parameters used in Atlantic bluefin tuna stock assessment (ICCAT, 2013). More specifically, traditional and recent information on population structure and stock mixing from otolith microchemistry, genetics, tagging, and life history parameters was reviewed. The workshop recommended that the effects of complex population structure on the scientific advice should be tested.

22.3.6 Beaked Redfish (*Sebastes mentella*) in the Irminger Sea

As a pelagic fishery developed for *S. mentella* off Iceland, ICES provided fishery management advice for two distinct management units: (1) a demersal unit on the continental shelf and (2) a pelagic unit in the Irminger Sea and adjacent areas (Hammer and Zimmermann, 2005). However, stock identity was uncertain, and a multinational research initiative (the EU Redfish Project) was designed to investigate population structure. ICES hosted two workshops to determine the most parsimonious view of stock structure that is consistent with all information available on *S. mentella* in the Irminger Sea and adjacent areas (ICES, 2005, 2009).

As the EU Redfish Project was in the final stages of documenting results, the ICES Study Group on Stock Identity and Management Units of Redfishes met to review all stock identification material, identify most likely biological stocks, and suggest practical management units (ICES, 2005). Information from the EU and Faroese Redfish projects as well as spatial analyses of fishery and survey data were reviewed. The Study Group concluded that *S. mentella* exhibit population structure, but the nature of the structure (i.e., reproductively isolated groups or demographic groups) was not clear. Research recommendations were that microsatellite analyses were the most reliable approach to stock identification, and temporal stability of all geographic differences should be evaluated.

In 2009, ICES organized a second workshop to reconcile the new genetic results with all previous information on stock structure with the aim of identifying the most likely definition of biological stocks and to recommend practical management units in the Irminger Sea and adjacent waters (ICES, 2009). The process for interdisciplinary stock identification described in Section 22.2 (above) was developed and implemented to meet the objectives of the 2009 workshop. Specific studies were reviewed on geographic distribution (e.g., fishing grounds, survey data of early life stage, juveniles, and adults), genetic variation (e.g., allozymes, mitochondrial DNA, nuclear DNA), phenotypic variation (e.g., life history traits, morphology, fatty acid composition), and connectivity (e.g., larval dispersal, natural tags, and artificial tags) of redfish to form a general conclusion about stock structure from the perspective of that discipline. An interdisciplinary evaluation was formed by synthesizing information from each discipline to develop a holistic perspective on biological stocks. Each of

the a priori hypotheses was tested using the most objective information available. Recommendations for practical management units considered geographic delineations that most accurately reflect the consensus on biological stock structure.

Based primarily on genetic information (i.e., microsatellites), and supported by other information on stock structure, the 2009 workshop concluded that there are three biological stocks of *S. mentella* in the Irminger Sea and adjacent waters (Figure 22.4): (1) a “Deep Pelagic” stock, (2) a “Shallow Pelagic” stock, and (3) an “Icelandic Slope” stock (ICES statistical areas Va and XIV). Although biological stocks of *S. mentella* were partially defined by depth, the workshop recognized that definition of management units by depth and the associated fishery monitoring by depth would be impractical. Therefore, management units were based on geographic proxies for biological stocks that minimize mixed-stock catches (Figure 22.4, Cadrin et al., 2010). Although both ICES workshops included all interested parties, debate continues on the topic of stock identity (e.g., Cadrin et al., 2011; Makhrov et al., 2011), and research continues to resolve stock composition of nursery grounds on the Greenland shelf, as well as to further clarify the role of depth as a driver of population structure.

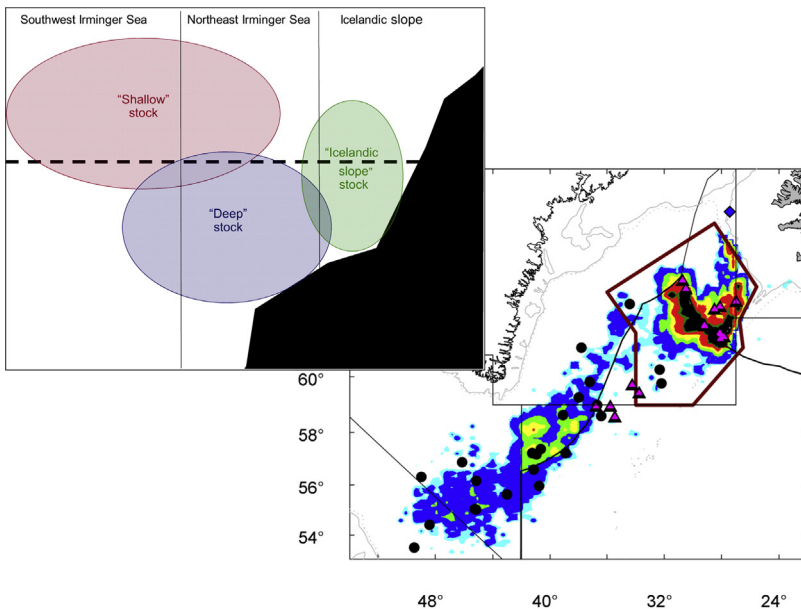


FIGURE 22.4 Vertical schematic of *Sebastes mentella* biological stocks (upper left) and spatial management unit boundary of the deep pelagic stock (map polygon), with distribution of the pelagic fisheries (isopleths) and genetic sample locations (circles and triangles). (For color version of this figure, the reader is referred to the online version of this book.) Adapted from ICES (2009) and Cadrin et al. (2010).

22.3.7 Striped Sea Bream (*Lithognathus mormyrus*) in the Mediterranean and Adjacent Atlantic Waters

Striped sea bream (or sand steenbras) is a coastal marine species whose adults reside in shallow coastal waters but release eggs offshore. Juveniles recruit to lagoons and sheltered bays and settle along the coast as they grow. Striped sea bream are not subjected to rigorous management strategies and are targeted by small-scale, artisanal fisheries throughout the Mediterranean, often in mixed-species local fisheries (the photograph chosen for the cover of this book is taken from the crate of one such catch in Italy).

An independent population biology study characterized genetic differences in this species, showing the different signals yielded using microsatellites and mitochondrial DNA and revealing that parasitic fauna approximated more closely the structure identified using microsatellites (Sala-Bozano et al., 2009). The analysis of life history data (growth, maturation, sex change) offered additional information, detecting differences between groups that were otherwise indistinguishable (Sala-Bozano and Mariani, 2011). When all available data for each individual are analyzed in a multivariate framework (Figure 22.5), it is possible to obtain an overall picture of the relationships among population inhabiting the studied areas, which is more exhaustive than that obtained with any one method employed separately.

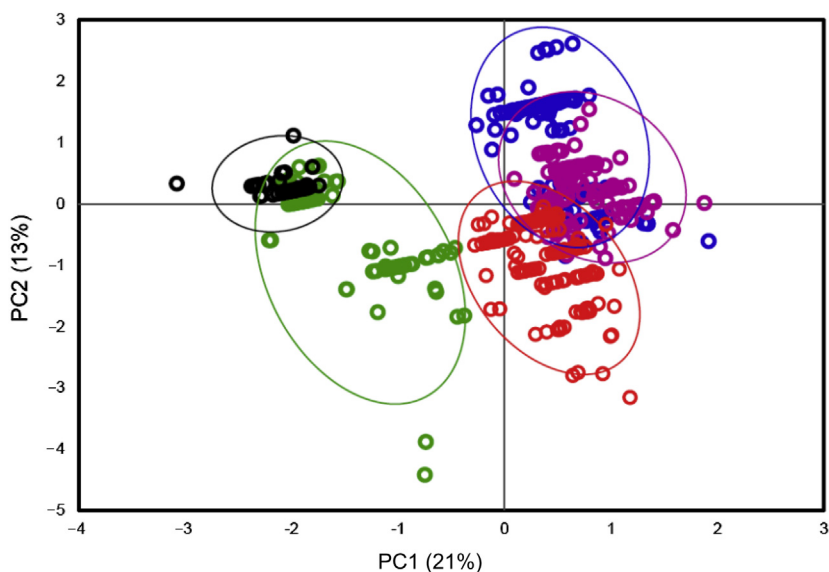


FIGURE 22.5 Individual striped sea bream data points plotted in the space identified by the first two principal components, based on 20 different variables (i.e., 14 parasites, microsatellite assignment, mtDNA lineage, weight—length condition factor, and coefficients for growth, maturation, and sex change). Colors refer to the marine basins sampled (see Sala-Bozano and Mariani, 2011): blue: Atlantic; purple: Alboran; red: Balearic; green: Tyrrhenian; black: Adriatic. Ellipses show 95% distribution limits for each data series. (For interpretation of the references to color in this figure legend, the reader is referred to the online version of this book.)

22.4 CONCLUSIONS

The many approaches to stock identification described in this book offer many perspectives on stock structure that can be considered for fishery science and management. Although the first edition of the book (Cadrin et al., 2005) encouraged a multidisciplinary approach, it fell somewhat short of providing guidance and examples on reconciling information from various methods and studies. The chapter on interdisciplinary sampling and analysis by Abaunza et al. (2013) in this second edition offers a method for integrating information from different methods within a single study, but we often need to integrate information from across many disparate studies. The process for interdisciplinary stock identification described here was developed through the practice of inclusive workshops, peer review, and application to fishery management decisions. Despite the complexity of studying population structure, the case studies demonstrate that information from different stock identification approaches can be reconciled to form consensus conclusions and practical recommendations. One emergent theme from the case studies was the presence of uncertainty in stock identification and the search for the most likely scenario that is supported by all available information. The steps taken thus far provide the platform for more decisive interdisciplinary stock identification studies in the coming years. It is envisaged that through increasingly integrated collaborative efforts, and the sophistication of statistical approaches, it will become more achievable to address pressing issues of resource management and conservation by delivering more robust stock structure information to policy makers that will not be over reliant on any one specific methodology.

ACKNOWLEDGMENTS

Many colleagues contributed to the case studies we reviewed. Greg DeCelles led the review of winter flounder, with contributions from Wendy Gabriel, Gary Shepherd, Arnold Howe, Steve Correia, and others in the 54th SAW. Mike Armstrong, Kevin Friedland, Karen Bolles, Bill Overholtz, Dave Richardson, Jon Deroba, Steve Correia, and others in the 54th SAW contributed to the Atlantic herring review. Dan Goethel, Vaughan Silva, Larry Alade, Azure Westwood, Dave Martins, and others in the 36th SAW contributed to the yellowtail flounder review. Matthias Bernreuther, Anna Kristin Danielsdottir, Einar Hjorleifsson, Torild Johansen, Kristjan Kristinsson, Kjell Nedreaas, Christophe Pampoulie, Benjamin Planque, Jakup Reinert, Fran Saborido-Rey, Thorsteinn Sigurðsson, Christoph Stransky, and others in WKREDS contributed to the redfish review. John Annala chaired the cod workshop with contributions from Doug Zemeckis, Jon Loehrke, Dave Martins, Adrienne Kovach, Shelly Tallack, Hunt Howell, Tim Miller, Graham Sherwood, Kevin Friedland, Jake Kritzer, Tom Nies, David Goethel, Ted Ames, and other workshop participants. Dave Secor, Ben Galuardi, Molly Lutcavage, Tim Lam, Walt Golet, Clay Porch, Shannon Cass-Calay, Doug Butterworth, Mike Sissenwine, and others in the ICCAT workshops contributed to the Atlantic bluefin tuna review. Maria Sala-Bozano led the striped sea bream review.

REFERENCES

- Abaunza, P., Murta, A.G., Campbell, N., Cimmaruta, R., Comesaña, S., Dahle, G., Gallo, E., García Santamará, M.T., Gordo, L., Iversen, S., MacKenzie, K., Magoulas, A., Mattiucci, S., Molloy, J., Nascetti, G., Pinto, A.L., Quinta, R., Ramos, P., Ruggi, A.,

- Sanjuan, A., Santos, A.T., Stransky, C., Zimmermann, C., 2008. Considerations on sampling strategies for an holistic approach to stock identification: the example of the HOMSIR project. *Fish. Res.* 89, 104–113.
- Abaunza, P., Murta, A.G., Stransky, C., 2013. Sampling for interdisciplinary analysis. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Ames, E.P., 2004. Atlantic cod stock structure in the Gulf of Maine. *Fisheries* 29, 10–28.
- Annala, J. (Ed.), 2012. Stock Structure of Atlantic Cod in the Gulf of Maine Region. Gulf of Maine Research Institute. Workshop Report www.gmri.org/mini/index.asp?ID=52.
- Aps, R., Lassen, H., Rice, J., Andrejeva, K., Aps, J., 2004. Application of Baltic Herring and Cod Stock Identification Results to Fishery Management. ICES C.M. 2004/EE:23.
- Cadrin, S.X., 2010. Interdisciplinary analysis of yellowtail flounder stock structure off New England. *Rev. Fish. Sci.* 18, 281–299.
- Cadrin, S.X., Secor, D.H., 2009. Accounting for spatial population structure in stock assessment: past, present and future. In: Rothschild, B.J., Beamish, R. (Eds.), *The Future of Fishery Science in North America*. Springer Verlag, pp. 405–426.
- Cadrin, S.X., Friedland, K.D., Waldman, J. (Eds.), 2005. *Stock Identification Methods: Applications in Fishery Science*. Elsevier Academic Press.
- Cadrin, S.X., Bernreuther, M., Daníelsdóttir, A., Hjørleifsson, E., Johansen, T., Kerr, L., Kristinsson, K., et al., 2010. Population structure of beaked redfish, *Sebastes mentella*: evidence of divergence associated with different habitats. *ICES J. Mar. Sci.* 67, 1617–1630.
- Cadrin, S.X., Mariani, S., Pampoulie, C., Bernreuther, M., Daníelsdóttir, A.K., Johansen, T., Kerr, L., Nedreaas, K., Reinert, J., Sigurðsson, Þ., Stransky, C., 2011. Counter-comment on: Cadrin et al. (2010) “Population structure of beaked redfish, *Sebastes mentella*: evidence of divergence associated with different habitats. *ICES J. Mar. Sci.* 67, 1617–1630”. *ICES J. Mar. Sci.* 68, 2016–2018.
- Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. *Int. J. Geogr. Inf. Syst.* 5, 321–339.
- DeCelles, G.R., Cadrin, S.X., 2010. Movement patterns of winter flounder in the southern Gulf of Maine: observations using passive acoustic telemetry. *Fish. Bull.* 108, 408–419.
- DeCelles, G., Zemeckis, D., 2013. Acoustic and radio telemetry. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- DeCelles, G., Cadrin, S.X., Cowles, G., 2010. The Fate of Winter Flounder Larvae Spawmed in Coastal Waters of the Gulf of Maine. ICES CM 2010/A:01.
- DeCelles, G., Roman, S., Cadrin, S., 2012. Winter flounder distribution in southern New England—insights from industry-based trawl surveys. In: Mercaldo-Allen, R., Calabrese, A., Danila, D., Dixon, M., Fairchild, E., Jearld, A., Munroe, T., Pacileo, D., Powell, C., Sutherland, S. (Eds.), 13th Flatfish Biology Conference 2012, pp. 12–28. Northeast Fish Sci Cent Ref Doc.
- Fetterolf Jr, C.M., 1981. Foreword to the stock concept symposium. *Can. J. Fish. Aquat. Sci.* 38, iv–v.
- Galuardi, B., Lam, C.H., 2013. Telemetry analysis of highly migratory species. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Gilbert, C.H., 1914. Contributions to the Life History of the Sockeye Salmon. Report to British Columbia Fisheries Department, Vancouver, BC.
- Goethel, D.R., Legault, C.M., Cadrin, S.X., 2009. A Spatially Explicit Stock Assessment Model Incorporating Tagging Data. ICES CM 2009/J:02.
- Hall, D.A., 2013. Conventional and radio frequency identification (RFID) tags. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Halliday, R.G., Pinhorn, A.T., 1990. The delimitation of fishing areas in the northwest Atlantic. *J. Northw. Atl. Fish. Sci.* 10, 1–51.

- Hammer, C., Zimmermann, C., 2005. The role of stock identification in formulating fishery management advice. In: Cadrin, S.X., Friedland, K.D., Waldman, J.R. (Eds.), *Stock Identification Methods. Applications in Fishery Science*. Elsevier Academic Press, pp. 631–658.
- Higgins, R.M., Danilowicz, B.S., Balbuena, J.A., Danélsdóttir, A.K., Geffen, A.J., Meijer, W.G., Modin, J., Montero, F.E., Pampoulie, C., Perdiguer-Alonso, D., Schreiber, A., Stefánsson, M.Ö., Wilson, B., 2010. Multi-disciplinary fingerprints reveal the harvest location of cod *Gadus morhua* in the northeast Atlantic. *Mar. Ecol. Prog. Ser.* 404, 197–206.
- Hjort, J., 1914. Fluctuations in the great fisheries of northern Europe. *Rapp. P.-v Réun. Cons. Int. Explor. Mer.* 20, 1–228.
- ICCAT (International Commission for the Conservation of Atlantic Tunas), 2001. Workshop on bluefin mixing (Madrid, Spain, September 3–7, 2001). SCRS/01/020.
- ICCAT (International Commission for the Conservation of Atlantic Tunas), 2012. Report of the 2012 Atlantic bluefin tuna stock assessment session. Doc. No. SCI-033/2012.
- ICCAT (International Commission for the Conservation of Atlantic Tunas), 2013. Report of the 2013 bluefin meeting on biological parameters review (Tenerife, Spain – May 7 to 13, 2013).
- ICES (International Council for the Exploration of the Sea), 2005. Report of the study group on stock identity and management units of redfishes (SGSIMUR). ICES CM 2005/ACFM:10.
- ICES (International Council for the Exploration of the Sea), 2009. Report of the workshop on redfish stock structure. ICES CM 2009/ACOM:37.
- Jakobsson, J., 1970. On fish tags and tagging. In: *Oceanogr. Mar. Biol. Ann. Rev.*, vol. 8, 457–499.
- Janssen, R., 2001. On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. *J. Multi-Crit. Decis. Anal.* 10, 101–109.
- Kerr, L., Campana, S., 2013. Otolith elemental composition. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Kerr, L.A., Goethel, D.R., 2013. Simulation modeling as a tool for synthesis of stock identification information. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Kovach, A.I., Breton, T.S., Berlinsky, D.L., Maceda, L., Wirgin, I., 2010. Fine-scale spatial and temporal genetic structure of Atlantic cod off the Atlantic coast of the USA. *Mar. Ecol. Progr. Ser.* 410, 177–195.
- Larkin, P.A., 1972. The stock concept and management of Pacific salmon. In: Simon, R.C., Larkin, P.A. (Eds.), *The Stock Concept in Pacific Salmon*. H.R. MacMillan Lectures in Fisheries. Univ. British Columbia, Vancouver.
- Makhrov, A.A., Artamonova, V.S., Popov, V.I., Rolskiy, A. Yu, Bakay, Y.I., 2011. Comment on: Cadrin et al. (2010) “Population structure of beaked redfish, *Sebastes mentella*: evidence of divergence associated with different habitats. ICES J. Mar. Sci. 67, 1617–1630”. *ICES J. Mar. Sci.* 68, 2013–2015.
- Mariani, S., Bekkevold, D., 2013. Nuclear DNA and proteomics. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- National Research Council (NRC), 2004. Improving the Use of the “Best Scientific Information Available” Standard in Fisheries Management. The National Academies Press, Washington DC.
- Northeast Fisheries Science Center, 2003. 36th Northeast Regional Stock Assessment Workshop (36th SAW) Assess. Summ. Report. NEFSC Ref Doc 03–06.
- Northeast Fisheries Science Center, 2011. 52nd Northeast Regional Stock Assessment Workshop (52nd SAW) Assess. Summ. Report. NEFSC Ref Doc 11–11.
- Northeast Fisheries Science Center, 2012. 54th Northeast Regional Stock Assessment Workshop (54th SAW) Assess. Summ. Report. NEFSC Ref Doc 12–14.

- Rooker, J.R., Bremer, J., Block, B.A., Dewar, H., de Metrio, G., Corriero, A., et al., 2007. Life history and stock structure of Atlantic bluefin tuna (*Thunnus thynnus*). *Rev. Fish. Sci.* 15 (4), 265–310.
- Rounsefell, G.A., 1948. Development of fishery statistics in the North Atlantic. U.S. Fish Wildl. Serv. Spec. Sci. Rep. 47.
- Royce, W.F., Buller, R.F., Premetz, E.D., 1959. Decline of the yellowtail flounder (*Limanda ferruginea*) off New England. *Fish. Bull.* 146, 1–267.
- Runge, J.A., Kovach, A., Churchill, J., Kerr, L., Morrison, J.R., Beardsley, R., Berlinsky, D., Chen, C., Cadrin, S., Davis, C., Ford, K., Grabowski, J.H., Howell, W.H., Ji, R., Jones, R., Pershing, A., Record, N., Thomas, A., Sherwood, G., Tallack, S., Townsend, D., 2010. Understanding climate impacts on recruitment and spatial dynamics of Atlantic cod in the Gulf of Maine: integration of observations and modeling. *Prog. Oceanogr.* 87, 251–263.
- Ruzzante, D.E., Mariani, S., Bekkevold, D., Andre, C., Mosegaard, H., Clausen, L.A.W., Dahlgren, T.G., Hutchinson, W.F., Hatfield, E.M.C., Torstensen, E., Brigham, J., Simmonds, E.J., Laikre, L., Larsson, L.C., Stet, R.J.M., Ryman, N., Carvalho, G.R., 2006. Biocomplexity in a highly migratory pelagic marine fish, Atlantic herring. *Proc. R. Soc. B* 273, 1459–1464.
- Sala-Bozano, M., Mariani, S., 2011. Life history variation in a marine teleost across a heterogeneous seascape. *Estuar. Coast. Shelf Sci.* 92, 555–563.
- Sala-Bozano, M., Ketmaier, V., Mariani, S., 2009. Contrasting signals from multiple markers illuminate population connectivity in a marine fish. *Mol. Ecol.* 18, 4811–4826.
- Schwarz, C., 2013. Estimation of movement from tagging data. In: Cadrin, S.X., Kerr, L.A., Mariani, S. (Eds.), *Stock Identification Methods. Applications in Fishery Science*, second ed. Elsevier Academic Press.
- Serchuk, F.M., Wigley, S.E., 1992. Assessment and management of the Georges Bank cod fishery: an historical review and evaluation. *J. Northw. Atl. Fish. Sci.* 13, 25–52.
- Shepherd, G., Cadrin, S., Correia, S., Gabriel, W., Gibson, M., Howe, A., Howell, P., Grout, D., Lazar, N., Lambert, M., Ling, W., 1996. Assessment of winter flounder in the southern New England and the Mid-Atlantic. NEFSC Ref. Doc. 96–05b.
- Taylor, N., McAllister, M., Lawson, G., Carruthers, T., Block, B., 2011. Atlantic bluefin tuna: a novel multistock spatial model for assessing population biomass. *PLoS One* 6 (12), e27693. <http://dx.doi.org/10.1371/journal.pone.0027693>.
- Thorsteinsson, V., 2002. Tagging methods for stock assessment and research in fisheries. Report of concerted action FAIR CT.96.1394 (CATAG). Reykjavik. Mar. Res. Inst. Tech. Rep. 79.
- Wirgin, I., Maceda, L., Grunwald, C., Roy, N.K., Waldman, J.R., Coastwide stock structure of winter flounder *Pseudopleuronectes americanus* using nuclear DNA analyses. *Trans. Am. Fish. Soc.* (in press).
- Wood, A.D., Cadrin, S.X., 2013. Mortality and movement of yellowtail flounder, *Limanda ferruginea*, tagged off New England. *Fish. Bull.* 111, 279–287.

Index

Note: Page numbers followed by “f” denote figures; “t” tables.

A

- AB, *see* Ascertainment bias
- Acanthocephalans, 191–192
- Acoustic tags and receivers, 399
- Acoustic telemetry, 398–399
 - advantages and disadvantages, 401
 - animals tagging, 402f
 - array design, 407–409
 - contingent structure, 419–420
 - data analysis, 410–411
 - daily detection histories, 412f
 - encounter histories, 412f
 - multistate models, 415
 - presence/absence, 411–413
 - residence time, 413–414
 - triangulation, 415–417
 - deployment, 407–408
 - homing and site fidelity, 417–419
 - methods, 448–449
 - objectives and assumptions, 402–403
 - receiver array, 408f
 - scope of experiment, 409–410
 - stock mixing, 420
 - tag selection, 403
 - tagging method, 403–405
 - technology, 398–400
 - tracking method
 - active telemetry, 405
 - passive telemetry, 405–407
 - Vemco VPS, 409f
- Acoustic transmitters, 398–399
- Active acoustic tracking, 460
- Active telemetry, 405
- Active tracking, *see* Active telemetry
- Ad hoc method, 79–81
- Adaptive sampling, 494–495
- Adopted migration theory, 17
- ADR model, *see* Advection-diffusion-reaction model
- Adult cestodes, 191–192
- Adult movement
 - from Eulerian perspective, 514–515
 - from Lagrangian perspective, 513–514
- Advection (Ad), 333
- Advection-diffusion-reaction model (ADR model), 386, 513–514
- AFLP, *see* Amplified Fragment Length Polymorphism
- Age effects, 134–135
- Age-0 scaphirhynchus sturgeons, 224–225
- Age-structured models, 519–520
- Akaike Information Criterion (AIC), 93
- Algorithmic approach, 455–456
- Allele stuttering, 304–306
- American Psychological Association (APA), 480–481
- Amplified Fragment Length Polymorphism (AFLP), 307–307
- Analysis of covariance (ANCOVA), 151, 220–222
- Analysis of variance (ANOVA), 150, 189–190
- Animal behavior, 462
- Annuli, 143
- ANOVA, *see* Analysis of variance
- APA, *see* American Psychological Association
- Apparent survival rate, 432, 434
- Area restricted search, 459–460
- Arnason-Schwartz multistate model, 415
- Arnason-Schwarz model, 431–433
- Ascertainment bias (AB), 310–311
- Assessment-management scenarios, 523–524
- Atlantic Bluefin tuna (*Thunnus thynnus*), 545–546
- Atlantic cod (*Gadus morhua*), 238–250, 336, 418, 503, 544–545
 - harvesting, 247f
 - north Atlantic stocks of, 238–250
 - PC1 vs. PC2 plot of, 248f
- Atlantic herring (*Clupea harengus*), 153, 179–180, 341, 541f, 542
 - assessment and management approach, 542–543
 - autumn-spawned herring larvae, 153

- Atlantic herring (*Clupea harengus*) (Continued)
 bluefin tuna larvae trajectories, 346f
 geographic distribution, 542
 herring spawning aggregations, 154
 Irish Sea, 155
 juvenile herring otoliths images, 154f
 larval bluefin tuna, 344–345
 larval distributions, 342f
 larval herring production, 343–344
 management boundaries, 543f
 patterns in otolith microstructure, 154
 probabilistic transport model, 345–346
 racial characteristics, 153
 spawning groups, 152–153
 spawning season, 542
 stock-specific growth patterns in,
 155–156
 Atlantic Salmon, 120
 Autumn-spawned herring larvae, 153

B

- Barcode of Life Data Portal, 272
 Barcode of Life Data System (BOLD), 272
 Barnacles (*Balanus glandula*), 515
 Basic Local Alignment Search Tool
 (BLAST), 271–272
 Basin model, 511
 Bayesian approaches, 277, 435
 Bayesian inference, 462–463
 Beaked redfish (*Sebastes mentella*),
 546–547, 547f
 Behavior modes, 459–462
 Best-fitting model, 441–442
 Billfish (Istiophoridae), 388
 Binned data, 451–452
 Biocomplexity, 502–503
 Biological environment, 63
 Biomarker analysis, 447–448
 Black rockfish (*Sebastes melanops*),
 161–162
 BLAST, *see* Basic Local Alignment Search
 Tool
 Blue shark (*Prionace glauca*), 455–456
 Blue threadfin, *see* *Eleutheronema*
tetradactylum (*E. tetradactylum*)
 Blue-green damselfish (*Chromis viridis*),
 161–162
 Bluefin tuna, 545
 Body cavity tags, 368–369, 369f, *see also*
 Self-locking tags
 BOLD, *see* Barcode of Life Data System
 Bootstrapping analysis, 277
 Box-transfer, 514
 Box-truss network, 114, 114f
 Bull trout (*Salvelinus confluentus*), 419
 Business card tags, 400

C

- C-start burst performance, 121
 Calcified structures, 142
 application, 142
 growth mark formation, 143
 growth pattern detection automation,
 147–150
 growth signatures, 142
 intraspecific differences in growth
 histories, 150–152
 life history transitions, 142–143
 otoliths, 144–146
 Salmon
 farmed fish with wild populations,
 157–160
 larval origin reconstruction and
 dispersal pathways, 160–162
 scales, 146–147
 stock identification, 142
 viewing and analyzing images, 147
 wild stocks of adult fish, 152–157
 Candidate gene approach, 311–311
 genome-wide sequencing applications,
 312–312
 HSPs, 311–312
 MHC genes, 312–312
 oxygen-carrying blood proteins,
 311–311
 Capillary-based automated fragment
 analyzer, 305f–305f
 Capture history vector, 431
 Capture method, 404–405
Carassius carassius (*C. carassius*), 62–63
Cardiocephaloides physalis (*C. physalis*),
 193–195
Caretta caretta, *see* Hatchling loggerhead
 turtles
 Carlin dangler tags, 372, *see also* Glue-on
 shellfish tags
 Catch per unit effort (CPUE), 465–466
 Catcher awareness, 380
 Catching methods, 378
 cDNA, *see* Complementary DNA
 Celtic Sea herring, 16
 Census population sizes, 318–318
Centropomus undecimalis
 (*C. undecimalis*), 83
 Cestode plerocercoids, 191–192
 Chinook salmon (*Oncorhynchus*
tshawytscha), 400
 Cholesterol, 254
Chrysoblephus laticeps (*C. laticeps*), 387
 Chum salmon, 122
 CI, *see* Confidence interval
 Circularity, 134

Circuli, 143, 210–211
 Clawed lobster, 384–385
Clupea harengus (*C. harengus*), 43–44, 83–84
 Cluster analysis, 117–118
 Coastal spawning beds, 16
 Coded Wire Tags (CWT), 376
 Coho Salmon, 121
 COI, *see* Cytochrome c oxidase subunit I
 Complementary DNA (cDNA), 313
Concholepas concholepas (*C. concholepas*), 48–49, 49f
 Confidence interval (CI), 190, 481–482
 Connectivity, 20, 523f
 contingents, 21
 life-time migration behaviors, 21
 types, 20
 Contingent stock, 336
 Contingent structure, 419–420
 Continuous time and space models, 430,
 see also Discrete stock/discrete time
 models
 continuous reading, 440–441
 example, 441–442
 movement pattern, 443f
 skipjack tuna analysis regions, 442f
 theory, 438–440
 Control region (CR), 265
 Conventional tag-and-recapture studies,
 401
 Conventional tagging methods, 452
 Coral trout, 37–39
Coryphaena hippurus (*C. hippurus*),
 79–81, 80f, 94f
 CPUE, *see* Catch per unit effort
 CR, *see* Control region
 CWT, *see* Coded Wire Tags
Cyprinodon variegates (*C. variegates*),
 63–64
 Cytochrome c oxidase subunit I (COI), 263

D

D-loop, 261
 Data hungry, 415
 Data storage tags (DST), 64, 451
 Data treatment methods, 389
 Dealing with less-than-perfect
 information, 434–435
 Deep sea crab, 383
 Deepwater fishery species, 85–86
 Desaturation process, 250–251
 Developmental conversion, 62
 DFA, *see* Discriminant function analysis
Dichistius capensis (*D. capensis*), 388
 Digenean metacercariae, 191–192
 Digenetic trematodes, 187

Digital imaging, 112
 Discrete stock/discrete time models,
 429–431
 Arnason–Schwarz model, 431–433
 dealing with less-than-perfect
 information, 434–435
 example, 436–438
 extended Arnason–Schwarz model, 433
 harvest models, 433–434
 model fitting, 435–436
 yearly movement rates between halibut
 management, 439t
 Discriminant function analysis (DFA), 151,
 174–175
 Disentangling sources
 experimental approaches, 70–71
 genetic methods, 70
 phenotypic variation, 67
 quantifying differences, 71–72
 sample standardization, 67
 statistical methods, 67–70
 Dispersion (Di), 333
 DNA barcodes, 268, 269, 300–301
 Dolphinfinh, *see* *Coryphaena hippurus*
 (*C. hippurus*)
 Dorsal pterygiophores, 368f
 Double-anchor T-Bar tags, 383
 Double-tagging experiments, 389
 Drivers of plasticity, 63–64
 DST, *see* Data storage tags
 Duty cycling, 460–461
 Dynamic Brownian bridge methods, 464

E

Early life stages (ELS), 340–341, 348
 information, 331, 332f
 Atlantic bluefin tuna, 344–346
 Atlantic herring, 341–344
 Lobster ELS, 346–348
 planktonic dispersal effect, 334f
 role of, 331–335
 use in stock identification
 distribution, 335–337
 holistic approach, 340–341
 Lagrangian particle tracking,
 339–340
 otolith chemistry, 337–338
 phenotypic traits, 338–339
 Easy-to-use software, 435
 Economic Exclusive Zone (EEZ), 11–12
 Ecophenotypes, 78
 ED-EM, *see* Energy-dispersive electron
 microprobe
 EEZ, *see* Economic Exclusive Zone
 EFA, *see* Elliptical Fourier analysis
 Effective population size, 318–319

- Elasmobranch dorsal fin spines, 212–213
 Electronic tag detectors, 366
 Electronic tagging, 3, 449, 456–457
 Elemental fingerprint, 207f
Eleutheronema tetradactylum
 (*E. tetradactylum*), 87, 87f
 Elliptical Fourier analysis (EFA), 129–130
 ELS, *see* Early life stages
 Energy-dispersive electron microprobe
 (ED-EM), 219
 Enzymatic activity, 493
 ESTs, *see* Expressed sequenced tags
 Estuarine spawning, 541–542
 EU-REDFISH project, 136–137
 Eulerian approach, 514–515
 European Union for Bird Ringing
 (EURING), 430
 European Union project, 521
 Exploratory data analysis, 494–495
 Expressed sequenced tags (ESTs),
 313–314
 Extended Arnason–Schwarz model, 433
 External attachment methods, 404
 External tag types, 367–374
- F**
- Fastloc systems, 451
 Fatty acid composition, 251
 Fatty acid profiles, 235, 255
 case histories, 238–250
 cholesterol, 254
 desaturation process, 250–251
 fish scales, 238–250
 garden experiments, 252
 genetic markers, 254
 Imsa and Namsen PC plot of parr, 251f
 labor consuming procedure, 251–252
 methodology, 236
 chromatographic equipment, 237t
 gas chromatographic output,
 236–237, 255
 PCA, 237–238
 RSD_{max}, 238
 SIMCA analysis, 238–250
 SIRIUS program package, 237–238
 muscle tissue FA value, 253f
 relative distance of fish, 245t, 246t
 stock identification, 236, 254–255
 water temperature, 252f
- Fecundity, 94–95
 Feeding, 467–468
 Filleted shark, 375f
 Fin rays, 212–213
 Fine-scale spatial structure, 544
 Fingerprint, 337
 Fish hard part chemical composition, 206
 age-0 scaphirhynchus sturgeons,
 224–225
 assumptions, 215
 characteristic and reproducible
 markers, 215–216
 group mixture characterization, 216
 chemical analysis, 219–220
 chemical fingerprint, 206–207
 data analysis, 220–222
 elasmobranch vertebrae, 211–212
 fin rays, 212–213
 influencing factors, 213–215
 limitations of application, 216–217
 material collection, 217–219
 material preparation, 217–219
 natal homing of bluefin tuna, 223
 otoliths, 208–210, 214
 resolving natal tags, 223–224
 scales, 210–211
 spawning component contribution, 224
 spines, 212–213
 Trans-Atlantic movement, 223
- Fish movement, 516
 Fish parasitological methods, 191
 Fish scales, 238–250
 Fish species taxonomy, 244t
 Fish stock identification, 278–282, 490
 Fish tagging methods, 366
 Fisheries scientists, 401
 Fishery management, 503–504, 536
 complex spatial structure, 29–30
 empty habitat patches, 30–31
 metapopulation structure benefits, 30
 quota setting
 harvest control rules, 39–42
 MSE, 36–39
 spatially structured stock assessment
 models, 31–36
 spatial management strategies, 42
 marine protected areas, 46–48
 nested scales of governance, 48–51
 spatial distribution of catch, 43–46
 stock assessment, 329–330
 stock identification process, 31
 stock structure for, 522–524
 thermal barriers, 30
 units, 537
- Fishery-independent sources, 81
 Fishing effort distribution, 390
 Fishing mortality, 78–79, 516–517
 Florida Keys, 88–89, 88f
 Fourier analysis, 131
 Fourier harmonics, 135
 Freshwater fishes, 388
 Full life history metapopulation models,
 526

Full life history models, 515–516
Fulton's condition factor, 61

G

GBRMP, *see* Great Barrier Reef Marine Park
GBS techniques, *see* Genotyping-by-sequencing techniques
Gene flow, 66–67
Generalized linear models (GLMs), 176–177, 190
Genetic
 drift, 66
 markers, 254, 487
 methods, 70
 stocks, 544–545
 structure, 516–517
 techniques, 493–494
Genetic stock identification (GSI), 310
Genetic variability
 gene flow, 66–67
 genetic drift, 66
 selection, 66
 stock structure, 65
Genomics, 303
Genotypic stock, 330
Genotyping-by-sequencing techniques (GBS techniques), 310
Geographic apportionment, 512
Geographic map, 274–275
Geolocation, 452–453
Geometric methods, 115–116
Gill Raker Counts, 174t, 175f
GLMs, *see* Generalized linear models
Global positioning system (GPS), 451
Glue-on shellfish tags, 372, 372f
GPS, *see* Global positioning system
Great Barrier Reef Marine Park (GBRMP), 38f–39f
Growth mark formation, 143
Growth pattern detection automation, 147–150
Growth signatures, 142
GSI, *see* Genetic stock identification

H

Habitat based models, 465–466
Handling mortality, 389–390
Hard boundary constraints, 459
Harvest control rules, 39–42
Harvest models, 433–434
Hatchling loggerhead turtles (*Caretta caretta*), 449–450
Heat-shock proteins (HSP), 311–312
Herring (*Clupea harengus*), 486–487

Heteroplasmy, 262, 267
Hidden Markov Model filters (HMM), 465
High resolution photographic image, 173
High-resolution passive monitoring systems, 406
Hill-Robertson effects, 264
Hitch-hiking selection, 306
HMM, *see* Hidden Markov Model filters
Hogfish, 89
Holistic approach tests complex networks, 479–480
Homarus gammarus (*H. gammarus*), 384–385
Homing, 417–419
Homology, 131
Homoplasmy, 262
Homoscedasticity, 174
HOMSIR project, 491–493, 492f
Horse mackerel (*Trachurus trachurus*), 135f, 486–487
HSP, *see* Heat-shock proteins
Hypothesis testing, 508–509

I

IA, *see* Individual assignment
IAT, *see* Implanted archival tags
IbD, *see* Isolation by Distance
IBMs, *see* Individual-based models
ICCAT, *see* International Commission for the Conservation of Atlantic Tunas
ICES, *see* International Council for the Exploration of the Sea
ICPMS, *see* Inductively coupled plasma mass spectrometry
Illegal, unreported, and unregulated (IUU fisheries), 317
Image analysis software, 147
Image processing, 130
Imaging software, 112
Implanted archival tags (IAT), 451, 455–456
Imprinting, 16–17
Individual assignment (IA), 317
Individual-based models (IBMs), 513
Inductively coupled plasma mass spectrometry (ICPMS), 219
Interdisciplinary analysis
 approaches to same specimen, 490
 exploratory data analysis, 494–495
 holistic approach to stock identification, 479
 interpreting results, 482–483
 logistics, operation and organization, 491–494
 matched sampling, 484–485
 mixed-stock analysis, 478–479

Interdisciplinary analysis (*Continued*)

null hypothesis significance testing,
479–481

observational studies, 483

point estimation and confidence
intervals, 481–482

power analysis, 483–484

realized sampling site positions for,
486f

sample size, 489–490

sampling

in space, 485–487

in spawning area and time,
488–489

in time, 487–488

Interdisciplinary stock identification

process, *see also* Stock
identification

biological stock structure, 539

case studies, 539–540

Atlantic Bluefin tuna, 545–546

Atlantic cod in New England,
544–545

Atlantic herring off New England,
542–543

beaked redfish in, 546–547

striped sea bream in, 548

winter flounder, 540–542

yellowtail flounder off New England,
543–544

consensus interpretation, 538

fishery management units, 537

multidisciplinary review, 538–539

priori hypotheses, 538

recommendations, 539

sources of information, 538

spatial management units, 537

Internal implantation, 404

Internal tag types, 375–376, *see also*

External tag types

International Commission for the

Conservation of Atlantic Tunas
(ICCAT), 11–12, 539–540

International Council for the Exploration

of the Sea (ICES), 2, 516–517,
539–540

International Standardization Organization

(ISO), 382–383

Intramuscular game fish tags, 372–374,
373f

Irish Sea, 155

ISO, *see* International Standardization
Organization

Isolation by Distance (IbD), 318

IUU, *see* Illegal, unreported, and
unregulated fisheries

J

Jackass morwong (*Nemadactylus
macropterus*), 160–161

Juvenile Atlantic menhaden (*Brevoortia
tyrannus*), 161

Juvenile coho salmon, 121

Juvenile Salmon Acoustic Telemetry
System (JSATS), 399

K

Kalman filter, 456–459

Kernel density method, 463–464

Kruskal–Wallis test, 174, 189

L

LA-ICPMS, *see* Laser ablation inductively
coupled plasma mass spectrometry

Lagrangian approach, 512–513

Lake Baikal fish populations, 238–250

Large marine ecosystem (LME), 463

Large population size issue, 301–302

Large subunit (LSU), 265

Larval dispersal, 513

Larval nematodes, 191–192

Laser ablation inductively coupled plasma
mass spectrometry (LA-ICPMS),
219

Leptocephalus, 61

Leucoraja erinacea (*L. erinacea*), 81

Leucoraja ocellata (*L. ocellata*), 81

Life history traits, 77–78

distribution and abundance
data and designing new studies,
79–82

life cycle, 82–83

metapopulations and contingents,
83–84

ecophenotypes, 78

fishing mortality, 78–79

life history modeling, 468

natural selection, 78

reproduction and recruitment, 91–95

size and age, 85–91

stock identification, 79

testing stock structure hypotheses, 79
variation in, 78

Light based geolocation, 452–454

Limanda ferruginea (*L. ferruginea*), 35, 35f

Linear morphometric distances, 114

LME, *see* Large marine ecosystem

Location accuracy, 460–461

Locking flaps, 370–371

Log likelihood approach, 457

Logistic model, 92–93

Logistic regression, 174–175

Longer-term research recommendations, 545
 Longitude, 453–454
 Longitude matching accuracy, 456
 LSU, *see* Large subunit
 Lumpfish specimens, 117f

M

Magnetic body cavity tags, 366
 Major histocompatibility complex (MHC), 312
 Management strategy evaluation (MSE), 37, 522–523
 Coral trout, 37–39
 GBRMP map, 38f–39f
 management procedures, 37
 simulation models, 37
 stock assessment models, 36–37
 Management units, 536
 Mann–Whitney tests, 189
 MANOVA, *see* Multivariate analysis of variance
 Marine finfish, 387
 Marine protected areas (MPA), 46–47
 attributes, 47–48
 effects, 47
 Icelandic cod fishery, 48f
 spawner density, 46–47
 Markov Chain Monte Carlo sampling (MCMC sampling), 462–463
 Matched sampling, 484–485
 Maximum likelihood, 277
 Maximum sustainable yield (MSY), 507
 Maximum-likelihood estimates, 435
 MCEA, *see* Multi-criteria evaluation analysis
 MCMC sampling, *see* Markov Chain Monte Carlo sampling
 Meristics, 171
 case studies in stock identification
 Atlantic herring, 179–180
 Striped bass, 180–181
 winter flounder, 177–179
 sampling techniques, 172–173
 statistical analysis, 174–177
 stock discrimination, 171–172
 stock structure, 172
 variables, 174
Merluccius merluccius (*M. merluccius*), 40, 42f
 Messenger RNA (mRNA), 313
 Metacercaria, 193–195
 Metapopulation, 477–478
 Methanolysis, 236
 MHC, *see* Major histocompatibility complex
 Microsatellites, 304–307
 Migratory contingent, 520
 Migratory species, telemetry analysis of
 algorithmic approach, 455–456
 archival tags, 451–452
 Bayesian inference, 462–463
 behavior modes, 459–462
 biological parameters, 447–448
 comparison, 461f
 data from conventional tags, 448
 depth, 465–466
 electronic tagging methods, 449
 error estimates for, 455f
 geolocation, 452–453
 HMM, 465
 beyond light, 454–455
 light based geolocation, 453–454
 SLRTs, 449–451
 statistical approach, 456–459
 stock boundaries, 463–464
 synthesis, 466–468
 tagging study road map, 449, 450f
 telemetry methods, 448–449
 Mitochondrial DNA (mtDNA), 261
 advantages and limitations, 260–261
 data processing
 mtDNA sequence data tools, 271–272
 phylogeographic analysis of mitotypes, 274–277
 evolution, 263–264
 extraction, 270
 fish stock identification, 278–282
 genetic approaches, 258–259
 genetic data, 259
 marine ecosystems, 258
 meta populations, 259
 molecular techniques, 259–262
 PCR, 269
 restriction analysis, 269–270
 sequencing, 270–271
 in species and stock identification, 265–269
 stock structure information, 258–259
 transmission genetics, 262–263
 MitoFish, 272
 Mitotype phylogeographic analysis, 274–277
 MitoZoa database, 272
 Mixed stock analysis (MSA), 478–479
 Mixed stocks, 13
 Model validation, 507–508
 Model verification, 507
 Modeling complex population structure, 506–507

- Modern practice, 435
 - Molecular marker classes, 306f
 - Mollusk valves, 129–130
 - Monogenetic trematodes, 187
 - Morone Americana* (*M. Americana*), 84
 - Morphometric analysis, 281–282
 - Morphometric landmarks, 109
 - methodological protocols
 - choice of characters, 112–116
 - sampling, 111–112
 - statistical analysis, 116–118
 - morphometric differences interpretation, 118
 - Salmon case studies, 118–123
 - phenotypic stock definition, 110–111
 - stock identification studies, 109–110, 110f
 - Morphometric outlines, 129
 - case studies in stock identification, 135–137
 - image processing, 130
 - interpretation, 135
 - mollusk valves, 129–130
 - multivariate analysis, 134–135
 - shape variation, 129
 - statistical model fitting, 130–133
 - Movement estimation from tagging data
 - continuous time and space models, 430, 438–442
 - discrete stock/discrete time models, 429–438
 - Movement rates, 432, 434
 - Movement studies, 370
 - MPA, *see* Marine protected areas
 - mRNA, *see* Messenger RNA
 - MSA, *see* Mixed stock analysis
 - MSE, *see* Management strategy evaluation
 - MSY, *see* Maximum sustainable yield
 - mtDNA, *see* Mitochondrial DNA
 - mtDNA sequence data tools, 271
 - BOLD, 272
 - chromatograms and interpretation, 273f
 - extraction, 271–272
 - MitoZoa database, 272
 - Mullica RivereGreat Bay estuary, 419
 - Multi-criteria evaluation analysis (MCEA), 539
 - Multistate models, 415
 - Multivariate analysis, 115, 134–135
 - Multivariate analysis of variance (MANOVA), 151, 196, 221–222
 - Multivariate maximum-likelihood model, 190
 - Myxosporeans, 191–192
- N**
- NAFO, *see* Northwest Atlantic Fisheries Organization
 - Natal homing mechanisms
 - adopted migration theory, 17
 - closed populations in marine fishes, 17f
 - imprinting, 16–17
 - NCPA, *see* Nested clade phylogeographic analysis
 - NEAFMC, *see* North East Atlantic Fisheries Commission
 - Neighbor-joining, 276
 - Nested clade phylogeographic analysis (NCPA), 276
 - Nested scales of governance
 - C. concholepas*, 48–49
 - MPAs, 48
 - river herring, 50–51, 50t
 - TURF and non-TURF areas, 49–50
 - Next generation screening panels, 316–317
 - Next-generation sequencing (NGS), 269, 304
 - NGS, *see* Next-generation sequencing
 - Nonparametric methods, 463–464
 - Nonparametric tests, 174
 - North East Atlantic Fisheries Commission (NEAFMC), 11–12
 - Northeast U. S. Stock Assessment Workshop, 539–540
 - Northwest Atlantic Fisheries Organization (NAFO), 11–12
 - Nuclear DNA (nucDNA), 265
 - Nuclear genome, 298–299
 - effective population size, 318–319
 - gene structure, 299f
 - genetic patterns and processes, 300
 - DNA barcodes, 300–301
 - large population size issue, 301–302
 - neutral evolutionary forces, 302
 - nuclear markers applicability task, 315t
 - mixed stock analysis, 317
 - neutral vs. adaptive variation, 302–303
 - nuclear “tool kit” for stock identification
 - candidate gene approach, 311–312
 - microsatellites, 304–307
 - proteomics, 312–314
 - restriction-assisted methods, 307–309
 - single nucleotide polymorphisms, 309–311
 - transcriptomics, 312–314
 - seascape genetics, 318

- GIS approach, 318
 - marine spatial planning, 318
- stock identification, 299–300
- stock structure, 315–317
- Null hypothesis significance testing, 479–481

O

- Observational studies, 483
- Ontogenetic rates, 112–113
- Ontogeny, 61
- Operating model development, 506–507, 509
- Operational validation, 507–508
- Otoliths, 143, 208–210, 214
 - annual growth marks in, 149f
 - choice of, 144
 - clarity of growth marks, 146
 - edge contours, 148
 - elemental signatures, 161–162
 - growth, 338–339
 - microstructure patterns, 150
 - mounting, 144–145
 - sectioning and polishing, 145–146
 - shape, 136
- Overlap model, 514–515

P

- Pacific ocean perch (*Sebastes alutus*), 512
- Pacific Ocean Shelf Tracking (POST), 400
- Pan1*, 311
- Panulirus argus* (*P. argus*), 45f
- Parameter fitting, 23
- Parametric tests, 189–190
- Parasite assemblage approach, 190
- Parasites tags, 185
 - biological tagging, 186
 - case studies, 193–196
 - in fish population studies, 185–186
 - hosts and parasites collection, 191–193
 - interpretation of results, 193
 - methodology, 188–191
 - selection, 187–188
 - stock identification, 186
- Parsimony analysis, 276–277
- Partial least square (PLS), 237–238
 - plots of heart tissue, 249f
 - plots of salmon, 239f
- Partial warp analysis, 112
- Passive integrated transponder tags (PIT tags), 373f, 374–376
 - detection, 382–383
- Passive monitoring systems, 400
- Passive telemetry, 405–407
- Passive tracking, *see* Passive telemetry
- Patuxent River estuary, 519f
- PCA, *see* Principal component analysis;
 - Principal components analysis
- PCR, *see* Polymerase chain reaction
- PCs, *see* Principal components
- PD, *see* Planktonic dispersal
- PDur, *see* Planktonic duration
- Peterson Disc tag, 366
- Phenotypic character, 253
- Phenotypic modulation, 62
- Phenotypic stock, 330
- Phenotypically plastic variability, 62
 - drivers of plasticity, 63–64
 - in environments, 62
 - interpretation of population structure, 62
 - reaction norms, 64–65
 - types, 62–63
- Pink salmon, 91–92, 122
- PIT tags, *see* Passive integrated transponder tags
- PIXE, *see* Proton-induced X-ray emission
- Planktonic dispersal (PD), 333
- Planktonic duration (PDur), 333
- Planktonic larvae stage, 350
- Planktonic survival (PS), 333
- Planktonic transport (PT), 333
- Plastic anchor tags, 367–368
- Plastic head in-water tags, 372–374
- Plastic tipped dart tag, 367, 367f
- PLS, *see* Partial least square
- PMRN, *see* Probabilistic maturation
 - reaction norms
- Point estimation, 481–482
- Poisson distribution, 439–440
- Polishing, 145–146
- Polyethylene streamer tags, 370–371, 371f
- Polygon methods, 463–464
- Polymerase chain reaction (PCR), 267, 269
- Polynomials, 131
- Pomoxis nigromaculatus* (*P. nigromaculatus*), 380
- Pooled-group PCA, 117–118
- Pop-up satellite tags (PSATs), 451
- Population
 - parameters, 489, 523–524
 - restoration morphology, 122–123
 - structure types, 510–511
- Population dynamics, 468
 - movement, 512–513
 - from Eulerian perspective, 514–515
 - full life history models, 515–516
 - from Lagrangian perspective, 513–514
 - larval dispersal, 513
 - straying and entrainment, 515
- operating models development, 509
- population structure types, 510–511

- Population dynamics (*Continued*)
 spatial heterogeneity, 511–512
 spatially structured populations, 510f
 spawning isolation, 512
 POST, *see* Pacific Ocean Shelf Tracking
 Postsmolt scale growth patterns, 157
 Power analysis, 483–484
 Prawns, 386
 Prerequisites, 485
 Presence/absence, 411–413
 Principal component analysis (PCA), 111, 116, 134, 174–175, 237–238
 Principal components (PCs), 237–238
 of fish samples, 241f
 heart tissue samples of, 242f
 muscle tissue samples of, 242f
 overlapping, 250
 of parr, 250f
 Probabilistic maturation reaction norms (PMRN), 93
 Probabilistic transport model, 345–346
 Probability density function, 333–334
 Probe-based assay techniques, 219–220
 Productivity and susceptibility analysis (PSA), 39–40
 Protein coding genes, 264, 268
 Proton-induced X-ray emission (PIXE), 219
 Proven correct validation, 508
 PS, *see* Planktonic survival
 PSA, *see* Productivity and susceptibility analysis
 PSATs, *see* Pop-up satellite tags
 Pseudogenes, 267
 PT, *see* Planktonic transport

Q

- Q Factor, 382
 Quantitative traits
 continuous variability, 60
 disentangling sources of phenotypic variation, 67–72
 phenotypic traits, 60
 population structure, 60
 variation in, 59, 61
 genetic variability, 65–67
 phenotypically plastic variability, 62–65
 variability due to demography, 61
 Quota setting
 harvest control rules, 39–42
 MSE, 36–39
 spatially structured stock assessment models, 31–36

R

- Radio Frequency Identification tags (RFID tags), 375–376
 external tag types, 367–374
 fish movement pattern, 383–388
 internal tag types, 375–376
 tagging data analysis, 389–391
 tagging methods, 378–383
 Radio telemetry, 398–399
 advantages and disadvantages, 401
 animals tagging, 402f
 bull trout, 419
 Random forests technique, 190
 Random variability, 523–524
 Range testing, 408–409
 RE, *see* Restriction enzymes
 Reaction norm approach, 89, 90f
 Reaction norms, 64–65
 Recapture rate, 432
 Receiver arrays, 400
 Recovery rate, 434
 Rectangularity, 134
 Red Steenbras (*Dentex rupestris*), 367–368
 Redfish (*Sebastes mentella*), 133f
 Reduced genomic representation (RGR), 308–309
 REs, *see* Restriction endonucleases
 Residence index, 413–414
 Residence time, 413–414
 Residual standard deviation max (RSD_{max}), 238
 Response diversity, 502–503
 Response variables, 507
 Restriction analysis, 270
 Restriction endonucleases (REs), 269
 Restriction enzymes (RE), 307
 Restriction fragment length polymorphism analysis, 270
 Restriction-assisted methods, 307
 adaptor ligation, 307
 AFLP, 307
 fragmentation process, 307
 genomic DNA, 307
 PCR amplification, 307–308
 whole-genome analyses, 308–309
 RFID tags, *see* Radio Frequency Identification tags
 RGR, *see* Reduced genomic representation
 Rotational harvest strategies, 44
 RSD_{max}, *see* Residual standard deviation max
 Russell's catch equation, 9

S

- Sablefish (*Anoplopoma fimbria*), 515
- Sagitta, 144
- Sailfish (*Istiophorus platypterus*), 459
- Salmon
- farmed fish with wild populations, 157–160
 - larval origin reconstruction and dispersal pathways, 160–162
- Salmon case studies, 118–120
- adaptive hypotheses, 122
 - body morphology of Atlantic, 120
 - breeding experiments, 120
 - burst performance, 121
 - C-start burst performance, 121
 - Chum salmon, 122
 - Coho Salmon, 121
 - fineness ratio, 120
 - functional hypotheses, 123
 - morphometric patterns, 120
 - morphometric stock identification, 123
 - morphometrics, 120
 - pink salmon, 122
 - population restoration morphology, 122–123
 - swimming behavior, 118–120
 - swimming kinematics, 121–122
- Salmon parr, 238–250
- Salmon shark (*Lamna ditropis*), 455–456
- Salvelinus leucomaenis* (*S. leucomaenis*), 65
- Sampling, 111–112
- Sanger sequencing method, 270–271
- Satellite linked radio transmitter (SLRTs), 449–451
- SBT, *see* Southern bluefin tuna
- Scale growth patterns, 157
- Scale pattern analysis, 156
- Scales, 210–211
- Scanning electron microscope, 147
- SCCZ, *see* Spring Cod Conservation Zone
- School mackerel (*Scomberomorus queenslandicus*), 381
- Scientific endeavors, 536
- Sea surface temperature (SST), 455–456
- SEAPODYM, *see* Spatial ecosystem and population dynamics model
- Seascape genetics, 318
- Sebastes mentella* (*S. mentella*), 82, 546
- biological stocks, 547f
 - EU Redfish Project, 546
 - ICES, 546–547
- Self-locking tags, 370, 370f
- Sensitivity analyses, 508
- Shallow water crabs, 384
- Sharks, 386–387
- Shelled mollusks, 384
- Shifted stocks, 13–14, 14f
- Short tandem repeats (STR), 304
- SIMCA, *see* Soft Independent Modeling of Class Analogy
- Simple sequence repeats (SSR), 304
- Simulation modeling, 23, 37, 502–504
- assessment, stock structure implications for, 520–522
 - conceptual model, 506
 - considerations in, 505f
 - ecological consequences, 517–520
 - fisheries management, stock structure implications for, 522–524
 - hypothesis testing, 508–509
 - model validation, 507–508
 - model verification, 507
 - operating model development, 506–507
 - opportunities and limitations, 524–526
 - response variables, simulation and measuring, 507
 - stock structure, 516–517
 - tailor-made model, 504
 - 10 cod demes, 517f
- Single nucleotide polymorphisms (SNPs), 309–310
- advantage, 310
 - challenges, 310–311
 - chromosomal stretch, 309f
 - GBS techniques, 310
- Site fidelity, 417–419
- Skipjack tuna (*Katsuwonus pelamis*), 33, 386, 468
- SLRTs, *see* Satellite linked radio transmitter
- Small subunit (SSU), 265
- Small yellow croaker (*Larimichthys polyactis*), 523–524
- Small-scale PIT tag studies, 383
- SNPs, *see* Single nucleotide polymorphisms
- Soft Independent Modeling of Class Analogy (SIMCA), 238–250
- Southern bluefin tuna (SBT), 466
- Spatial distribution of catch
- basin dynamics, 44
 - Belizean spiny lobster, 46
 - C. harengus*, 43–44, 43f
 - Chile's red sea urchin, 46
 - demographic differences, 44–45
 - eroding spatial structure, 43
 - rotational harvest strategies, 44
- Spatial ecosystem and population dynamics model (SEAPODYM), 468, 515

- Spatial heterogeneity, 511–512
- Spatial indicators, 40
- Spatial management strategies, 42
 - marine protected areas, 46–48
 - nested scales of governance, 48–51
 - spatial distribution of catch, 43–46
- Spatially explicit models, 507
- Spatially structured stock assessment
 - models
 - application, 33
 - connectivity patterns, 36
 - cryptic biomass implications, 33
 - demographic units and exchange rates, 31–33
 - rebuilding trajectories, 35
 - stock area, 36
 - in 2008 assessment, 32f–33f
 - in 2010 assessment, 32f–33f
- Spatiotemporal variation, 488
- Spawning (Sp), 333–335
 - groups, 152
 - isolation, 512
 - migration, 516
 - periodicity, 91–92
 - sampling
 - in spawning area, 488–489
 - in spawning time, 488–489
 - seasonality, 91
- Spheniscus demersus* (*S. demersus*), 193–195
- Spines, 212–213
- Spiny lobster, 385
- Spotted mackerel (*Scomberomorus munroi*), 381
- Spring Cod Conservation Zone (SCCZ), 409f
 - male and female Atlantic cod resident proportion, 414f
 - residence times of spawning Atlantic cod, 413f
- Squid and octopus, 384
- SSR, *see* Simple sequence repeats
- SST, *see* Sea surface temperature
- SSU, *see* Small subunit
- State space models, 456–459
- State-space formulation models, 441
- State-space models, 440–441, 457–458
- Stationary reference tags, 408–409
- Statistical methods, 67–70, 116–118
- Statistical model fitting, 130–133
- Statistical power, 483–484
- Stock assessments, 398, 447–448
- Stock assignment application, 338–339
- Stock discrimination, 477–478
- Stock identification, 1, 79, 236, 477–478, 516, 536
 - applications, 3
 - case studies on, 2
 - cursorry treatment to, 1–2
 - ecosystem framework, 350–352
 - larval distributions formation, 352f
 - larval flatfish distribution, 354f
 - weakfish life history, 351f
 - ELS information, 331, 332f
 - Atlantic bluefin tuna, 344–346
 - Atlantic herring, 341–344
 - Lobster ELS, 346–348
 - planktonic dispersal effect, 334f
 - role of, 331–335
 - ELS use
 - distribution, 335–337
 - holistic approach, 340–341
 - Lagrangian particle tracking, 339–340
 - otolith chemistry, 337–338
 - phenotypic traits, 338–339
 - in fishery science, 1
 - fishery stocks, 330
 - geostatistics use, 348–349
 - ICES Study Group, 2
 - identification process, 315–316
 - life cycle models, 349–350
 - management units, 3
 - stock, 329–330
 - stock structure, 2–3, 349–350, 353
 - techniques, 340
- Stock identity research, 477–478
- Stock mixing, 420
- Stock structure, 22, 315–317
 - cod demes, 517f
 - connectivity, 523f
 - ecological consequences, 517–520
 - fish movement, 516
 - for fisheries management, 522–524
 - fishing mortality, 516–517
 - implications for assessment, 520–522
 - inferences, 366–367
 - model domain, 522f
 - movement scenarios investigation, 518f
 - Patuxent River estuary, 519f
 - simulation models, 516, 525f
 - spawning biomass simulations, 517
 - stock identification methods, 516
 - white perch simulation model, 520f
- STR, *see* Short tandem repeats
- Straying, 18, 515
- Striped bass (*Morone saxatilis*), 180–181
- Striped sea bream (*Lithognathus mormyrus*), 548, 548f
- Sun altitude, 452–453
- Sunfish (*Mola mola*), 449–450

Super-population
 fraction, 433
 size, 433
 Superglue, 372

T

T-Bar anchor tag, 368, 369f
 Tag
 durability, 379
 loss, 436
 recovery program, 376–377
 retention, 379
 selection, 403
 shedding rate, 389
 Tag-recovery models, 448
 Tagging method, 403–405
 catching methods, 378
 data analysis, 389–391
 holding techniques, 378
 procedure and impacts, 379–380
 reporting rates, 380–382
 sterilization of tags, 378
 use of anesthetics, 378
 Tagging mortality rates, 379
 Tailor-made model, 504
 Telemetry data, 463
 Telemetry methods, 448–449
 Template approach, 453
 Temporal stability, 487
 Territorial user rights fishing (TURFs),
 48–49
 Threshold based approach, 453
Thunnus thynnus (*T. thynnus*), 81
Thymallus thymallus (*T. thymallus*), 65
 Time series data, 451–452
Trachurus trachurus (*T. trachurus*), 81–82
 Track reconstruction, 454–455
 Tracking method
 active telemetry, 405
 passive telemetry, 405–407
 transfer RNAs (tRNAs), 261
 Transmission genetics, 262–263
 Trawl-caught specimens, 172
 Triangulation, 415–417
 tRNAs, *see* transfer RNAs
 Tropical fish in Lakes Victoria, 238–250
 TURFs, *see* Territorial user rights fishing
 Two-stock hypothesis, 81

U

UDs, *see* Utilization distributions
 Ultrasonic pulses, 400
 Ultrasonic tags, 399
 Unit stock, 7–8
 coastal spawning beds, 16
 collapse of canyon walls, 7–8

complex life cycles, 14–15
 connectivity, 20
 discrete groups of fish, 9
 fishing across boundaries
 hereditary rights, 11–12
 management unit, 12–13, 12f
 policy frameworks, 11
 mixed stocks, 13
 modern fisheries science, 8–9
 natal homing mechanisms
 adopted migration theory, 17
 closed populations in marine fishes,
 17f
 imprinting, 16–17
 open life cycles, 15
 open populations
 imprinting and straying, 18
 marine planktivorous fishes, 19
 school-trap, 19–20
 segments, 19
 operational definitions
 conservation biology, 10–11
 ecological organization levels, 10f
 internal dynamics, 9–10
 reef fishes, 18
 shifted stocks, 13–14, 14f
 spawning runs, 15–16
 track fish stocks, 21–23
 Universal primer, 262
 Utilization distributions (UDs), 416–417

V

Valid ageing methods, 85
 Variability
 confounding effects of demography,
 61
 interpretation, 69f
 leptocephalus, 61
 population-level averages, 61
 VBGF, *see* Von Bertalanffy growth
 function
 Vemco's Radio Acoustic Positioning
 system (VRAP system), 400,
 415–418
 Vertebrae, 211–212
 Vessel monitoring systems (VMS),
 525–526
 Visible Implant Alpha tags, 373f, 374
 Visible Implant Elastomer™ tags, 374, 374f
 VMS, *see* Vessel monitoring systems
 Volunteer angler tagging programs, 381
 Von Bertalanffy growth function (VBGF),
 86–87, 149–150
 VPS, *see* VR2W Positioning System
 VR2W Positioning System (VPS), 400
 array, 408–409, 416

VR2W Positioning System (VPS) (*Continued*)
 Vemco, 409f
 VRAP system, *see* Vemco's Radio
 Acoustic Positioning system

W

Wavelength-dispersive electron
 microprobe (WD-EM), 219
 WD-EM, *see* Wavelength-dispersive;
 Wavelength-dispersive electron
 microprobe
 White perch (*Morone americana*), 519
 White perch simulation model, 520f
 White sharks (*Carcharodon carcharias*),
 449–450
 Winter flounder (*Pseudopleuronectes*
americanus), 177–179, 420,
 540–541

Atlantic Canada and northwest Atlantic
 continental shelf, 541f
 Estuarine spawning, 541–542
 northeast United States and continental
 shelf, 540f
 regional genetic stock structure, 542
 Within-group PCA, 116–117, 174–175

Y

Yellowtail flounder (*Limanda ferruginea*),
 511, 543–544
 geographic variation of female, 119f
 morphometric landmarks, 113f
 sexual dimorphism, 115f

Z

Zone-based system, 340