FEATURE: FISHERIES MANAGEMENT

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Evaluating Localized vs. Large-scale Management: The Example of Tautog in Virginia

ABSTRACT: Choice of management spatial scale is a critical step of any stock assessment, but deciding on a conservative criterion is difficult because of risks associated with any choice. For example, if one large unit is selected when distinct sub-stocks exist, then some population components may disappear over time. Alternatively, choosing several small management units when one well-mixed stock exists may lead to costly and ineffective management. We consider the example of tautog (*Tautoga onitis*). Mortality estimated for a single stock using virtual population analysis has exceeded the target and resulted in mandated reductions in fishing. In Virginia, tag returns and catch curve analyses are consistent with a localized mortality rate that is less than the target. Therefore, reductions of fishing effort in Virginia may not alleviate overfishing elsewhere and might not be conservative. Thus, simple models used for localized assessment can have advantages over sophisticated models applied to an entire stock complex when multiple stocks exist.

Evaluación Local vs. Manejo a Larga Escala: El Caso de la especie (*Tautoga onitis*) en Virginia

ABSTRACTO: La selección de la escala espacial es uno de los puntos críticos en toda evaluación de "stocks" pero la definición de criterios de conservación es mucho más difícil considerando los riesgos asociados con este tipo de decisión. Por ejemplo si elegimos una unidad de larga escala cuando distintos sub "stocks" existen, algunos de los componentes de una población podrían desaparecer a través del tiempo. Alternativamente si consideramos la selección de pequeñas unidades de manejo cuando solo existe un "stock" muy mezclado; esto puede conducirnos a un manejo costoso y poco efectivo. Nosotro examinamos el ejemplo de la especie (*Tautoga onitis*) determinando que cuando la mortalidad estimada para un solo "stock" es aplicada a un análisis virtual de la población que ha excedido su quota de explotación esto resultaría en recomendaciones de medidas de regulación para reducir la pesca. En Virginia los resultados del marcado y las gráficas de capturas son consistentes con los análisis de que la mortalidad localizada es menor que la quota de captura. Consecuentemente reducciones en la pesca de esta especie en Virginia no serían una medida conservativa que aliviaria la sobre-pesca en otras localidades. En este caso los modelos simples de evaluación localizada podrían ser mas efectivos que los modelos sofisticados que se aplican a un "stock" complejo formado de unidades múltiples.

INTRODUCTION

The choice of management spatial scale is a critical step of any stock assessment. That decision depends upon the biology and behavior of the species and the operational considerations of the management policy. There are advantages and disadvantages of any choice of management unit that are strongly affected by the movement patterns of the species. We begin by reviewing the tradeoffs associated with few, large management units (large-scale management) compared with a greater number of small management units (localized management). We then discuss a case history of the tautog (*Tautoga onitis*) resource in Virginia, showing the application of a localized management design that contrasts with the established large-scale management practice.

TRADE-OFFS ASSOCIATED WITH LARGE-SCALE VS. LOCALIZED ASSESSMENT AND MANAGEMENT

There can be clear advantages to assessing a stock on a large-scale basis, i.e., treating a stock complex as a single unit for assessment and management (Table 1). When there is no significant spatial variability in population characteristics due to the fact that the stock is well mixed, large-scale analysis is appropriate and possibly requires less work since data compilation and analysis only need to be done once. A single stock management unit, when appropriate, also enables data from subunits to be used for estimating parameters for the whole stock complex. For example, to tune a Virtual Population Analysis (VPA) to obtain fishing mortality (F), it is appropriate to use a survey index of abundance from a portion of the species' range *provided* the index is representative of the entire stock complex. Additional advantages of defining a single stock unit arise from the aggregation of data from subunits within the management area that results in potentially lower costs to gather data and possibly more precise parameter estimates.

If the stock-complex is managed as a single unit, but is comprised of sub-stocks that have real biological differences in terms of population parameters, potential problems arise. The aggregation of data from the entire stock-complex results in estimated parameter values that represent averages spread across the spatial scale used in the analysis. If mangers use the average obtained from a coast-wide assessment and apply it to all sub-stocks, then for some sub-stocks restrictions will be too stringent, while in others restrictions will not be sufficient to meet management goals. This results in a loss of yield in both cases. Also, management regulations lacking spatial detail can potentially lead to localized serial depletion, lower recruitment, and instability in the fishery.

One way to address the risks of large-scale, single-stock analysis is to partition the management area into smaller spatial scales that reflect biologically meaningful units or sub-stocks (local populations that experience different mortality rates, have spatial or temporal isolation of spawning groups, show microevolution of morphological or genetic characteristics, or have abundances that are affected by local processes; Waldman 2005). Stephenson (1999) argued that spatially distinct spawning groups should be treated as sub-stocks under a "precautionary approach" until there is information to demonstrate otherwise. While data requirements increase as stocks are separated into smaller spatial scales, the potential of localized serial depletion is reduced. Localized management may also result in stability of the fishery and help to maintain genetic diversity and productivity in sub-stocks. However, if the spatial scale is too small, external forces (immigration and emigration) may overwhelm any management effort. For example, if unlimited fishing of a highly mobile species were allowed in a small management area, immigration into the area may dominate over depletion due to fishing, resulting in a constant catch rate and leading to the incorrect conclusion that fishing has little effect on the population. An additional consideration is that parameter estimates from smaller spatial scales may have more variance and the reduction in data availability could make localized management unwarranted.

A CASE STUDY OF LARGE-SCALE VS. LOCALIZED MANAGEMENT: TAUTOG IN VIRGINIA

Tautog, a member of the wrasse family (Labridae), is found from Nova Scotia to Georgia, with the greatest abundance found between Cape Cod, Massachusetts, and the Chesapeake Bay, Virginia. Tautog is a long-lived species (up to 30 years; Cooper 1967) that tends to inhabit structure such as wrecks and reefs, making it susceptible to overfishing (Briggs 1977). Springtime spawning typically occurs at or in the mouths of estuaries and bays and in nearshore waters, and juveniles settle in shallow estuarine habitats (Sogard et al. 1992).

Beginning in the mid-1980s, the coast-wide tautog stock began to decrease due to fishing pressure. The majority of Virginia landings (greater than 90%) result from a recreational fishery (ASMFC 2002). To facilitate management of the coast-wide stock, the Atlantic States Marine Fisheries Commission (ASMFC) adopted a Fishery Management Plan (FMP) for tautog in 1996 to rebuild spawning stock biomass by reducing fishing mortality. The ASMFC split the

Table 1. Advantages and disadvantages of different spatial scales for possible management units used in stock assessments.

	Several Small (Localized)	Few Large (Large-scale)
When Appropriate	* When there are real spatial differences	* When there are few spatial differences
Requirements	* Requres fine scale data	* Requires only aggregate data
Advantages	* Will detect localized depletions, maintain reproduction in substocks (genetic diversity), promote stability of fishery (avoid serial depletion)	* Potentially less work and expense to assess and enforce, may be able to "borrow strength" (obtain parameter values) from subunits
Disadvantages	* Possibly more work and expense to assess the stock, may be harder to enforce and identify location of catch, need information regarding recruitment and external factors (e.g., Immigration)	* Gives spatially averaged results, perhaps biased (if the stock is not well-mixed)
Risk if wrong management unit is chosen	* Additional, unnecessary expense; inappropriate scale may mask effects of management	* Local depletion goes undetected, potential for loss of genetic diversity, potential loss of legitimate yield

management region into two zones: a northern zone (Massachusetts, Rhode Island, Connecticut, New York, and New Jersey) and a southern zone (Delaware, Maryland, Virginia, and North Carolina). Since 1996, three addenda have been added to the FMP to reduce fishing mortality and rebuild spawning stock biomass by creating minimum size and possession limits, gear restrictions, and closed seasons.

The ASMFC uses a VPA to examine tautog stocks on a coast-wide basis (Table 2). Fisheries dependent data from Massachusetts to Virginia (and fisheries independent data from Massachusetts to New Jersey only) are aggregated and the entire stock is assessed resulting in annual estimates of abundance and fishing mortality by age and in annual estimates of recruitment (ASMFC 2002). If tautog are well mixed throughout the range and if the assumption that natural mortality (M) is constant throughout the stock is warranted, then extending the results of the VPA to include the southern zone is appropriate. However, if sub-stocks exist, then VPA may mask real localized differences in population parameters. For example, VPA will average *F* across the entire stock and not appropriately allocate mortality rates among sub-stocks. The result would be an overestimate of *F* in one area and an underestimate in another area that could lead to ineffective management decisions and potentially to sub-stock collapse. The *F* calculated for the entire stock complex is a potentially biased estimate of the stock average because the estimate depends on which sub-stocks supply tuning indices and how those indices are weighted.

The VPA conducted in 2001 using catch-at-age data from 1981 to 2000 showed that the fishing mortality rate declined from 0.71/y to 0.41/y between 1993 and 2000. Despite the decrease, the estimated fishing mortality rate remained above the ASMFC target of F = 0.29/y (= $F_{40\%SSB}$) established by the Tautog Plan Review Team (ASMFC 2002). As a result, the ASMFC mandated a reduction in fishing effort for all states in 2003. However, the age composition data used in the analysis were from the northern zone and a lack of sufficient data from states south of New Jersey prevented a regional assessment based on VPA for this zone. In a subsequent VPA (2005), the estimated fishing mortality rate decreased to 0.30/y, but was still above the target value.

The Virginia Marine Resources Commission (VMRC) believed that tautog in Virginia experienced a lower fishing mortality rate compared with northern populations (White et al. 1997). Catch curves were constructed using samples collected primarily from the commercial fishery in Virginia to derive an age-length key that was applied to landings data obtained by the Marine Recreational Fisheries Statistics Survey (MRFSS) and the VMRC. The estimated total instantaneous mortality rate (Z) from the catch curves varied between 0.26 and 0.58/y from 1985 to 1996 and were lower than the coast-wide average of Z = 0.73/y at that time (Figure 1).

To examine the possibility of sub-stock structure in tautog, tagging studies conducted by the Virginia Saltwater Gamefish Tagging Program since 1995 were reviewed. These showed that 3 out of 1,410 tag returns (0.21%) from tautog tagged in Virginia were caught outside of the state of Virginia: one from Ocean City, Maryland, one from Delaware Bay, and the other from Oregon Inlet, North Carolina (Hoenig and Lucy 2004; Lucy, unpublished data). A variety of sizes were tagged both inshore and offshore throughout much of the year. The majority of tagged fish were caught near the tagging location although there was some inshore-offshore migration as well. Acoustic telemetry data also suggest limited movements for Virginia tautog (Arendt et al. 2001). Similar migration patterns for tautog have been found in Rhode Island (Cooper 1966) and New York (Olla et al. 1974). Investigations into stock structure based on genetics have shown a low level of genetic diversity between samples taken from Virginia, Rhode Island, and Delaware, which could be related to low effective population size, a historical bottleneck from previous glacial events, or larval transport processes (Orbacz and Gaffney 2000). The complication for basing stock structure on genetic criteria is that tautog release pelagic larvae that persist for up to three weeks in nearshore waters where there is the potential for along-shelf transport. The dispersal of early stages would not only result in reduced genetic variation, but may also explain the lack of observed differences in biological parameters such as age, growth, and reproduction throughout their range (Hostetter and Munroe 1993). The supporting evidence from the tagging data that Virginia tautog remain in Virginia waters or offshore of Virginia and show little along-shelf movement provides a mechanism to justify using localized fishing mortality rates and thus we have restricted our analysis to tautog landed in Virginia territorial waters and seaward to the outer edge of the Exclusive Economic Zone (324.2 km).

Table 2. Comparison of virtual population analysis and cross-sectional catch curve analysis.

	VPA	Cross-sectional Catch Curve
Data Requirements	* Catch at age matrix for more years than there are ages, tuning index, need to know (or assume) natural mortality (*M*)	* Catch at age composition, need to know (or assume) natural mortality (*M*)
Output	* Get a value for fishing mortality (*F*) and abundance by age and year, and recruitment by year	* Get one (or more) value(s) for total mortality
Assumptions	* *M* is known and is constant throughout the stock, stock is spatially well mixed, generally need some assumptions about catchability and possibly about a plus group	* *F* and *M* are constant across age groups, vulnerability to fishing gear is constant above a given age, no trend in recruitment over time
Advantages	* *F* can be determined for each age class in each year	* *F* can be calculated from a single years' data, can give localized estimates
Disadvantages	* Looks at the population from a historic perspective, the dependability of the results is poorest for most recent years; does not provide information on spatial variability	* Provides less detail about the stock than VPA, cannot discriminate between all possibilities (e.g., change in mortality vs change in recruitment)

NON-EQUILIBRIUM CATCH CURVES

Opercle and otolith samples obtained primarily from the commercial fishery were examined to continue to monitor Virginia tautog mortality rates following the study by White et al. (1997). Additional samples were collected from recreational catches opportunistically. Ages were determined by Old Dominion University. The resulting aged samples were used to derive cross-sectional catch curves for each year from 1997 through 2004. Cross-sectional catch curve analysis was used because it provides an estimate of total instantaneous mortality rate and only requires information on relative abundance of cohorts from a single year (Table 2). Two assumptions of cross-sectional catch curves are: catchability of the cohorts is constant across age, and recruitment shows no trend over time for the cohorts being examined, but recruitment may fluctuate randomly about a stationary mean. Another possibility for examining localized mortality rates is the use of a longitudinal catch curve, which assumes that catchability of the fishing gear remains constant from year to year, that catchability of the cohort remains constant as the fish grow larger, and that the catch curve is based on known catch-per-unit-effort. Because longitudinal catch curves follow a single cohort through time, the analysis requires catch rates over multiple years. On the other hand, cross-sectional catch curves can be examined using a single year of catch composition data. An assumption of both longitudinal and cross-sectional catch curves is that the stock and fishery are at equilibrium. When there is equilibrium (no change in fishing or natural mortality rates and no trend in recruitment over time), the descending limb of the catch curve is a straight line whose slope reflects the total instantaneous mortality rate. However, for tautog, a stock undergoing rebuilding efforts, changing fishing mortality rates result in non-equilibrium conditions and departures from linearity (resulting in a bend in the catch curve). Interpretation of the non-equilibrium catch curve can provide insight into changes in stock dynamics, although additional years of data are required. If the bend in a cross-sectional catch curve always occurs at the same point every year, then either catchability changes with age or mortality changes with age, but distinguishing between the two is not possible (Figure 2). On the other hand, if the bend in the curve moves one time step to the right each subsequent year, then either there has been a change in mortality with time or a change in recruitment with time (Figures 3 and 4). A fixed percentage change in recruitment every year results in a series of catch curves over time that consists of two linear segments (Figure 4), whereas a one-time permanent change in recruitment results in a complicated pattern evolving in the catch curve over time (Figure 5). Distinguishing between the different explanations for bent catch curves is not possible without further information, but catch curves do provide a tool for examining non-equilibrium conditions using limited data.

CROSS-SECTIONAL CATCH CURVES FOR VIRGINIA TAUTOG

Ordinary (equilibrium) cross-sectional catch curve analysis was used first for tautog in Virginia because available data included age composition of the catch. Results of the analyses suggest a slight reduction in total mortality in recent years relative to the 1980s and early 1990s (average Z estimate = 0.38/y from 1985 to 1996, average Z estimate = 0.30/y from 1997 and 1999 to 2004) with values that are below the target Z of 0.44/y established by the ASMFC (Figures 1 and 6). To check for the possibility that mortality may have changed over time, we then constructed non-equilibrium catch curves for 1997 and for 1999 to 2004. Total instantaneous mortality rate estimates for younger fish that only experienced the recent mortality rate ranged from 0.18/y in 2000 to 0.41/y in 2004, while the mortality rate for older fish that experienced both old and recent mortality rates ranged from 0.24/y in 2003 to 0.51/y in 1999 (Table 3; Figure 6). An important point is that the recent total mortality rate is below the ASMFC target Z = 0.44 (assuming M = 0.15). If the entire age range is used in the catch curve analysis (assuming there is no bend in the catch curve), then the estimated total instantaneous mortality rate for tautog ranged between 0.26/y in 2000 and 0.42/y in 1997 (Table 3; Figure 6). A possible criticism of catch curve analysis is that the age of full recruitment may not be the peak as used in this analysis, but may occur at an older age. If the age at full recruitment is assumed to be age 5 in all years based on the oldest observed peak (2001), then the estimated total instantaneous mortality rate for tautog changes, but still remains below the target value (Table 3). Thus, the conclusion that the mortality rate in Virginia is below the ASMFC target is robust to the interpretation of the shape of the catch curves and the age at full recruitment. In addition, the increase in MRFSS catch and effort estimates observed during 2003 and 2004

Figure 1. Estimates of the total instantaneous mortality rate obtained using cross-sectional catch curves for Virginia tautog by White et al. (1997, columns 2 and 6 of Figure V.7) and this study.

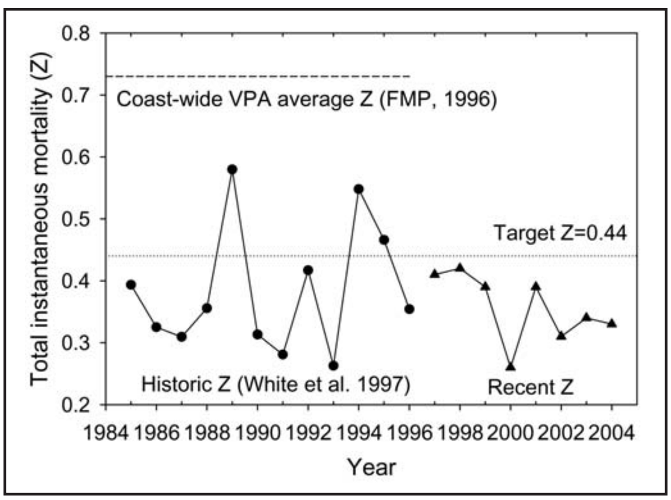
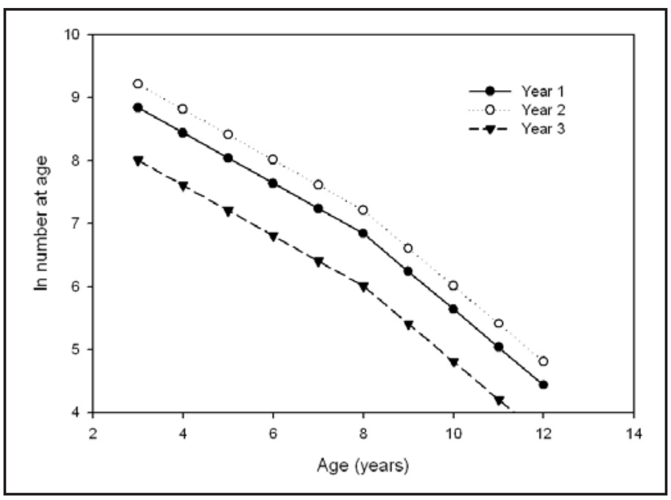


Figure 2. Non-equilibrium cross-sectional catch curves for three years of data showing a consistent bend in the curve at age 8. Such a pattern is consistent with mortality increasing with age or catchability decreasing with age.



(Figure 7) correspond to a steepening of the catch curve at the extreme left of the descending limb, suggesting that the non-equilibrium catch curves may be tracking a recent change in the mortality rate (Figure 6, data for 2004). Additional years of data could verify this trend.

In theory, another possible explanation for the bend in the catch curve is a violation of the assumption of no trend in recruitment. If recruitment continuously decreased at a constant percentage rate with time, the result would be to pull the left side of the catch curve downward and appear as a reduction in total mortality estimates for younger ages, i.e., for recent years (Figure 4). Observing a constant decrease in recruitment over time, such as 20% per year, is possible but not likely. Unfortunately, data for recruitment of Virginia tautog are not available and we are currently unable to definitively exclude this possibility. However, recruitment estimates from the VPA do not show any decreasing trend over time throughout the northern management area and actually show an increase in biomass and recruitment in recent years (ASMFC 2002). Inasmuch as recruitment is influenced by regional factors, such as climate (Myers et al. 1997), the results from the VPA concerning recruitment are consistent with the idea that recruitment in Virginia has not declined. Additionally, the MRFSS data showing lower fishing effort in recent years relative to the early 1990s (with a notable increase in only the last two years) support the conclusion that fishing mortality has decreased in recent years. Finally, the implementation of minimum size restrictions, closed seasons (commercial fishery), and possession limits (recreational fishery) for tautog in Virginia that began in 1997 would reduce fishing mortality of young tautog and tend to increase recruitment.

DISCUSSION

The management spatial scale that is chosen for a particular species may be based upon known biological criteria of the species or for convenience in terms of identifiable and enforceable management units. Because the true nature of the stock is unknowable, it is good practice to use a variety of assessment models, assess if the data are appropriate, and compare results. When model results vary the logical question to ask is "Why?" The argument for using a cross-sectional catch curve analysis does not negate the idea of using a VPA but, rather, suggests that different assessment tools may be complementary and show insight into stock dynamics that a single methodology may not reveal. For example, while VPA is superior in providing mortality rates and absolute abundance by age and year, it is inferior in that the parameters are averaged over the entire management unit. If substocks are not well-mixed, as appears to be the case for tautog, then mortality rates may not be accurate for any jurisdiction and management decisions may be less effective. Virginia's fishing mortality rate may be below the value obtained using a VPA for the entire stock complex. If so, then cutting back fishing effort in Virginia results in unnecessary regulations and loss of yield. Furthermore, there must be higher values of *F* in another area (or areas) within the management unit that balances the below average value in Virginia. Therefore, the reduction in effort that is averaged across the management substocks may not be sufficient to decrease *F* to

Figure 4. Non-equilibrium cross-sectional catch curves over a series of years showing a consistent 20% decrease in recruitment every year. Here total mortality (*Z*) is constant over all ages and all years and the departure from linearity is due to changing recruitment. The slope to the right of the bend reflects the true mortality rate. For clarity, each successive year's catch curve is displaced below the previous years curve. In practice, the height of the curve is determined in part by sampling effort.

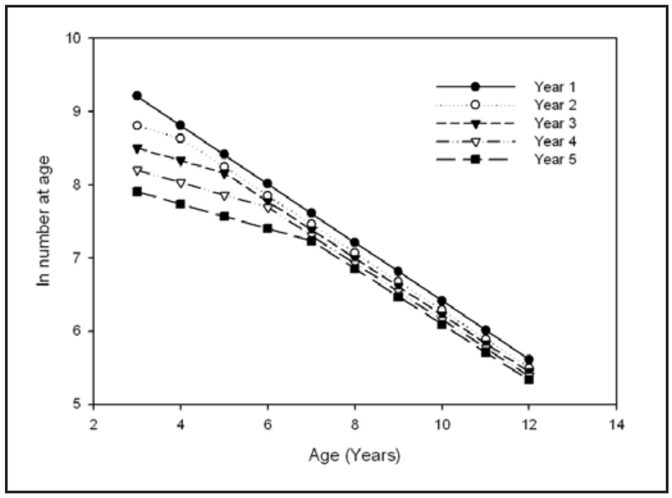


Figure 3. Non-equilibrium cross-sectional catch curve for three years of data showing a migration of the bend to the right. This is consistent with a decrease in mortality with time or a decreasing trend in recruitment. The slope of the line to the left of the bend shows the recent mortality rate if the mortality rate has changed.

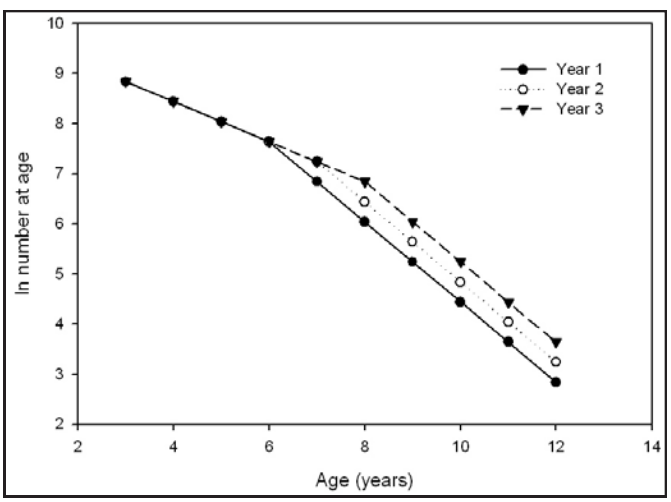
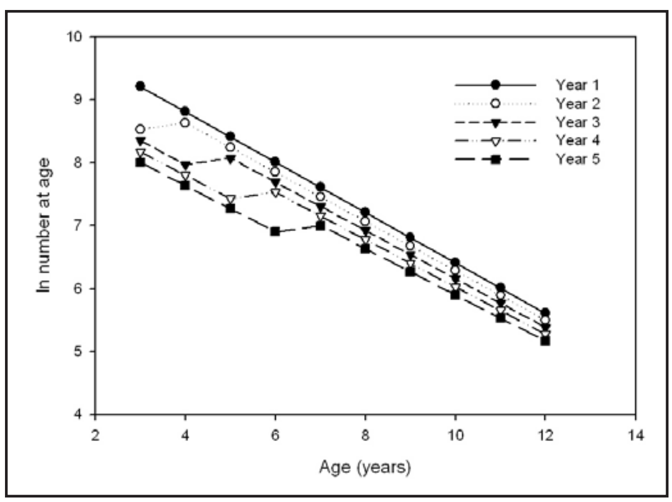


Figure 5. Effect of a permanent decrease in recruitment from one constant level to another on a non-equilibrium cross-sectional catch curve starting in year two. For clarity, each successive year's catch curve is displaced below the previous year's curve. In practice, the height of the curve is determined by sampling effort.



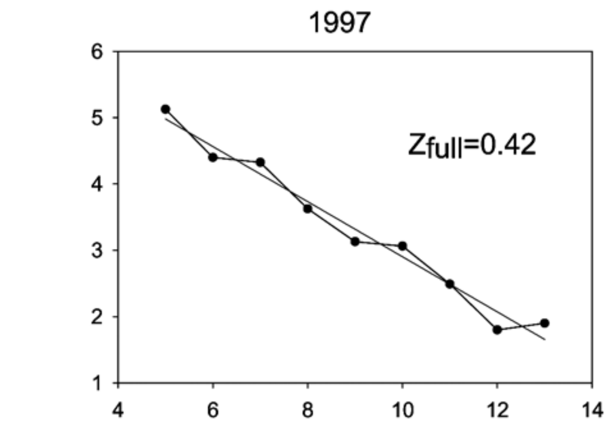
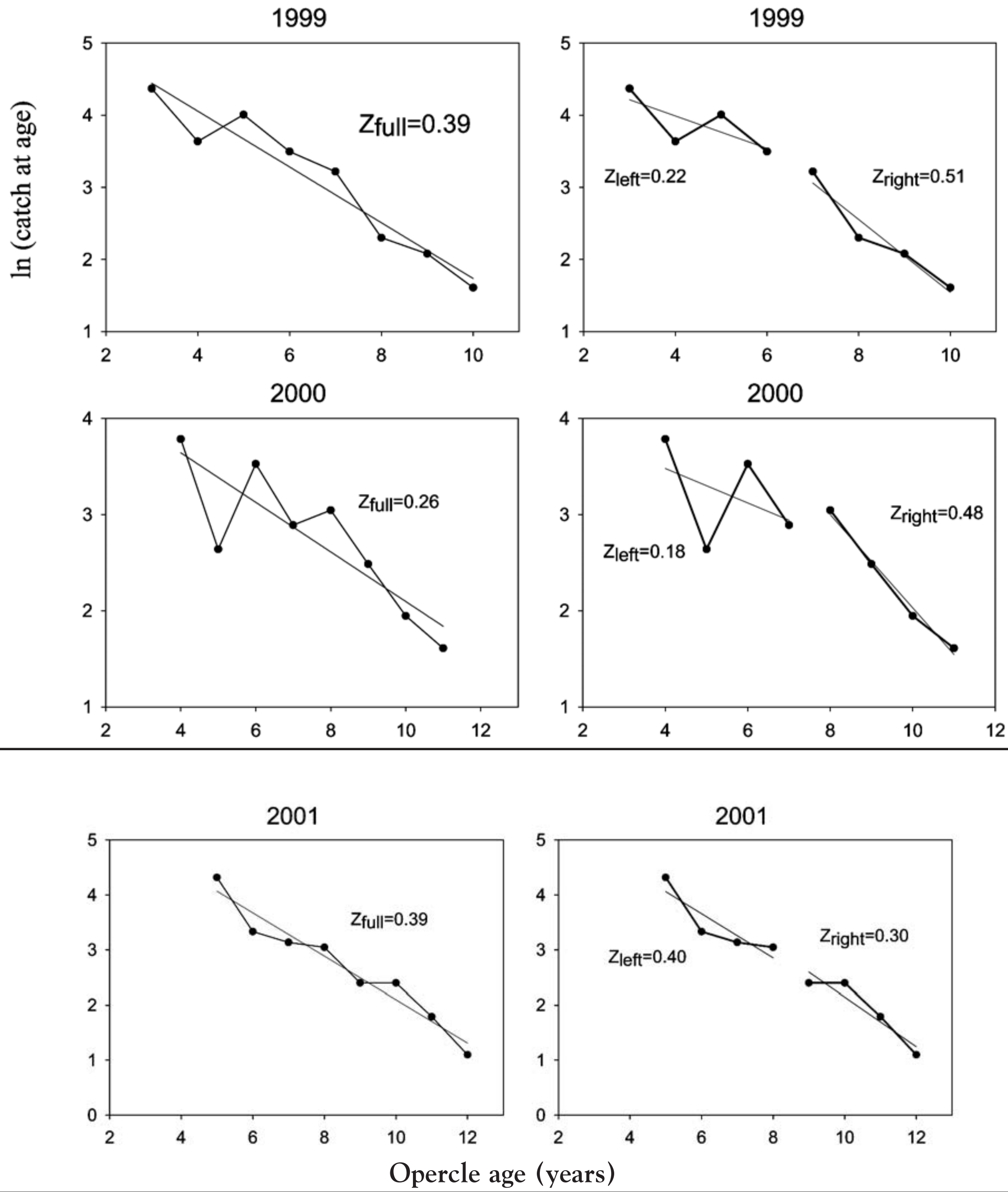


Figure 6. Cross-sectional catch curves (left) and non-equilibrium cross-sectional catch curves (right) for 1997 and for 1999 through 2004. Operculum age was derived from tautog obtained primarily from commercial landings with some opportunistic data obtained from recreational catch. Ages represented by less than five fish were not used in the regression and only the descending limb is shown.



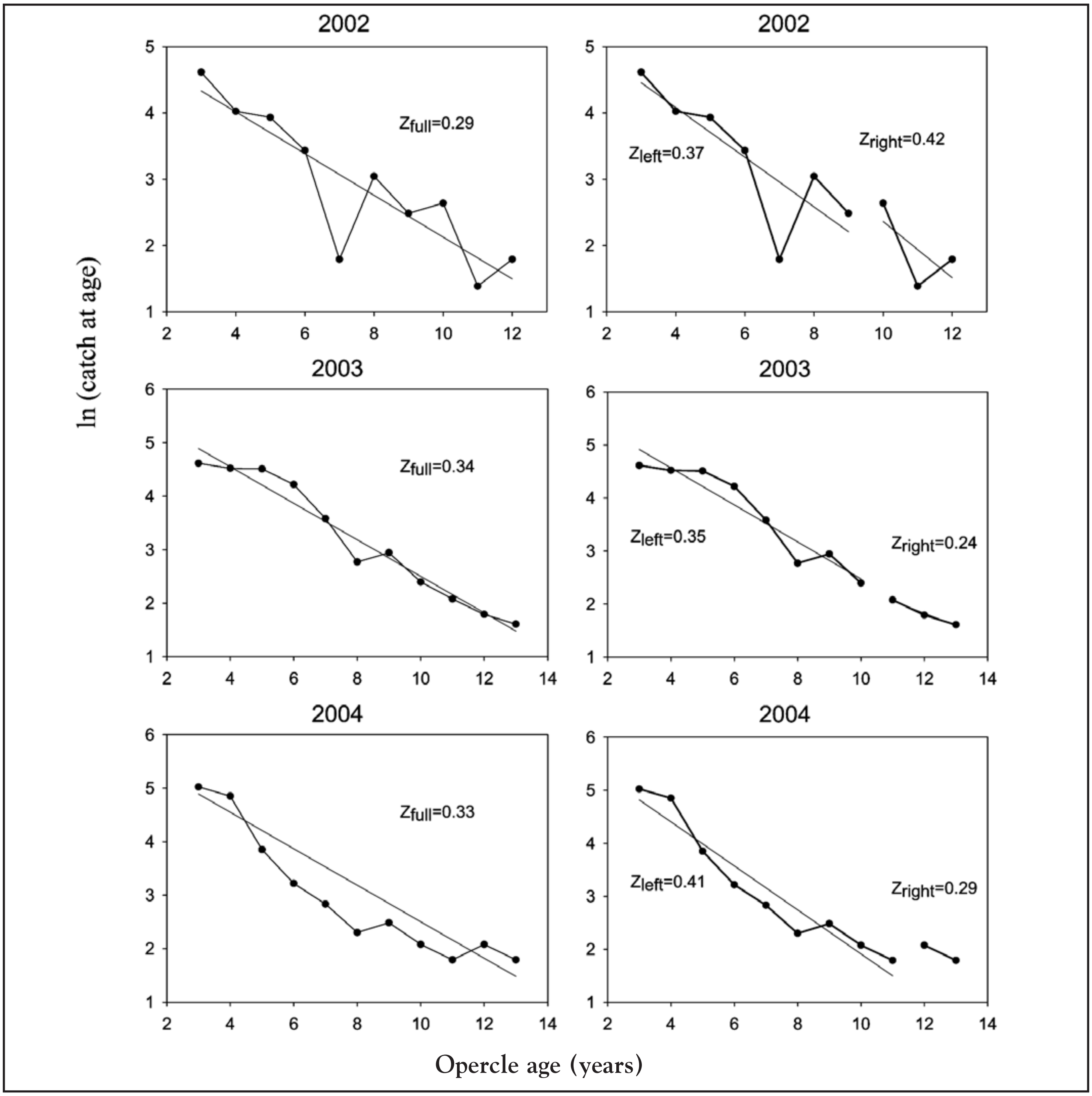
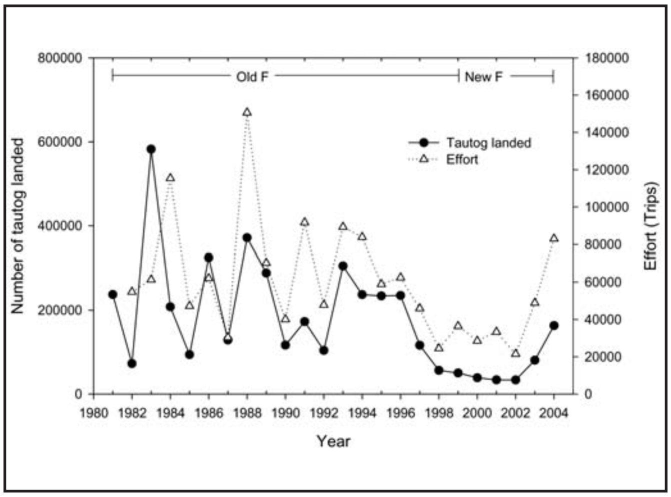


Table 3. Total instantaneous mortality estimates (Z_{full}) and non-equilibrium total instantaneous mortality estimates for recent years (Z_{left}) and earlier years (Z_{right}) for Virginia tautog from 1997 through 2004 (excluding 1998). Age of full recruitment is assumed equal to the highest observed catch-at-age (Peak) or the oldest observed peak for all years (Age 5). Bold faced values are above ASMFC target Z=0.44 (F=0.29 and assumed M=0.15). Note that estimates for 1998 are not shown because only 51 fish were aged. Effort is estimated from the Marine Recreational Fisheries Statistics Survey.

		Age of full recruitment to fishery							
	Bend located	Peak			Age 5				
Year	at age	Z_{full}	Z_{left}	Z_{right}	Z_{full}	Z_{left}	Z_{right}	# Aged	Effort
1997	NA	0.42	NA	NA	0.42	NA	NA	~500	45,938
1999	6	0.39	0.22	**0.51**	**0.49**	**0.51**	**0.51**	267	36,368
2000	7	0.26	0.18	**0.48**	0.24	0.13	**0.48**	181	28,499
2001	8	0.39	0.40	0.30	0.39	0.40	0.30	293	33,290
2002	9	0.29	0.37	0.42	0.28	0.33	0.42	372	21,474
2003	10	0.34	0.35	0.24	0.37	0.43	0.24	510	48,890
2004	11	0.33	0.41	0.29	0.23	0.31	0.29	443	82,959

Figure 7. Combined effort and landings data for Virginia tautog from commercial and recreational catch from 1981 through 2004. Marine Recreational Fisheries Statistics Survey data include an assumed 2.5% post-release mortality. "Old F" refers to the mortality rate experienced by Virginia tautog under greater fishing pressure prior to rule changes in 1998, whereas "New F" refers to current estimates of fishing mortality associated with lower fishing effort.



the target value established by the ASMFC in all areas and the regulations may not be conservative. On the other hand, if Virginia's mortality rates are the same as values obtained through VPA, then not reducing effort in Virginia may result in sub-stock depletion. Managers are faced with the choice between results and risks from a detailed stock analysis (VPA) that may not be applicable in all areas and a less detailed analysis (non-equilibrium cross-sectional catch curve) that leaves some uncertainty with respect to the cause of the resulting estimated parameters. This uncertainty is minimized by considering additional information such as effort data and tag returns. Our contention is that if real biological differences exist between sub-stocks, then applying results obtained from the more sophisticated model may not achieve management goals, but that the less detailed analysis may provide additional information and help clarify management options. For tautog, the evidence supports local populations of adult tautog throughout their range and suggests mixing only during the pelagic, larval stage. If the local fishing mortality rate is high and recruitment is low, then local depletion is possible. Recovery is probable given the lack of genetic and biological differences observed, however it may take a number of years. The example of using cross-sectional catch curve analysis to evaluate tautog in Virginia provides a real-world application of two methodologies that have different data requirements and assumptions and demonstrates the risks associated with assessment and management decisions. In the case of tautog, where spatial scale appears to matter, the simple, yet spatially explicit model (catch curve analysis) provided details that were obscured by the more sophisticated model (VPA).

POSTSCRIPT

The latest assessment of the stock complex includes results of VPA, catch curve analysis and other methods because it was recognized that spatial scale may be important. For example, Rhode Island used a biomass dynamic model, Connecticut investigated trends using harvest values and survey indices, New York examined harvest trends, while New Jersey and Delaware conducted cross-sectional and longitudinal catch curve analyses (ASMFC 2006). The Tautog Review Panel encourages states to develop local stock assessments using appropriate models, with caution due to the lack of data in some cases, to complement the coast-wide assessment because of the potential for sub-stock structure in this species (ASMFC 2006).

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REFERENCES

Arendt, M. D., J.A. Lucy, and **T.A. Munroe.** 2001. Seasonal occurrence and site-utilization patterns of adult tautog, *Tautoga onitis* (Labridae), at manmade and natural structures in lower Chesapeake Bay. Fishery Bulletin 99: 519-527.

ASMFC (Atlantic States Marine Fisheries Commission). 2002. Review of the Atlantic States Marine Fisheries Commission fishery management plan for tautog (*Tautoga onitis*). Report prepared by H. Stirratt (ASMFC) and the Tautog Plan Review Team (P. Caruso, D. Simpson, F. Steimle, and N. Lazar). ASMFC, Washington, D.C.

_____. 2006. Stock assessment report 06-02 (supplement) of the Atlantic States Marine Fisheries Commission. Tautog stock assessment report for peer review. ASFMC, Washington, D.C.

Briggs, P. T. 1977. Status of tautog populations at artificial reefs in New York waters and effects of fishing. New York Fish Game Journal 24(2):154-167.

Cooper, R. A. 1966. Migration and population estimation of the tautog, *Tautoga onitis* (Linnaeus), from Rhode Island. Transactions of the American Fisheries Society 95: 239-247.

_____. 1967. Age and growth of the tautog, *Tautoga onitis* (Linnaeus), from Rhode Island. Transactions of the American Fisheries Society 96: 134-142.

Hoenig, J. M., and **J. Lucy.** 2004. Project RF03-15: Determining stock status of tautog in Virginia waters using data from Virginia's fishery. Final Report to the Virginia Marine Resources Commission, Project RF03-15. Newport News, Virginia.

Hostetter, E. B., and **T. A. Munroe.** 1993. Age, growth, and reproduction of tautog *Tautoga onitis* (Labridae: Perciformes) from coastal waters of Virginia. Fishery Bulletin 91:45-64.

Myers, R. A., G. Mertz, and **J. Bridson.** 1997. Spatial scales of interannual recruitment variations of marine, anadromous, and freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 54: 1400-1407.

Olla, B. L., A. J. Bejda, and **A. D. Martin.** 1974. Daily activity, movements, feeding, and seasonal occurrence in the tautog, *Tautoga onitis*. Fishery Bulletin 72:27-35.

Orbacz, E. A. and **P. M. Gaffney.** 2000. Genetic structure of tautog (*Tautoga onitis*) populations assayed by RFLP and DGGE analysis of mitochondrial and nuclear genes. Fishery Bulletin 98:336-344.

Stephenson, R. L. 1999. Stock complexity in fisheries management: a perspective of emerging issues related to population sub-units. Fisheries Research 43:247-249.

Sogard, S. M., K. W. Able, and **M. P. Fahay.** 1992. Early life history of the tautog, *Tautoga onitis*, in the Mid-Atlantic Bight. Fishery Bulletin 90:529-539.

Waldman, J. R. 2005. Definition of stocks: an evolving concept. Pages 7-16 *in* S. X. Cadrin, K. D. Friedland, and J. R. Waldman eds. Stock identification methods. Elsevier Academic Press, Burlington, MA.

White, G. G., J. E. Kirkley, and **J. A. Lucy.** 1997. Quantitative assessment of fishing mortality for tautog (*Tautoga onitis*) in Virginia (Preliminary Report). Final Contract Report RF-96-11 to Virginia Marine Resources Commission. Newport News, Virginia.