SCRS/1989/088 Col.Vol.Sci.Pap. ICCAT, 32 (2) : 262-269 (1990)

A REVIEW OF ATLANTIC BLUEFIN TUNA LARVAL SURVEYS

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SUMMARY

The results of the larval fish surveys used to estimate the size of the spawning stock of Atlantic bluefin tuna in the Gulf of Mexico have been reviewed. These surveys have demonstrated that the Gulf of Mexico is the sole, or at least the main bluefin spawning area in the western Atlantic. They have also demonstrated that the spawning season is mainly, if not entirely, during the period April to July. Further, the results are roughly compatible with other population estimates.

However, the surveys under consideration were not designed to estimate bluefin tuna so it is not surprising that the results are demonstrably not adequate to track year-to-year changes in the spawning stock, or to calibrate or fine tune other measures of the spawning stock such as those obtainable from Virtual Population Analysis (VPA). Their primary weakness is that the surveys do not bracket the spawning in time and space. Their other weakness is the lack of the detailed biological information on growth, mortality, etc., on the larvae. This information is required on an annual basis if larval catches are to be used to accurately estimate year-to-year changes in the spawning stock. However, acquisition of this information is not practical.

Accordingly, a two-stage program is suggested. The first stage is to improve the larval tuna surveys by conducting a comprehensive survey, comprised of three cruises, bracketing the spawning season in time and space, every three years. The second stage is to change to egg surveys in order to overcome the problems inherent in using larvae. This will require development of biochemical reagents for identifying bluefin tuna eggs, and the development of surveys based on the "egg production method." Then, and only then, will maximally accurate, fishery independent estimates of spawning stock become available. In addition, there will be considerable savings over using larvae.

RESUME

On a examiné les résultats des prospections larvaires de poissons utilisés pour estimer la taille du stock reproducteur du thon rouge de l'Atlantique dans le golfe du Mexique. Ces prospections indiquent que le golfe du Mexique est l'unique, ou du moins la principale zone de ponte dans l'Atlantique ouest. Elles démontrent aussi que la saison de ponte a lieu principalement, pour ne pas dire toujours, durant la période d'avril à juillet. Par la suite, les résultats sont généralement compatibles avec d'autres estimations de population.

Néanmoins, les prospections à l'étude ne sont pas conçues pour estimer le thon rouge et il n'est donc pas surprenant que les résultats ne soient pas adéquats, tel qu'il a été démontré, pour traquer d'une année sur l'autre les changements dans le stock reproducteur ou calibrer ou trouver un ajustement d'autres mesures du stock reproducteur telles que celles obtenues à partir des Analyses des Populations Virtuelles (VPA). Leur premier défaut est que les prospections ne mesurent la ponte ni en temps ni en espace. L'autre défaut est le manque d'information biologique détaillée sur la croissance, la mortalité, etc., sur les larves. Cette information est nécessaire sur une base annuelle si les prises larvaires doivent être utilisées pour estimer de façon précise les changements d'une année à l'autre du stock géniteur. Toutefois, l'acquisition de cette information n'est pas pratique.

Par conséquent, un programme à deux étapes est suggéré. En premier lieu, améliorer les prospections larvaires de thonidés en menant à bien une prospection exhaustive, comprenant trois croisières, mesurant la saison de ponte de façon spatio-temporelle, tous les trois ans. La seconde étape est de changer à des prospections d'oeufs pour résoudre le problème inhérent d'utiliser les larves. Pour cela, il sera nécessaire de développer des réactifs biochimiques pour identifier les oeufs du thon rouge, ainsi que le développement de prospections basées sur la "méthode de production des oe ". Ensuite, et uniquement après, les estimations de la pêcherie du stock reproducteur deviennent disponibles de la façon la plus exacte. De plus, l'utilisation de larves baissera considérablement les coûts.

RESUMEN

Se revisaron los resultados de las prospecciones de larvas de peces utilizados para estimar el tamaño del stock reproductor del atún rojo atlántico en el Golfo de Méjico. Estas prospecciones han demostrado que el Golfo de Méjico es la única zona, o al menos, la mayor, de desove de atún rojo en el Atlántico Oeste. Han demostrado, asimismo, que la temporada de desove tiene lugar, principalmente, si no en su totalidad, durante el período de abril a julio. Además, los resultados son bastante compatibles con otras estimaciones de población.

No obstante, las prospecciones que se consideran no fueron diseñadas para estimar atún rojo, así que no es sorprendente que se pueda demostra que los resultados no son adecuados para hacer un seguimiento de año en año de los cambios del stock reproductor, o para calibrar o hacer ajustes finos de otras mediciones del stock reproductor, como las que se obtienen del VPA. Su principal deficiencia viene de que las prospecciones no definen el desove en tiempo y espacio. Su otra carencia es la falta de información biológica detallada sobre crecimiento, mortalidad, etc. de las larvas. Esta información se necesita sobre una base anual en el caso de que las capturas de larvas deban utilizarse para estimar de forma precisa los cambios de año en año del stock reproductor. Sin embargo, no resulta práctico obtener esta información.

Por consiguiente, se sugiere un programa en dos etapas. La primera, para mejorar las prospecciones de larvas de túnidos mediante una prospección amplia, compuesta por tres campañas, definición de la temporada de desove en tiempo y espacio, cada tres años. La segunda etapa consiste en cambiar la prospección de huevos con el fin de resolver los problemas inherentes a la utilización de larvas. Ello requerirá el desarrollo de reagentes bioquímicos para identificar los huevos de atún rojo, y el desarrollo de estudios basados en el "método de producción de huevos". Entonces, y sólo entonces, se podrá disponer de estimaciones del stock reproductor con la mayor precisión posible. Además, supondrá un importante ahorro en relación a la utilización de larvas.

INTRODUCTION

There is a long history of using egg and larval surveys as a tool for life history studies and evaluation of spawning stock size. Such surveys are attractive in a philosophical sense because they measure an important attribute of a population of fish without disturbing the organisms being measured. On a more pragmatic level the approach is considerably less expensive than any other method. However, the utility of larval surveys is limited because of the sophisticated information needed to confidently interpret the catches in terms of spawning stock size. Egg surveys are much more straightforward in this respect and less expensive.

Most of the assumptions in interpreting larval surveys do not apply to egg surveys as has been demonstrated in California. A comprehensive review of the methods developed in California with respect to the northern anchovy has been published (Lasker ed. 1985). All of the biological parameters, except predation, required to interpret the egg catches can be related to water temperature, which of course can easily be measured at the time of the egg collection. Predation can be ignored because of the short time between spawning and hatching for most pelagic eggs. Nasty questions such as dodging are avoided entirely.

Despite attempts by highly qualified scientists to identify Atlantic bluefin tuna eggs by morphological characteristics, it has not been possible to separate them from other round eggs. Hence the present use of larval surveys because all tuna larvae are reasonably easy to identify. However, there is a very real probability that modern biochemical methods can be applied to provide rapid, definitive identification of bluefin eggs from plankton samples.

Finally, it should be noted that most, if not all, of the substance of this report has been anticipated in one form or another by the results of a recent review of the bluefin tuna larval assessment program (Panel 1989).

HISTORICAL REVIEW

The first solid evidence that the Gulf of Mexico was an important spawning ground for the Atlantic bluefin tuna in the western Atlantic was developed by Cuban scientists (Juarez 1974) who had available the results of a wide-ranging systematic survey of the Gulf of Mexico. Some of their results were discussed by Richards (1976) who added new data from the western Gulf in Richards (1977).

The Gulf-wide data were analyzed in some detail in Montolio and Juarez (1977). They presented the results of the grid of plankton stations that covered all of the non-shelf area of the Gulf of Mexico during May and June of 1974. They interpreted the data using the methods of Sette and Ahlstrom (1948). In addition, because they were working with larvae instead of eggs, they employed a range of mortality, and average larval age, in order to estimate the spawning stock. This resulted in a wide range of estimates of the spawning biomass (their Table 4) from which they selected 6,515 to 18,367 metric tons (MT) as the range most likely to include the true value.

This work seems to have been ignored in later papers, although the estimates of spawning biomass, while lower than most of the later estimates, are compatible with them when properly adjusted, given the wide variances of all of the larval estimates as demonstrated by later studies, e.g., McGowan and Richards (1986, 1987).

Subsequent to the work discussed by Juarez (1974), larval surveys were conducted in the Gulf of Mexico by United States and Mexican laboratories. Many, if not most of these, were multipurpose surveys, often resulting in station patterns not well suited to evaluating the bluefin spawning stock even on a relative basis. The results of these cruises were considered in a number of papers, e.g., Richards and Potthoff (1980), Richards, Potthoff, and Houde (1981), Richards, McGowan and Ortner (1983), and McGowan and Richards (1986, 1987). These papers in effect supersede the earlier papers in that all years except 1974 are considered and more sophisticated statistical estimation procedures (Pennington 1983) are applied, but basically the analyses are also a variant of the approach of Sette and Ahlstrom (1948).

McGowan and Richards (1986) paper, in addition to applying more advanced statistical procedures, recognizes many of the factors that are not known, or not well enough known to develop a precise index of larval abundance from which an estimate of relative or absolute spawning stock size could be developed.

In their introduction they note inadequate knowledge of the batch fecundity of bluefin, temperature and age dependent growth and mortality rates of larvae, rates of extrusion and escapement of larvae, shrinking of larvae during capture and preservation, and incomplete sampling of the spawning area and seasonal factors that limit the precision of present estimates of spawning stock. Nevertheless they conclude, "Therefore the larval survey data can be an index of an estimate of stock size, given complete sampling coverage, better knowledge of life-history parameters of the bluefin, and estimates of plankton net sampling bias for bluefin larvae."

The primary basis of this conclusion is the apparent consistency of the larval results with VPA estimates (their Figure 17). In the figure there are five years that permit comparison of the larval estimate with the VPA estimate. Of these five years, the authors suggest that sampling was inadequate during two. Of the remaining three years, the VPA spawning stock is higher in two years and lower in one. This suggests that the larval surveys are providing estimates that are compatible with VPA, but does not suggest they provide a basis for adjusting VPA.

Some of the more important results of the several larval surveys are collected in Table 1. The table is not comprehensive. It is presented to give summary results and some indication of the statistical variation of those results.

The 1974 value was obtained by adjusting the results of Montolie and Juarez (1977) as follows: their tabulated result was used for mean larval age of 7 days and Z=.8 to approximate the several values used by McGowan and Richards (1986). This value was adjusted upward by .56/.41 to compensate for the difference in assumed sex ratio. Finally, their result was further raised by 60/22 because the earlier study integrated the

TABLE 1

ESTIMATES OF THE GULF OF MEXICO BLUEFIN TUNA SPAWNING STOCK

The 1974 value is derived from Montolie and Juarez (1977). The remaining entries are taken from McGowan and Richards (1986) and McGowan and Richards (1987).

Years	Metric Tons	Coefficient of Variation	
1974	24,500	-	
1977	37,600	0.281	
1978	97,700	0.206	
1981	46,400	0.206	
1982	24,300	0.282	
1983	19,000	0.400	
1984	8,100	0.3201	
1986	9,600	0.3901	
1977-1986	34,700	0.2979	MEAN

result only over the duration of the single cruise rather than the estimated duration of the spawning season. In the absence of individual station results it was, of course, impossible to compute any statistics. Higher values for 1983 were obtained by McGowan and Richards (1986, 1987) by extrapolating the 1983 results. Their published values are 45,519 MT (McGowan and Richards 1986) and 39,623 MT in McGowan and Richards (1987). No explanation is given for the difference so the higher estimates for that year were not included in Table 1.

A crude estimate of the general reliability of the several estimates of the spawning stock can be obtained by applying 2.5 times the mean coefficient of variation to the mean of the five surveys from which the statistics were derived. From this, 95 percent confidence limits of 8,900 to 60,500 MT result. These limits embrace all but the 1978 and 1984 estimates, suggesting that most of the observed variation cannot be interpreted as real changes in the spawning stock. The 1978 estimate of 97,700 MT is well outside the limits, but re-examination of the two papers originally reporting those results does not suggest an explanation except that the survey caught large numbers of larvae at "many" stations during the 1978 cruise that covered the entire Gulf. Perhaps the cruise coincided with the peak of the spawning season.

The useful conclusions are that the larval surveys do strongly confirm the Gulf of Mexico and adjacent waters as the main, if not the only, bluefin tuna spawning ground in the western Atlantic, and the results give general support to other measures of the magnitude of the spawning stock such as those resulting from VPA. The spawning stock estimates from larvae are not, however, sufficiently precise to form the basis of management decisions or to calibrate other measures, e.g., VPA. This conclusion is suggested from even a cursory examination of

Table 1 because a spawning stock comprised of 10 or so age classes cannot vary from year to year in the erratic manner of these larval survey results. A particularly glaring discrepancy is the dramatic fall in the estimated spawning stock between 1983 and 1984 (11,000 MT using the low estimate for 1983). This is not even remotely compatible with the 1983 total allowable catch (TAC) of bluefin of 2,660 MT.

The report of the panel established in 1989 to review the bluefin larval assessments (Panel 1989) suggests another possibility for the general downward drift in larval bluefin tuna catches. They note, item 5, p.3 that, "The seasonal timing of surveys appears to have shifted (to later in the spawning season) over the years." Such a shift might easily result in the apparent decline in larvae by sampling the downward shoulder to the spawning season. Under the present regime of extracting bluefin data from surveys with broader, or different objectives, these problems can only be noted, but noted with the caution that the results cannot be taken too seriously.

INFORMATION REQUIRED TO USE LARVAL SURVEYS FOR POPULATION ESTIMATION

This section expands on the information requirements that must be met if larval data are to be used to estimate spawning biomass. They are the same requirements listed by McGowan and Richards (1986).

Batch fecundity. This is relatively easy to obtain. More difficult is the estimation of batch spawning frequency, or the time interval between batches. When this problem is studied, the frequency of spawning is usually found to be much greater than estimated from an examination of an excised ovary.

Temperature and age dependent growth. In principle this can be determined by laboratory studies, but evaluating the effect of the ambient food supply would require a massive effort each year.

Temperature and age dependent mortality. This is very difficult to evaluate. The value used by Richards, et al. (1981) is an educated guess based on other species reported on by Dahlberg (1979). In any event, the rate must vary over time and space. Lower temperatures reduce development and growth lowering the possibility of starvation, but prolonging the larval life, prolongs the relatively helpless larval stages, possibly resulting in dramatic increases in predation mortality, as discussed in Murphy (1961, p.68). While predation mortality cannot be measured directly, starvation mortality can now be measured with considerable precision using biochemical methods (Hakanson 1989 a,b).

Extrusion and escapement of larvae. These factors can be estimated in a straightforward manner. Extrusion can be estimated by appropriate double net experiments, and escapement can be examined by comparing towed net catches with the catches of other types of nets, e.g., plankton purse seines (Murphy and Clutter 1972).

Incomplete sampling of the spawning area and season. This is an absolute requirement because no amount of statistical finesse can rescue a survey that does not bracket the spawning in space and time. As already noted, much or most of the present bluefin larvae data has been obtained from multipurpose cruises obviously not designed to target on bluefin. This problem may be resolved at a relatively minimum cost. Annual bluefin tuna larval surveys are probably not needed because of the large number of age classes in the spawning population. That is, because of the large number of age classes in the spawning stock, it is relatively immune to year-to-year fluctuations caused by year class fluctuation. Under this circumstance comprehensive surveys at two- or three-year intervals would be considerably more useful than incomplete annual surveys.

PROGRAMMATIC RECOMMENDATIONS

In this section the most important results of this review are consolidated in the form of three recommendations to be applied sequentially, although it would be more efficient, in terms of producing the most useful results in a timely manner, to act on one and two simultaneously. Research funds are in short supply; however, in the long term there should be considerable savings. In the short term, with the exception of item two, there should be no increase over today's costs. Also, the recommendations are directed to ICCAT scientists generally rather than to particular country scientists.

1. As an interim measure, develop a standard bluefin tuna sampling grid that is covered by three cruises every three years, patterned so that the spawning is bracketed in space and time. While the present opportunistic pattern has yielded very useful results, e.g., definition of the spawning area and spawning season, it is unlikely to be of further use. This new program should yield data that provide more realistic relative estimates of the spawning stock. It would lay a foundation for item 3. It must be emphasized that while this approach overcomes the single most serious defficiency in the present surveys, there remain the several variables that would have to be estimated annually, e.g., larval mortality, in order to develop accurate annual estimates.

2. By contract with a suitably talented and equipped laboratory, develop the biochemical reagents and protocols needed to positively identify Atlantic bluefin tuna eggs. It has been suggested that this is very feasible, and would cost about US$75,000. However, the reagents that would be developed have an indefinite shelf life making this, in effect, a one-time expense.

3. After item 2 is complete, change the larval surveys to egg surveys. National Marine Fisheries Service scientists at the Southwest Laboratory have either developed, or been instrumental in the development of the egg production method for estimating the spawning biomass of pelagic fish. They should be co-opted to establish the sampling grid(s), estimate batch fecundity, establish the initial laboratory protocols, and establish the procedures for interpreting the results. Relevant ICCAT scientists should prescribe the desired precision of the results, work with them, and gradually assume responsibilty for the program.

CONCLUSIONS

The main conclusion of this review is that the results of cruises not designed to estimate bluefin tuna larvae cannot be used to estimate annual variations in spawning stock, or to adjust other estimates of spawning stock such as VPA.

The secondary conclusion is that unbiased but not necessarily adequate data can be obtained by comprehensive larval surveys every three years.

And finally, the very best estimates can be obtained by developing egg surveys designed to utilize the "egg production method."

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OCTOBER 1989