APPROACHES TO DEVELOPING MANAGEMENT PROCEDURES WHICH INCORPORATE MIXING

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SUMMARY

Atlantic bluefin tuna (BFT) have been known to move extensively with individual fish moving between and within the western Atlantic Ocean, the eastern Atlantic and the Mediterranean Sea. Traditionally the fisheries, and thus the management of BFT, have focused on western Atlantic versus eastern Atlantic plus Mediterranean (partly due to there being only two known areas of spawning: one in the Mediterranean and one in the Gulf of Mexico). Recent electronic tagging results indicate that BFT movements are complex. Also, there has been a spatial evolution of the fisheries which do not lend themselves well to current management schemes, yet there remains significant data quality issues in some areas. The Commission has called for the SCRS to "develop operational options for implementing alternative approaches for managing mixed populations of Atlantic bluefin tuna." This paper explores approaches for developing formal evaluations of BFT management procedures that recognize the biological and spatial variability and the limitations in data through development of operational models.

RÉSUMÉ

Le thon rouge de l'Atlantique parcourt de vastes zones, les poissons se déplaçant entre l'Atlantique ouest, l'Atlantique est et la Méditerranée et à l'intérieur de ces eaux. Traditionnellement, les pêcheries, et par conséquent la gestion du thon rouge, se sont concentrées sur l'Atlantique ouest par opposition à l'Atlantique est plus la Méditerranée (ce qui s'explique en partie par le fait qu'il n'existe que deux zones de frai connues: une dans la Méditerranée et une dans le Golfe du Mexique). Les récents résultats du marquage électronique indiquent que les déplacements du thon rouge sont complexes. Les pêcheries ont également connu une évolution spatiale, ce qui rend plus difficile l'application des schémas de gestion actuels. Il demeure, en outre, d'importantes questions de qualité des données dans certaines zones. La Commission a prié le SCRS d'élaborer des options opérationnelles visant à mettre en œuvre des approches alternatives destinées à gérer les populations mixtes de thon rouge de l'Atlantique. Le présent document explore les approches visant à élaborer des évaluations formelles des procédures de gestion du thon rouge qui reconnaissent la variabilité biologique et spatiale et les limites des données en mettant au point des modèles opérationnels.

RESUMEN

Se sabe que el atún rojo del Atlántico (BFT) se mueve ampliamente, con peces individuales moviéndose entre y dentro del Océano Atlántico occidental, el Atlántico oriental y el Mediterráneo. Tradicionalmente las pesquerías, y por lo tanto la ordenación del BFT, se han centrado en el Atlántico occidental frente al Atlántico oriental más el Mediterráneo (en parte debido a que sólo se conocen dos zonas de desove: una en el Mediterráneo y otra en el Golfo de México). Recientes resultados de marcado electrónico indican que los movimientos del BFT son complejos. Además, ha habido una evolución espacial de las pesquerías que hace que no se ajusten bien a los actuales esquemas de ordenación, y continúa habiendo temas significativos respecto a la calidad de los datos en algunas zonas. La Comisión ha solicitado al SCRS que "desarrolle opciones operativas para implementar enfoques alternativos de gestión de las poblaciones mezcladas de atún rojo del Atlántico". Este trabajo explora enfoques para desarrollar evaluaciones formales de los procedimientos de ordenación del atún rojo que

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reconozcan la variabilidad biológica y espacial y las limitaciones en los datos mediante el desarrollo de modelos operacionales.

KEYWORDS

Stock Assessment, Fishery Management, Migrations

1 Introduction

The International Commission for the Conservation of Atlantic Tunas (ICCAT) and its scientific committee (Standing Committee on Research and Statistics or SCRS) have been concerned with the movement and mixing of Atlantic bluefin tuna and its impact on the determination of appropriate management measures for several decades. Recently, ICCAT (2002) suggested approaches for integrating spatial factors into assessments and management which involve the definition of practical spatial and temporal strata for which alternative operational models, assessment models and management procedures might be employed; and extensive testing by simulation of the robustness of those procedures. Additionally, ICCAT Commissioners have recommended that there be a "Working Group to develop management alternatives" (see Appendix 1). The objective of this paper is to review the guidance in ICCAT (2002) and to examine progress as a basis to begin evaluating management alternatives for this mixed or multi-stock fishery. Additionally, directions for further research and organization of that research are suggested.

2 Historical Basis for Current Management Boundaries

Since the SCRS started its scientific work in 1971, the stock structure of the bluefin tuna has been the subject of intensive discussion. While significant tag-release data were available at that time, most of the recoveries were from the same side of the Atlantic as the releases. However, there were some trans-Atlantic recoveries and there was some evidence of morphometric difference between east and west bluefin tuna. Nevertheless, a one-stock hypothesis was deemed more plausible at that time for the Atlantic with some separation between Atlantic and the Mediterranean stocks.

In 1976, SCRS considered factors which supported a two stock hypothesis (two stocks being the western Atlantic versus the eastern Atlantic and Mediterranean combined) and those supporting one-stock. The factors supporting two stocks included the occurrence of small to large fish on both sides of the ocean; the occurrence of spawning on both sides but at different time periods; no evidence of spawning activities in the mid-Atlantic; tagging and historical records of traps in the Gibraltar area that show east Atlantic bluefin enter into the Mediterranean spawning area; the distribution of larvae and juveniles in the Mediterranean; irregularities of trans-Atlantic tag returns. On the other hand, factors supporting a one-stock hypothesis were uniformity in long-time trends in the catch between east and west; similarity in growth rates; transatlantic tag returns.

Balancing these lines of evidence, the SCRS considered that the east Atlantic and the Mediterranean are closely related and, for management purposes, that the two-stock hypothesis might be more advantageous. In 1978, SCRS stated that "the present evidence (which is still somewhat weak) is towards the hypothesis of separate eastern and western stocks, with a small, and variable, interchange of fish between them." It was considered that tagging results supported low mixing and the observed difference in the strength of year classes (strong year class of 1973 in the west and 1974 in the east) between east and west also supported separate stocks.

In 1980, the SCRS presented stock assessments separately for east and west stocks, and for a total Atlantic stock. The area divisions were suggested for statistical convenience and because they were aligned with discontinuities in the distribution of catches *at the time* in the Atlantic as a whole. The division line adopted at the 1980 SCRS session was used to define the east and west stock management units. In addition to Atlantic-wide minimum size and effort restrictions recommended by the Commission in the 1970s, in 1981, the Commission set a scientific monitoring level for the west bluefin tuna using the division line established by the 1980 SCRS at 45^{o} W in the north Atlantic.

However, recent events in the fishery, coupled with new scientific evidence suggest that the simple east-west management boundary may no longer be the most appropriate mechanism for management. Specifically, it was demonstrated that even small rates of net movement across the east-west boundary could have significant

implications on assessment (Punt and Butterworth 1995); electronic tagging showed that movement of large fish from west to east occurred, but that the migration routes were complex (Block et al. 2001, Lutcavage et al. 2001). Just as significantly, fisheries for bluefin moved and expanded. Originally, the bluefin fisheries tended to be located relatively close to the continents. But it is clear that changes in the longline fishing distribution have occurred and since the 1990s and that there is considerably more fishing (and bluefin catch) in the central Atlantic region. It appears the overall distribution of catch in the 1990s was much more continuous across the north Atlantic than was seen in previous decades. Therefore, the pragmatic basis for the original boundary (that the boundaries were aligned with discontinuities in the distribution of catches *at the time*) appears to no longer be relevant.

3 Assessment Research

In response to the changing circumstances, extensive research was conducted on alternative assessment methods which incorporate movement (Punt and Restrepo 1995, Cooke and Lankester 1996, Punt and Butterworth 1995). In particular movement/mixing models focused on diffusion (where the probability of trans-Atlantic migration depends only on the location (zone) of the potential migrant) and overlap(where the ranges of the eastern and western populations are assumed merely to overlap). Many SCRS scientists believed it was more likely that migrants return annually to their natal spawning grounds (ICCAT, 1995, p. 108-110). Additionally, results of the diffusion model were sensitive to how the estimation was structured (Turner and Powers, 1995; Punt and Butterworth, 1995, Porch et al 1998). The overlap model has been shown to provide the better fit to the indices of abundance, but not necessarily to the conventional tagging data (Porch et al., 2001). The electronic tagging data suggest that the great prevalence of western bluefin that cross the boundary at 45^{o} W return within a few months, which would seem to favor the overlap model. As yet, however, the data are limited to rather few large fish that were tagged mostly in two locations in the Northwest Atlantic. Thus, it is premature to reject the diffusion model at this time.

More important than developing the "true" model of movement is the usefulness of a model for management purposes. The structure of the model should adequately reflect the goals of management. Powers and Cramer (1996) suggested that incorporating reproductive behavior of the stock into models is important, if the goal is to maintain a viable western spawning population, whereas it is less so if the goal is to maintain high yield ocean-wide. Additionally, Porch et al. (1998) showed that the performance of stock assessments might be improved by use of the diffusion model if it is correct, but not otherwise. Similarly, Punt and Restrepo (1995) found that the performance of the management procedure might be improved by use of a correctly specified diffusion model, depending on factors such as the initial state of the system and ability of management to enforce regulations.

In response to the assessment research discussed above, the SCRS has begun to focus on the most appropriate management model, rather than the "correct" movement model (ICCAT 2002).

4 Management Models

Recognizing that it is unlikely that any management unit boundary between the Western and Eastern Atlantic will be effective in separating bluefin tuna of Gulf of Mexico (Western Atlantic) and Mediterranean Sea (Eastern Atlantic) origin, into non-overlapping populations, ICCAT (2002) suggested several management approaches whose selection will require trade-offs between biological realism and practicality. The approaches were referred to as the "Disaggregation Approach", the "Spawning Grounds Approach", and the "Pooling Approach" and a compromise approach, referred to as "The Regional Concentrations Approach." The description below is taken directly from ICCAT (2002).

4.1 Disaggregation Approach

This is the preferred way (in terms of realism, if data were available) to treat spatially overlapping populations. It requires the following steps:

1. Define spatial/temporal/fishery (by country, gear) cells for which catch at age and abundance indices at age are disaggregated into the spawning ground origin of the fish.
2. Conduct an assessment of each of the groups of fish (summed across all cells) of each spawning ground origin. This would include recalculation of MSY reference points and conducting projections as the basis of rebuilding options.

3. Set TACs for the catch of fish of each spawning ground origin.
4. Use linear or dynamic programming (or other modeling forms) to allocate catch to cells such that neither TAC is violated. However, even with a simple disaggregation, it seems likely that the current data is inadequate for reliable results. It may be a worthwhile approach for sensitivity analyses. In the future, microconstituent analyses may be capable of classifying fish to spawning ground origin.

4.2 Spawning Ground Approach

This is the opposite extreme from the Disaggregation Approach in the context of information needs. There is no attempt to classify fish off spawning grounds to spawning ground origin. However, it is assumed that all fish captured on spawning grounds during the spawning season were produced on that spawning ground.

1. Base assessment of status and trends on abundance indices on spawning grounds during spawning seasons. The indices might be more intense larval surveys, other fishery independent surveys, and/or CPUE indices.
2. Set TACs to be taken only on spawning grounds about at the time of spawning. The fishing season might be set to lag the timing of the spawning season to prevent it from disrupting spawning. This approach would have strong allocation implications, and it would have large social and economic effects.

4.3 *Pooling Approach*

A pooled assessment is relatively easy to conduct. It could be used to judge the overall productivity of the Atlantic and Mediterranean Sea, and to set a "pooled" TAC. Catch could be allocated to areas (among countries) to prevent excessive take from fish originating from either spawning ground. Ideally, spatial allocations would be based on area specific relative abundance indices that are comparable throughout the Atlantic and Mediterranean Sea.

1. Conduct a pooled assessment.
2. Set "pooled" TAC based on the pooled assessment.
3. Allocate shares of the pooled TAC in time and space to prevent excess mortality on either spawning component or localized depletion based on relative abundance.
4. Allocate shares by time and area to each country. While the Pooling Approach has the advantage of being a relatively easy way of treating Atlantic bluefin tuna as a closed population, it could jeopardize the weaker and/or smaller of the spawning components of the population. It could also lead to the dilution of relatively high quality data with data of poorer quality. Without comparable relative abundance data for all areas it is unclear how to spatial distribute the catch to prevent depletion of the fish in some areas. Historical catch information could be used, but this might institutionalize existing problems

4.4 Regional Concentrations Approach

This approach recognizes that there are large areas (regions) where fish are consistently distributed. It does not assume the fish are of the same origin, but it does assume that the fish tend to remain as members of a concentration for most of their life span. This approach weakens or renders meaningless spawner-recruit analyses for the regional concentrations. However, yield and spawning biomass per recruit reference points may be used as the basis for management. If typical YPR/SPR reference points (e.g., F0.1) are used throughout the Atlantic and Mediterranean Sea, the approach might be a reasonable proxy for an MSY strategy for the entire pool of fish.

1. Set management boundaries at discontinuities in distribution of fish, as indicated by abundance information, tagging and/or catches.
2. Assess the management units as usual.
3. Set TACs on YPR/SPR reference points consistently for all management units.
4. Areas believed to be particularly important areas of overlap, or transitory (i.e., the fish are only members of the concentration for a short period of time), might be managed separately to prevent a fishing from adversely impacting adjacent areas.
5. If the boundary between the current Eastern and Western Atlantic management units is changed, country allocations would have to be reconsidered

5 Examples

Management approaches like those above will require structuring of models that accommodate more biological realism indicated by newly-collected information on eastern and western bluefin movement patterns and recent changes in the distribution of catches in the north-central and northeastern Atlantic. ICCAT (2002) recommended that future models incorporate
quarterly temporal divisions and six spatial divisions (Figure 1). The Gulf of Mexico (spatial stratum 1, which includes the Straits of Florida and Caribbean Sea) and Mediterranean Sea (spatial stratum 6) were recommended because of the location of known spawning areas, the inherent productivity of the fisheries in the Mediterranean and the inadequacy of Mediterranean catch data (ICCAT 2002). The current operational East/West management boundary was retained except that it was shifted northwards in the vicinity of Brazil to include the unique oceanographic features of the region and associated large catches during the 1960's as part of the western zone. A distinct Central Atlantic zone including the region off the Flemish Cap (spatial stratum 3) was also specified in recognition of the fact that few of the fish tagged in the west with electronic tags moved beyond 30 degrees west. Spatial stratum 4 includes the Northeastern Atlantic region from south of Iceland extending northeastward to include waters off the Norwegian coast; while stratum 5 includes the remainder of the Eastern Atlantic. Figure 1 was a starting point for use in organizing data for preliminary model development and parameterization research.

Operational modeling coupled with the development of management procedures is a mechanism by which the " Regional Concentrations Approach" and possibly other approaches, might be tested against various management scenarios and mechanisms for their utility and robustness. The first step in this process is the development of *operational models*, i.e. models of biological, ecological and fisheries "reality" which may be used to test assessment and management procedures. There will be more than one plausible reality or hypothesis on how the system works, e.g. how fish move, the sparseness of catch data and other factors. These should be constructed carefully to assure that tests will be meaningful. Operational modeling is an approach that has been undertaken in various forms (CCSBT 2002). Then *management procedures* are developed, i.e. simple models or rules using alternative management structures are tested against the operational models to evaluate their effectiveness, robustness and practicality. Indeed, Porch et al (1998) presented an early effort for Atlantic bluefin in which complicated movement patterns (expressed through advection-diffusion mixing between 5^{o} squares) were modeled and then assessed using the current east-west boundaries. The following example uses the six areas defined in ICCAT 2002 and assumes a specific overlap in each area.

The following operational model was created as an example. In this example, fish originate in either the western spawning area or the eastern spawning area. Then they distribute themselves among the six areas (numbered as in Figure 1). The fraction of each stock inhabiting each area varied with age as in Table 1.

Recruitment was assumed to be constant for the east, and declining in the west. Fishing mortality in each area ranged between 0.1 and about 0.5. VPA's were conducted for each area, ignoring the origin of the fish in that area.

As expected, the sum of the vpa assessments of abundance is the same as the sum of the true abundances of East Origin fish plus West Origin fish (Fig 2). Likewise, the trends for areas 1-3 look more like the true trend for West Origin fish and the trends for areas 4-6 look more like the trends for East Origin fish. This suggests the regional concentrations approach may perform reasonably, depending on the extent of overlap and the degree to which the East stock is larger than the West.

This example suggests that there is some optimism for developing management procedures when the number of areas is expanded from the two examined by Porch et al (1998) to the six areas suggested by ICCAT (2000). However, if management is to move toward the Regional Concentrations Approach, a number of further analyses need to be explored. In particular, alternative underlying operational models (including the overlap model) need to be developed and examined. Also, the effect of different availability of data in terms of quality, as well as quantity for the six areas should be evaluated in the context of alternative assessment models. Additionally, the management procedure approach recognizes that all models will perform sub-optimally under some conditions. The simulations need to be conducted to guide both scientists and managers in determining when those conditions occur and alternative management that might be implemented to ameliorate the situation.

6 Summary and Conclusions

As noted before ICCAT Commissioners have recommended that there be a "Working Group to develop management alternatives" (see Appendix 1). The wording implies that this will be done by both managers and scientists. Initial efforts of model evaluation indicate that in some instances simple models of closed populations when, in fact, the populations are *not* closed, may be useful for management. However, considerably more simulation and modeling research needs to be undertaken. This research will require input from managers, as well as an organized research effort to incorporate alternative biological hypotheses and model structure.

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Appendix 1 [02-11] RECOMMENDATION BY ICCAT TO ESTABLISH A WORKING GROUP TO DEVELOP INTEGRATED AND COORDINATED ATLANTIC BLUEFIN TUNA MANAGEMENT STRATEGIES

RECALLING that the current boundary between eastern and western management areas was established for the purpose of managing spatially distinct fishing grounds and spawning areas;

RECOGNIZING that one of the elements of uncertainty surrounding the assessment relates to the boundary between the eastern and western management areas for bluefin tuna that may impact negatively on the effectiveness of management actions throughout the Atlantic and Mediterranean;

BEARING IN MIND that evidence on mixing of the bluefin tuna of uncertain origin (eastern or western) is a key source of uncertainty to enable more precise assessments to be made, and it could reduce, to some unknown extent, the effectiveness of ICCAT management measures;

NOTING that the 2001 ICCAT Workshop on Bluefin Tuna Mixing (SCRS/01/020) concluded that "it is unlikely that any management unit boundary between the Western and Eastern Atlantic will be effective in separating bluefin tuna of Gulf of Mexico (Western Atlantic) and Mediterranean Sea (Eastern Atlantic) origin, into non-overlapping populations", and that the Standing Committee on Research and Statistics (SCRS) in 2002 stated that "the Committee lacked a quantitative basis for recommending a change in the management area boundary or the implications of the change;"

FURTHER RECALLING that the SCRS Response in 2002 to the Commission on Bluefin Tuna Mixing recommended research to better quantify the origin of fish, mixing and its implications in the central Atlantic;

RECOGNIZING, however, that much of the relevant research is being conducted in diverse locations, and there is a need to synthesize all available information within a unified framework.

THE INTERNATIONAL COMMISSION FOR THE CONSERVATION
OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THAT:

1. A Working Group, comprised of scientists and managers, shall be established to evaluate all available biological information relevant to the issue of stock structure and mixing, and to develop operational options for implementing alternative approaches for managing mixed populations of Atlantic bluefin tuna including but not limited to those developed by SCRS;

2. In developing options, the Working Group shall consider scientific information on the biology of bluefin tuna, historical data on fisheries, and the feasibility of alternative scenarios;

The Working Group shall meet no later than November 2003 and as necessary thereafter, and report to the Commission at its meeting in 2004.

Table 1. Hypothesized proportion of fish (at age) of western or eastern origin that occur in each of six areas used in simulations of Figure 2.

	Area						
	GOM	W Atl	Central	NE Atl	E Atl	Med	
	1	2	3	4	5	6	
West Origin	0.5	0.5	0	0	0	0	(age 1)
Fish	0.05	0.75	0.2	0	0	0	(ages 2-6)
	0.2	0.3	0.3	0.1	0.05	0.05	(ages 7-10+)
East Origin	0	0	0	0	0.5	0.5	(age 1)
Fish	0.00	0.1	0.1	0.2	0.3	0.3	(age 2-4)
	0.05	0.05	0.1	0.2	0.3	0.3	(ages 5+)

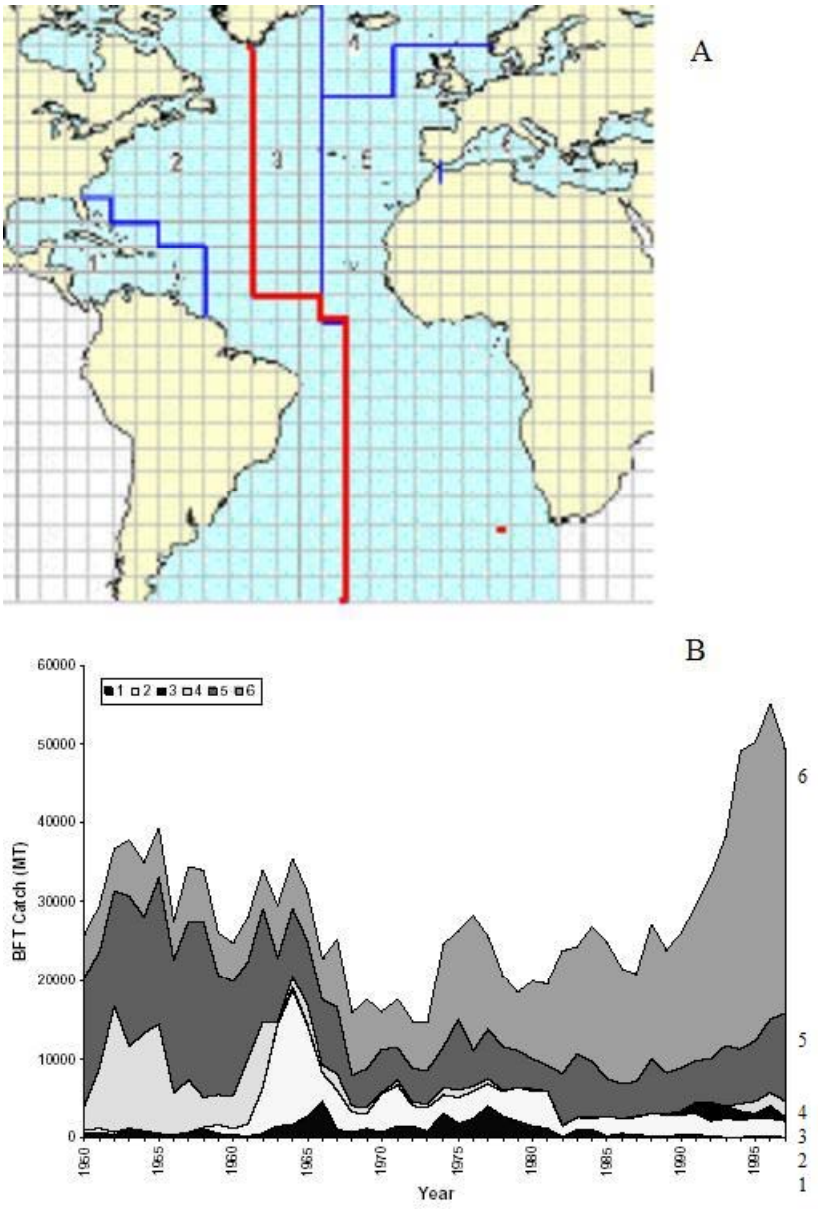

Figure 1. A. Spatial structure of six subareas recommended for accommodating greater biological realism into future assessments to address alternative management structures (the line between areas 2 and 3, and 2 and 5 is the current management boundary, except that it was shifted northwards in the vicinity of Brazil to include the unique oceanographic features of the region and associated large catches during the 1960's as part of the western zone.); B. historical catches by these subareas (area numbers legend located to the right of B).

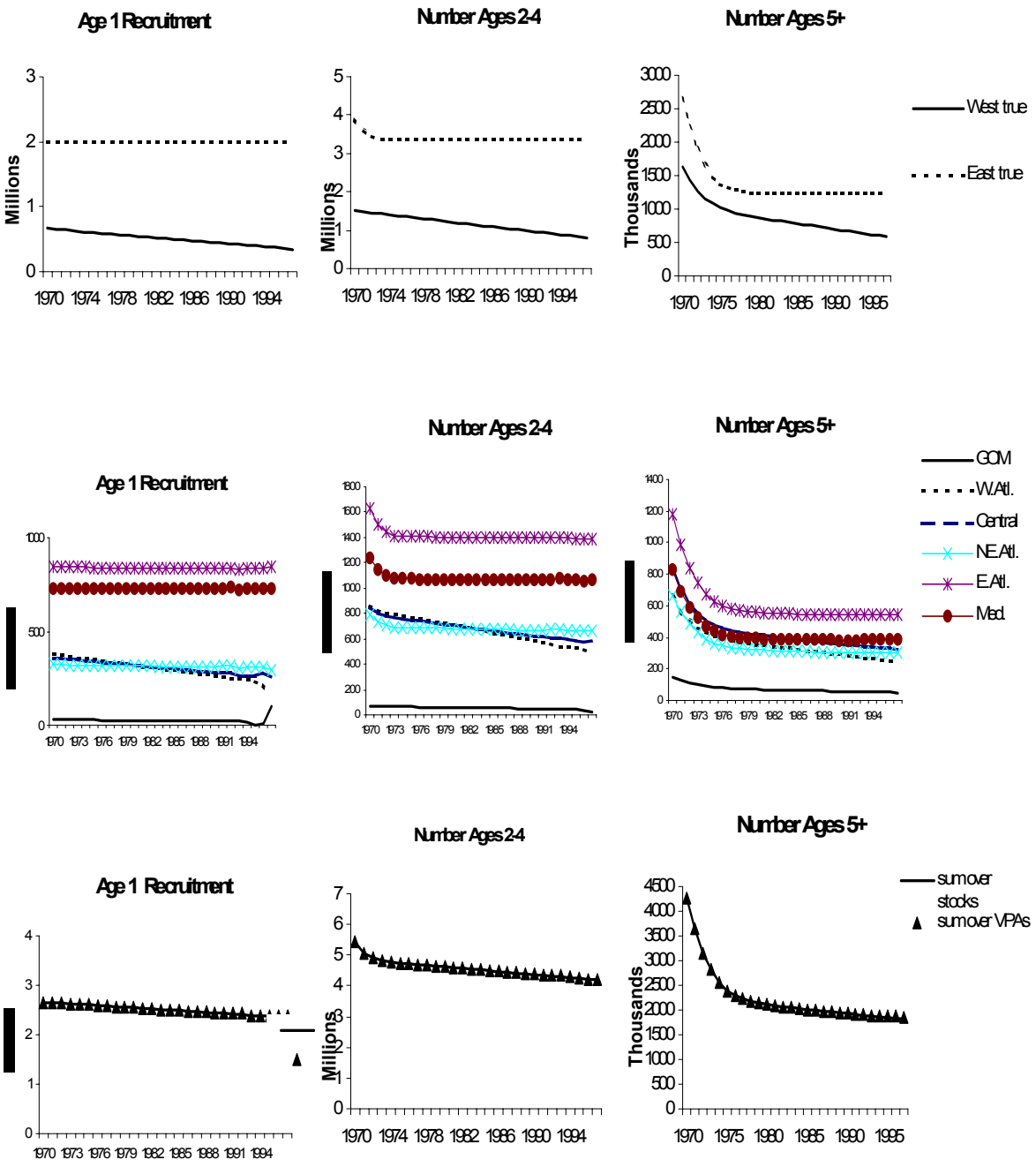

Figure 2. Simulated abundance of West Origin and East Origin fish. Top row is "true" abundance trends; middle row is abundance by area when each area was assessed by a vpa assuming independence from other areas; bottom row is combined abundance (combined over true East and West versus combined over are-specific VPAs).