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

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

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## CHAPTER OUTLINE





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## 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 a 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. Secondarily, 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

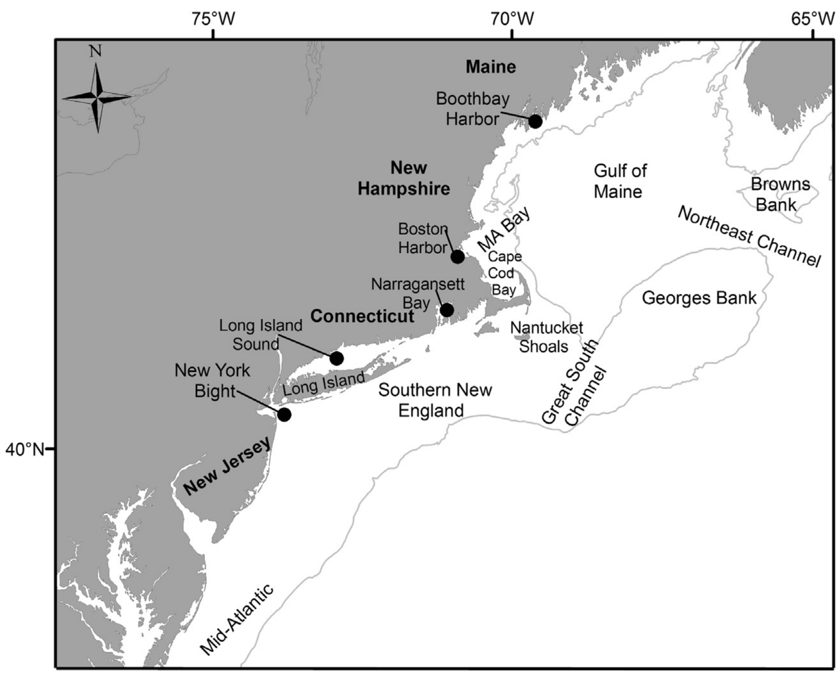


**FIGURE 22.1** The northeast United States and continental shelf. Modified from DeCelles and Cadrin (2010).

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

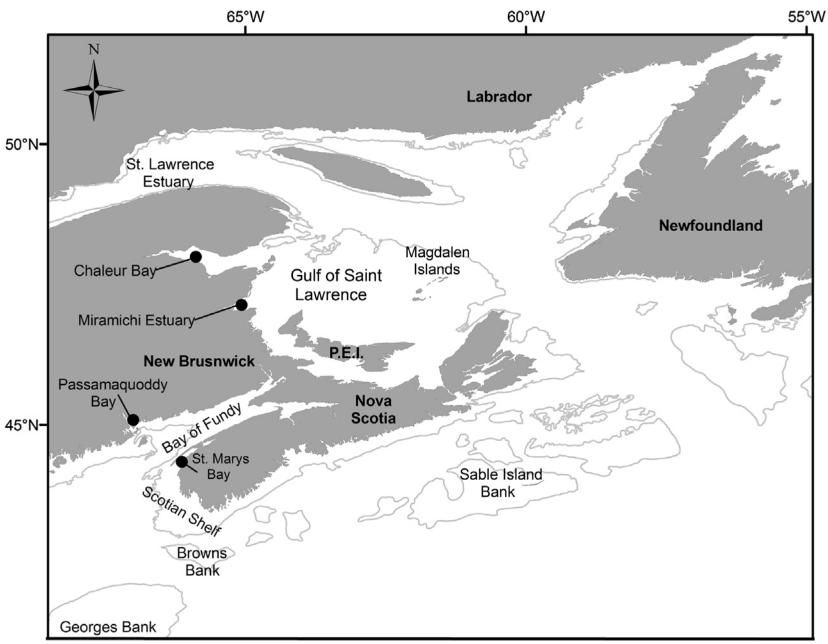


**FIGURE 22.2** Atlantic Canada and the northwest Atlantic continental shelf. Modified from DeCelles and Cadrin (2010).

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;

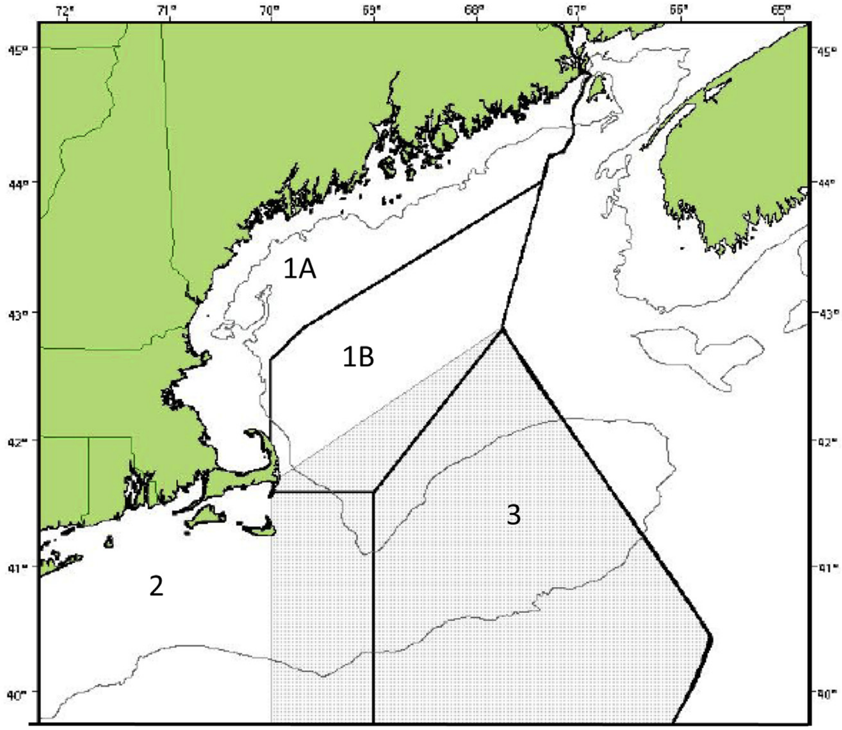


**FIGURE 22.3** Management boundaries for Atlantic herring in the Gulf of Maine and on Georges Bank. Lines indicate original boundaries, shaded area indicates 2006 revision to area 3 boundaries. (For color version of this figure, the reader is referred to the online version of this book.) Adapted from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

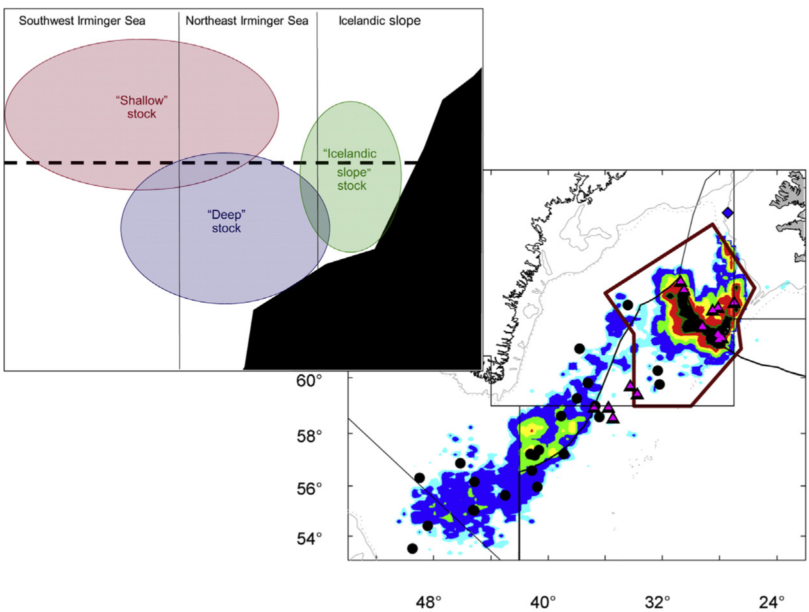


**FIGURE 22.4** Vertical schematic of *Sebastes mentella* biological stocks (upper left) and spatial management unit boundary of the deep pelagic stock (map polygon), with distribution of the pelagic fisheries (isopleths) and genetic sample locations (circles and triangles). (For color version of this 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.

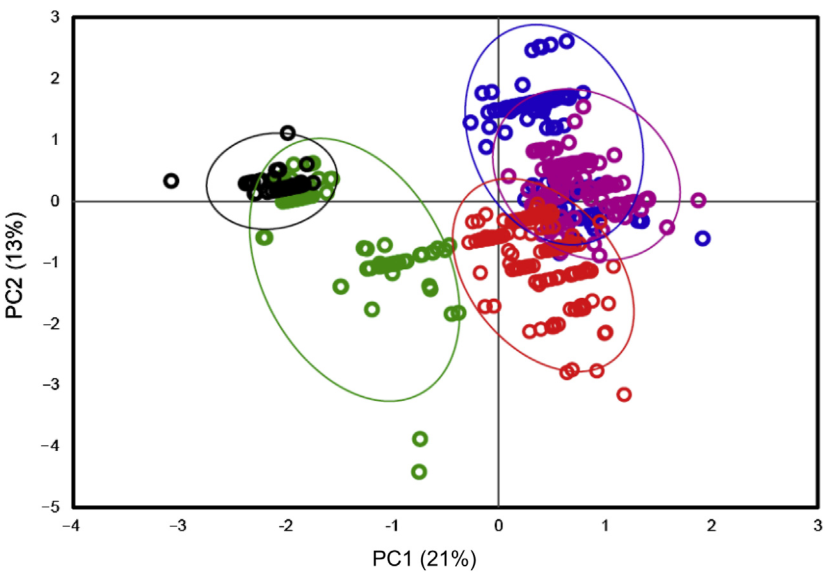


**FIGURE 22.5** Individual striped sea bream data points plotted in the space identified by the first two principal components, based on 20 different variables (i.e., 14 parasites, microsatellite assignment, mtDNA lineage, weight—length condition factor, and coefficients for growth, maturation, and sex 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

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