SCRS/2013/077 Collect. Vol. Sci. Pap. ICCAT, 70(1): 289-298 (2014)

ON THE NATURAL MORTALITY OF EASTERN AND WESTERN ATLANTIC BLUEFIN TUNA

Alain Fonteneau[1] and Jean-Jacques Maguire[2]

SUMMARY

This paper discusses the heterogeneity in the natural mortality at age presently assumed in the SCRS bluefin stock assessment of the eastern and western stocks. Based on the biological literature on natural mortality at age, the conclusion is that the constant natural mortality assumed in the western Atlantic Ocean is not realistic. Furthermore, the paper considers that it is not realistic to assume that natural mortality of bluefin crossing 45°W longitude would show major changes in their natural mortality. The paper recommends that future bluefin stock assessments should use a common best natural mortality at age, for instance at levels estimated by the Lorenzen or the Gislason methods. It also recommends developing more research on the potential increase of natural mortality for ageing bluefin, as this factor would condition the dynamics of the spawning stock.

RÉSUMÉ

Le présent document aborde l'hétérogénéité de la mortalité naturelle par âge actuellement postulée dans l'évaluation des stocks de thon rouge de l'Est et de l'Ouest réalisée par le SCRS. Sur la base de la littérature biologique portant sur la mortalité naturelle par âge, la mortalité naturelle constante postulée pour l'océan Atlantique Ouest n'est pas réaliste. De plus, le document considère qu'il n'est pas réaliste de postuler que la mortalité naturelle du thon rouge traversant 45ºW de longitude présenterait des changements profonds de mortalité naturelle. Le document recommande que les prochaines évaluations de stock de thon rouge utilisent la meilleure mortalité naturelle par âge commune, par exemple à des niveaux estimés par les méthodes de Lorenzen ou Gislason. Il est également recommandé de réaliser davantage de travaux de recherche sur l'accroissement potentiel de la mortalité naturelle pour déterminer l'âge du thon rouge, car ce facteur conditionnerait les dynamiques du stock reproducteur.

RESUMEN

En este documento se debate la heterogeneidad en la mortalidad natural por edad asumida actualmente en la evaluación del SCRS de los stocks oriental y occidental de atún rojo. Basándose en la bibliografía biológica sobre mortalidad natural por edad, la conclusión es que la mortalidad natural constante asumida en el océano Atlántico occidental no es realista. Además, el documento considera que no es realista asumir que el atún rojo que cruza la longitud 45ºE pueda mostrar cambios importantes en su mortalidad natural. En el documento se recomienda que las futuras evaluaciones de stock de atún rojo utilicen una mortalidad natural por edad común mejor, por ejemplo en los niveles estimados mediante los métodos Lorenzen o Gislason. También se recomienda que se desarrollen más trabajos de investigación sobre el potencial incremento de la mortalidad natural para determinar la edad del atún rojo, ya que este factor condicionaría la dinámica del stock reproductor.

KEYWORDS

Bluefin, West Atlantic, Natural mortality, Age, Senescence

[1]Alain Fonteneau, IRD EMERITUS scientist, 9 Bd Porée, 35400 Saint Malo, France; alain.fonteneau@ird.fr
[2]Jean Jacques Maguire, Halieutikos Inc.

1. Introduction

Natural mortality at age is a biological parameter of key importance in analytical stock assessment. During the Lake Arrowhead 1984 tuna Conference, natural mortality was identified[3] as the single most important but least well-estimated parameter in tuna fishery models (Vetter 1987). There is no doubt that this 1984 conclusion remains fully valid in 2013!

For instance, this biological parameter conditions the fishing mortality at age, the longevity of the modelled population, the interaction between fisheries and the potential spawning biomass. Another point to keep in mind is that this biological parameter remains very difficult to estimate. As a consequence, many estimates of natural mortality used by tuna RFOs are "guesstimates" or borrowed from other tuna commissions - very seldom are they obtained from statistical analysis of field data or experiments.

Such major uncertainties clearly apply to the Atlantic bluefin stock assessments, but, surprisingly, they are not reflected in the ICCAT assessments: most of the recent SCRS reports during recent years on bluefin are not discussing the basic uncertainties in the natural mortality at age used in their bluefin stock assessments. The uncertainties linked to the values of M used are seldom/never estimated and the recent SCRS reports never discuss the importance of this basic major uncertainty.

More importantly, recent bluefin stock assessments western Atlantic vs eastern Atlantic and Mediterranean stocks are widely different (**Figure 1**), a fact that may have not been noticed by several readers of SCRS reports (e.g. ICCAT 2012).

Sizes of the population at age will be of course widely different, as shown by **Figure 2**, for the same recruitment of 2 populations showing these 2 levels of natural mortality at age.

The main goal of this paper is to discuss the estimates of natural mortality assumed in the two Atlantic bluefin tuna assessment units, to consider using a common best natural mortality in both assessment units and to explore the consequences of these alternate and biologically more realistic patterns of M at age in the future ICCAT BFT stock assessments.

2. On the heterogeneity of natural mortality at age in the Eastern & Western Atlantic bluefin tuna stock assessments

The origins of the natural mortality presently assumed are distinct ones:

- M at age assumed for the Eastern stock is based on the M at age estimated for southern bluefin based from tagging experiments. The natural mortality vector for East Atlantic and Mediterranean bluefin tuna is variable as a function of age, declining from M=0.4 for class 0 BFT towards M=0.10 at an age of 9 years and older.

- M at age assumed for the Western stock is constant at 0.14 per year. The origin of this value is not clear (cf an. ICCAT 1999); there is no reference to natural mortality of bluefin in the Mather et al 1995 paper. The ICCAT bluefin meeting in 1983 suggested that Atlantic bluefin tuna stock assessments could use M in the range 0.10 to 0.18 without having to provide justifications. It seems that in later assessments, the average of these two values was chosen to avoid having to examine runs with two different assumptions about M. It should also be noted that surprisingly this rather magic constant M=0.14 has been accepted and used without real discussions upon its validity by the excellent NRC report (An. 1994). At the time that M was changed in the Eastern Atlantic and Mediterranean favouring the Ms estimated by tagging for southerm bluefin, tagging data for the Western Atlantic did not indicate that M on younger bluefin tuna was higher than for older ages. However, at least to our knowledge, this very important result that natural mortality of juvenile BFT in the Western Atlantic was constant and low, has not been statistically validated nor published in a rank A journal, or even in an ICCAT scientific document.

[3] Among the scientists involved in this conclusion : Chris Boggs, Andy Dizon, John Hoenig, Pierre Kleiber, Robert Olsen,

a) It seems unrealistic that the same species of tuna would show such major differences in the absolute value of natural mortality and its age specific patterns, especially taking note of the great similarity of growth that are now estimated in both sides of the Atlantic, and keeping in mind that many bluefin are crossing the E-W frontier.

b) That the natural mortality of the western bluefin would be the same during the entire life of the bluefin, being identical for a 0.5 kg age 0 fish or for a 500 kg giant bluefin.

Most biological studies on natural mortality show (for instance MacGurk 1986, Peterson and Wrobleski 1984, Gislason 2010, Lorenzen 1996), a basic variability of this natural mortality as a function of increasing sizes and ages, showing (1) either an exponential decline or (2) a U shape profile due to senescence of aging individuals experiencing higher rates of natural mortality.

Three examples of the typical patterns of natural mortality as a function of size or age from the literature are shown in **Figure 3a to 3c**. To our knowledge, there is no biological study on any terrestrial or marine animal's constant natural mortality for a very wide range of sizes, as the one presently that has been constantly assumed for the western bluefin stock since 1985?

Anecdotic ally, in the case of a migratory species such as bluefin tuna, it is amusing to think that natural mortality could be increasing or decreasing steeply, when these tunas cross the legal ICCAT 45°W frontier to change from one assessment unit to the other. Transatlantic recoveries of bluefin smaller the 120 cm have been noted in the history of ICCAT tagging in both directions westward & eastward (see **Figure 4**, made from the ICCAT recovery file).

Natural mortality assumed for these small bluefin, an average M=0.26 in the Eastern Atlantic and Mediterranean, i.e. 23 % of each cohort dying each year because of this natural mortality, and M=0.14 in the Western Atlantic, i.e. only 13 % dying due to M. As indicated above, this implies that when these bluefin tunas cross the ICCAT boundary, their natural mortality would be multiplied or divided by a factor of nearly 2. It should be noted that natural mortality of class 0 Pacific BFT has been estimated by tagging to be much higher ranging between 1.8 and 2.1 (Itawa 2012) (87% of the population dying yearly of natural mortality at such M=2.1). The same variation in natural mortality at age would be implied for adult bluefin that are seasonally migrating each year in the north Atlantic. The seasonal distribution of Atlantic bluefin tuna can be inferred from the seasonal distribution of Japanese longliners during the November to February period, see **Figure 5**.

These changes in the bluefin fishing areas are probably reflecting real and strong seasonal counter clock movement of bluefin tunas, with significant catches taken in the Western Atlantic between December & March on tunas probably migrating from the Eastern stock. It is highly unlikely that natural mortality on those migrating tunas would change when these tunas are moving to the western Atlantic in December & crossing the 45° W ICCAT frontier and the opposite when they return to the Eastern Atlantic, an unrealistic biological hypothesis. If such an unlikely implicit hypothesis is kept and used by SCRS, it needs to be clearly explained and justified in all the SCRS reports, targeting ICCAT commissioners.

Bluefin ageing & senescence? The possibility that M increases at older ages should also be seriously considered: most of the biological studies mentioned above indicate that the older fraction of the adult population often suffers increasing natural mortality rates:

a) due to long and rapid spawning migrations and to the great quantity of energy spent for spawning.

b) due to ageing and senescence: gradual senescence of the bodies and subsequent increase of natural mortality at increasing ages can be observed for most living terrestrial creatures: humans, elephants, cats and dogs, etc. Some species of fishes do not show any sign of senescence and can reach very old ages, well over 50 years (sturgeon , various species of Sebastes), but they seem to be the anomalies in the living world where senescence appears to be a logical and universal biological factor controlling most population sizes (Finch 1990). The general rule of a logical U shape natural mortality at increasing age due to an aging process should at least be envisaged as being an alternate working hypothesis. This pattern and its underlying potential causes are summarized in **Figure 6**.

Increased natural mortality due to ageing and senescence has never been evaluated for tunas, mainly due to the lack of studies and to the difficulty to evaluate natural mortality in the marine world. Ad hoc biological studies conducted by scientists who are expert in senescence should be recommended to study the potential ageing of bluefin tuna, for instance trying to identify the biological causes of increased natural mortality faced by old individuals, for instance: loss of thermoregulation, liver condition, increased parasites, status of gonads, lipids, arthritis, degradation of visual capabilities, etc. Without waiting for the results of these investigations, the biologically reasonable hypothesis that natural mortality of old bluefin may be slowly increasing should also be envisaged, e.g. in sensitivity analysis.

3. Proposal for a common natural mortality at age used for the two bluefin assessment units

Given that size at age is now considered to be very similar for the two assessment units, it seems unlikely that natural mortality differs widely between the two assessment units and given general biological knowledge, it also seems highly unlikely that the Western Atlantic natural mortality is low and stable over all the size range.

Based on our experience in tuna biology, we suggest that the Lorenzen method based on the longevity and on the growth curve of the species (Lorenzen 1996) should be used to estimate trends of natural mortality at age. The results for the western Atlantic bluefin tuna assessment unit are shown in **Figure 7** along with the values currently used and those used for the Eastern Atlantic and Mediterranean assessment unit.

This natural mortality at age estimated by the Lorenzen method appears to be quite similar to those presently assumed in the Eastern Atlantic (based on southern bluefin estimates). Furthermore, it is somehow logical that natural mortality of small immature bluefin should be higher than natural mortality of the very large spawners, as clearly they have few potential predators. In our mind, the declining pattern of M at age estimated by the Lorenzen method (Lorenzen 1996) would appear to be more logical and more realistic than the arbitrarily constant M presently assumed for ages 2 and 5 years in the Eastern Atlantic: there is a logical decline of M at age between an age 2 BFT (50 kg) and an age 5 BFT (120 kg).

4. Towards alternate alternate natural mortality at age?

To illustrate the implications of using for western Atlantic bluefin tuna the same M at age vector as used for the east Atlantic and Mediterranean cohort analysis (Pope 1972) was calculated using as input values the catch at age (1970 to 2011) and F at age (all ages in 2011 and oldest age for all years) from the most recent assessment to reconstruct the population at age table assuming that M at age is the same in the west as in the east Atlantic and Mediterranean. To verify that the calculations were correct, the reconstruction was first done using M=0.14 for all ages as in the SCRS assessment.

Figure 8 shows that the cohort approximation used (Pope 1972) provides estimates of recruits very similar to those in the SCRS assessment. Assuming M at age as in the east Atlantic and Mediterranean assessment results in higher absolute estimates at age 1, but the relative year class strengths are the same. Using the east Atlantic and Mediterranean M at age for the western Atlantic bluefin tuna therefore only scales up significantly the recruitment at age 1, but does not alter the relative strength of the year classes when using terminal fishing mortalities from the most recent SCRS assessment.

Note that the difference in numbers at age is expected to be largest for the youngest age. **Figure 9** below shows that at age 5, population estimates assuming M=0.14 for all ages or M equal to the M at age in the east Atlantic and Mediterranean results in very similar population estimates. Given that the using different Ms at age scales up the recruitment but does not changes substantially population estimates at age 5 we could expect the stock and recruitment scatter plot to remain substantially similar, but with higher absolute values of recruitment. This change would modify the yield per recruit and the intercation between fisheries targeting juvenile and adult bluefin: the new Mi producing lower negative impact of fisheries targeting juveniles, because of the increased recruitment.

5. Conclusion & recommendations

Our conclusion is that the possibility that M at age for both assessment units follows the pattern estimated by the Lorenzen method should be seriously investigated. Our conclusion and recommendation would be that:

a) Identical natural mortality should be used in the Eastern & Western Atlantic, as there is no biological reason to assume widely different vectors of natural mortality at age for the same migratory species living in similar ecosystems.

b) Biologically well founded natural mortality at age should be used in all the base case assessments. The pattern of M at age estimated by the Lorenzen method would appear to be providing such a realistic and biologically sensible working hypothesis. The Ms at age estimated for SBT should also provide a realistic Atlantic wide natural mortality, unless it could be demonstrated by a well founded quantitative analysis e.g. of tag recoveries that natural mortality of young BFT was low and constant in the Western Atlantic.

c) Due to the major structural uncertainties and to the importance of this parameter, extensive sensitivity analysis should also be conducted using alternate vectors of M at age, e.g. the higher M at age from the Gislason 2010 method. Natural mortality patterns assuming increasing M for old bluefin should also be envisaged, in order to better evaluate the uncertainties in the assessment results due to such logical aging process.

d) Active biological investigations should be recommended by SCRS and preferably included in the GBYP, in order to better estimate juvenile natural mortality and also to study the potential senescence and increase of natural mortality of adult bluefin. This biological program on BFT senescence should be quite easy to run, keeping in mind that the tuna farms make it easy to obtain the samples that are needed in a wide range of adult bluefin sizes that are needed for these investigations. These studies should preferably be conducted by experts in senescence and not by SCRS scientists (as they are not expert in senescence).

Cited literature

Finch, C. E. 1990. Longevity, senescence and the genome. The university of Chicago press. 922p.

Fonteneau A. and P. Pallares 2004. Tuna natural mortality as a function of their age: the bigeye tuna case Col.Vol. Sci. Pap. ICCAT, 57(2).

Fromentin J.M. 1998. Bluefin stock assessemnt in the north east Atalntic: difficulties related to data, knowledge and knowledge. Col.Vol.Sci.Pap. ICCAT, 49 (2) : 388-399.

Fromentin J-M, Powers JE (2005) Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. Fish and Fisheries 6: 281–306.

Gislason H., N. Daan, J.C. Rice & J. G Pope. Size, growth, temperature and the natural mortality of marine fish, 2010. FISH and FISHERIES , 11, 149–158.

Hampton J. 1991. Estimation of Southern Bluefin Tuna *Thunnus maccoyii* natural mortality and movement rates from tagging experiments. Fishery Bulletin US, 89:591-610.

Hampton J. 2000. Natural mortality rates in tropical tunas: size really does matter. Can. J. Fish. Aquat. Sci.. Vol. 57, no. 5, pp. 1002-1010.

Hearn, W.S., R.L. Sandland, and J. Hampton. 1987. Robust estimation of the natural mortality rate in a completed tagging experiment with variable fishing intensity. J. Cons.CIEM, 43:107–17.

ICCAT 1994 Assessment of Atlantic Bluefin Tuna. National Research Council report, National Academy Press, 167 p.

ICCAT. 1999. 1998 SCRS Detailed Report on Bluefin Tuna. Collect. Vol. Sci. Pap, ICCAT, 49: 1-191.

ICCAT. 2012. Report for biennial period, 2012-2013, PART I, Vol. 2.

Iwata S., K. Fujioka, H. Fukuda and Y. Takeuchi. 2012. Reconsideration of natural mortality of age -0 Pacific bluefin tuna and its variability relative to fish size. ISC/12-1/PBFWG/13

Leigh, G.M. 1988. A comparison of estimates of natural mortality from fish tagging experiments. Biometrika, 75:347–53.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in fish: a comparison of natural ecosystems and aquaculture. J. Fish Biol. 49: 627–647.

Mather, F.J., J.M. Mason, and A.C. Jones. 1995. Historical document: life history and fisheries of Atlantic bluefm tuna. NOAA Technical Memorandum NMFS-SEFSC - 370; 165 pp.

McGurk 1986. Natural mortality of marine pelagic fish eggs and larvae: Role of spatial patchiness. Marine ecology progress series, vol. 34, no. 3, pp. 227-242, 1986

Pauly D. 1980. On the interrelationship between natural mortality, growth parameters and mean temperature in 175 fish stocks. J.Cons. int. Explor. Mer, 39(2):175-192.

Peterson I. and S. Wrobleski. 1984. Mortality rate in the pelagic ecosystem. Can. J. Fish. Aquat. Sci. 41: 1117-1120.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Res. Bull. Int. Comm. Northwest Atl. Fish. 9: 65-74.

Reznick D., C. Ghalambor and L. Nunney. The evolution of senescence in fish. Mech Ageing Dev.; 123(7): 773-789.

Simon M, Fromentin J-M, Bonhommeau S, Gaertner D, Brodziak J, et al. (2012) Effects of Stochasticity in Early Life History on Steepness and Population Growth Rate Estimates: An Illustration on Atlantic Bluefin Tuna. PLoS ONE 7(10)

Vetter E. F. 1987. Estimation of natural mortality in fish stocks: a review. Fisheries Bulletin 86:25-43.

Whitlock R., M. McAllister and B.A. Block. 2011. Estimating fishing and natural mortality rates for Pacific bluefin tuna (*Thunnus orientalis*) using electronic tagging data. Fisheries Research, Vol. 119-120 Pages: 115-127

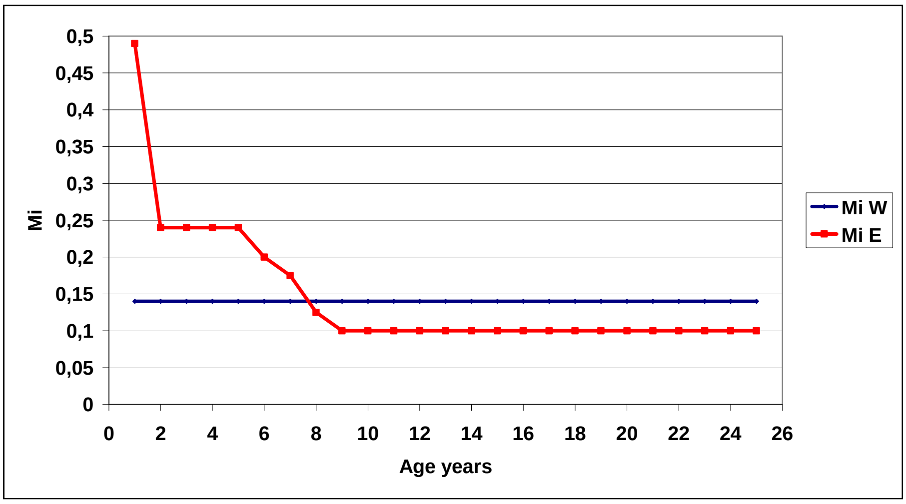


Figure 1. Natural mortality presently assumed for the eastern and western Atlantic bluefin stocks.

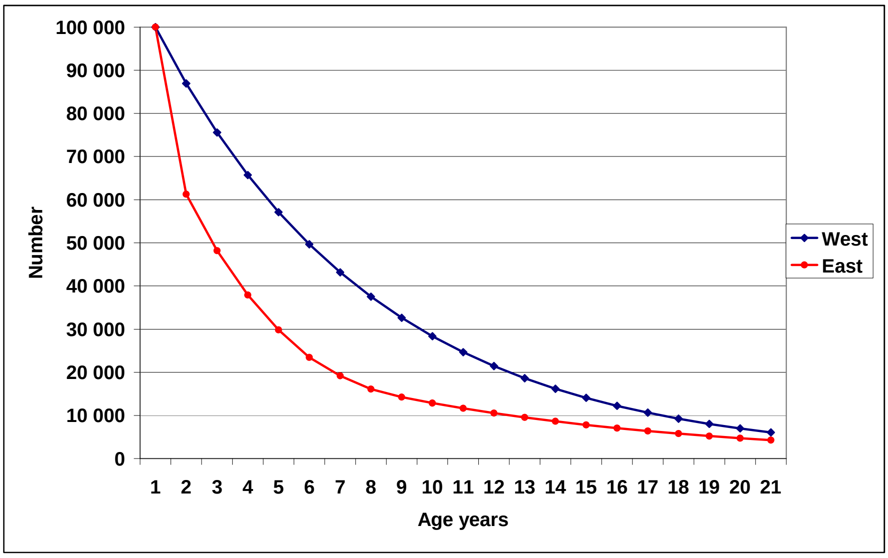
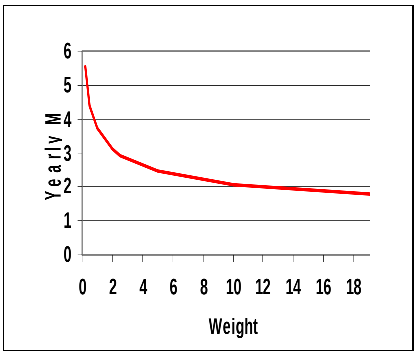
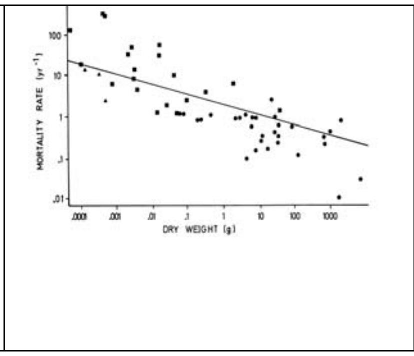


Figure 2. Yearly populations sizes estimated from a given recruitment under each hypothesis of eastern & western Atlantic BFT natural mortality.





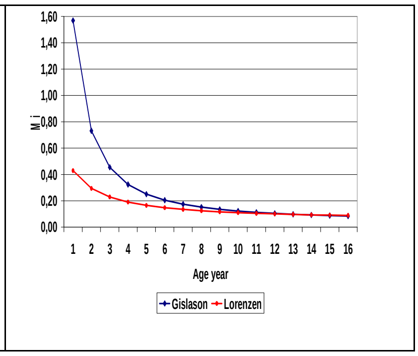


Figure 3a. Natural mortality estimated by Mac Gurk 1986 as a function of individual weight.

Figure 3b. Natural mortality of pelagic fishes estimated by Peterson and Wroblewski 1984 as a function of sizes

Figure 3c. Natural mortality at age of bluefin estimated by the Gislason 2010 & the Lorenzen methods

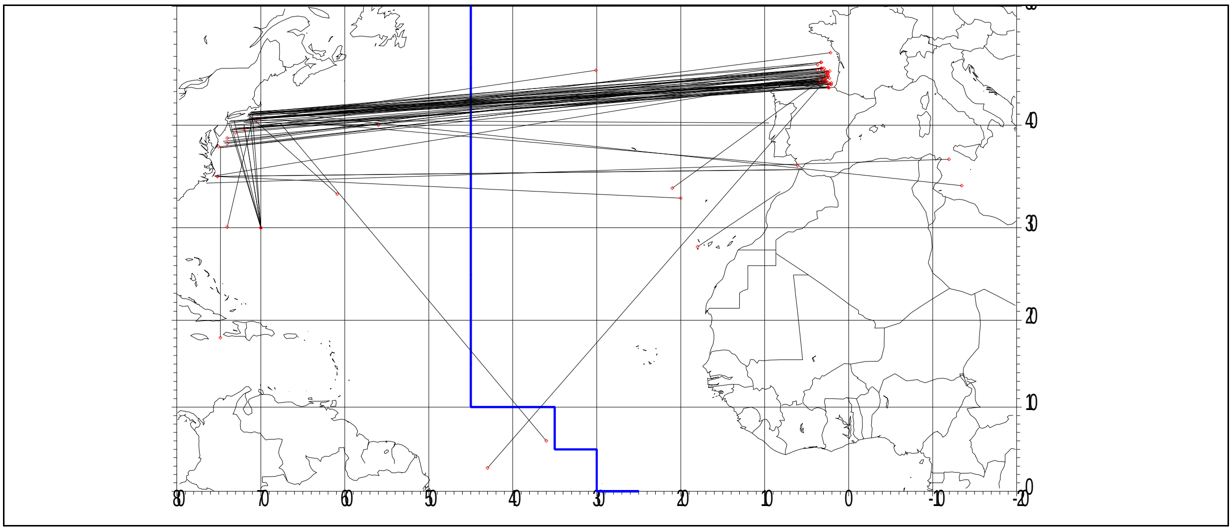


Figure 4. Recoveries of small bluefin recovered at less than 120 cm and at a distance >600 miles.

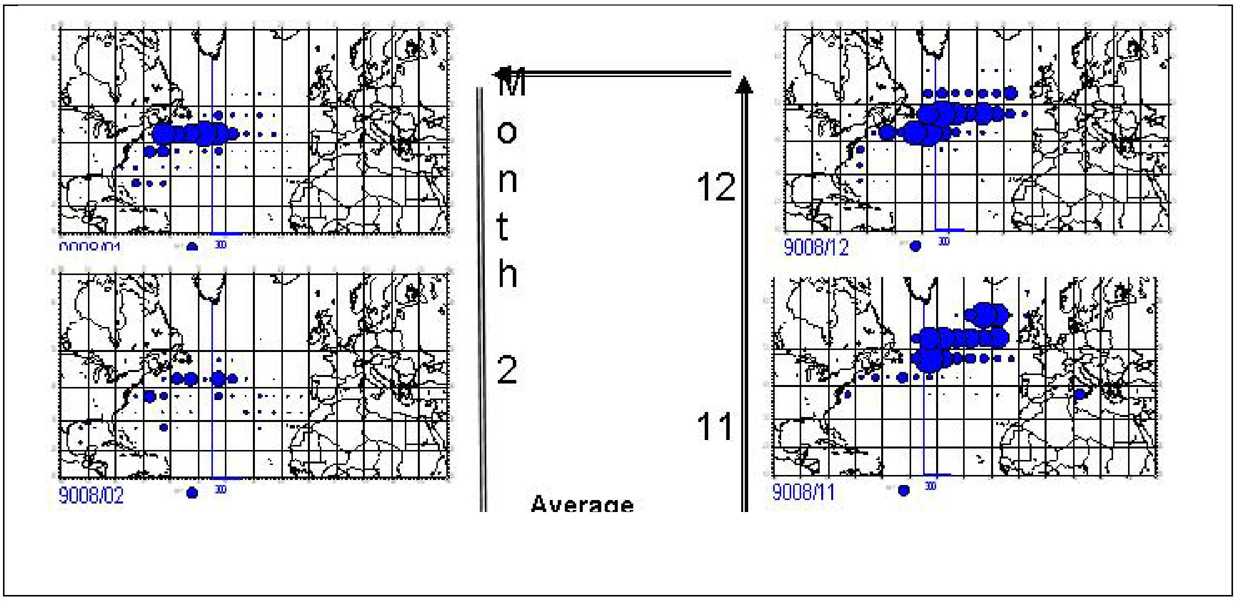


Figure 5. Seasonal pattern of bluefin catches (average 1992-2010) by Japanese longliners in the North Atlantic during the November to February period.

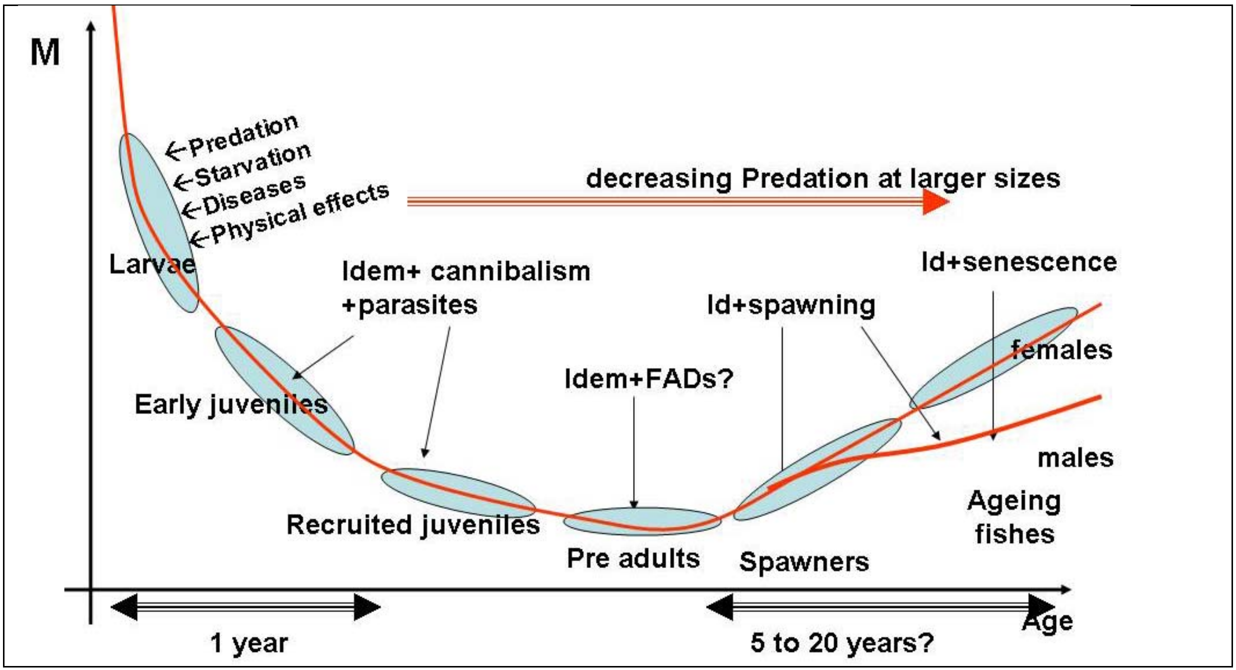


Figure 6. Conceptual overview of a logical trend in natural mortality as a function of age and gender.

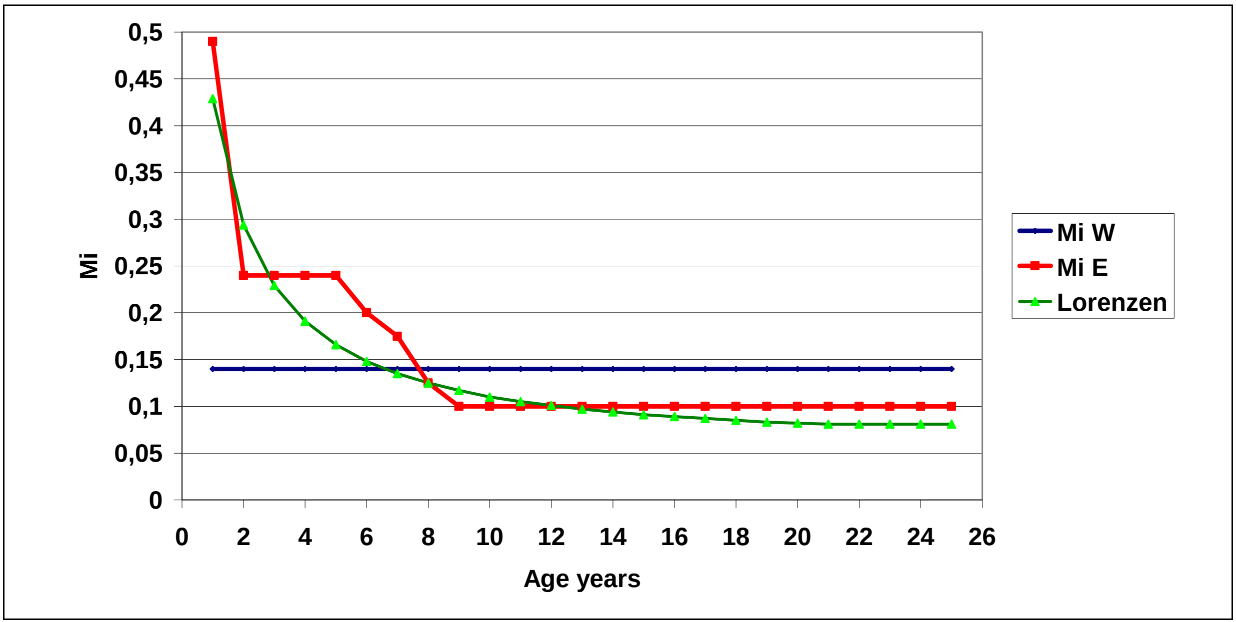


Figure 7. Natural mortality at age estimated for bluefin by the Lorenzen method (Eastern Atlantic Cort growth curve[4] and longevity = 30 years)

[4] BFT growth is now assumed to be being very similar in both sides of the Atlantic

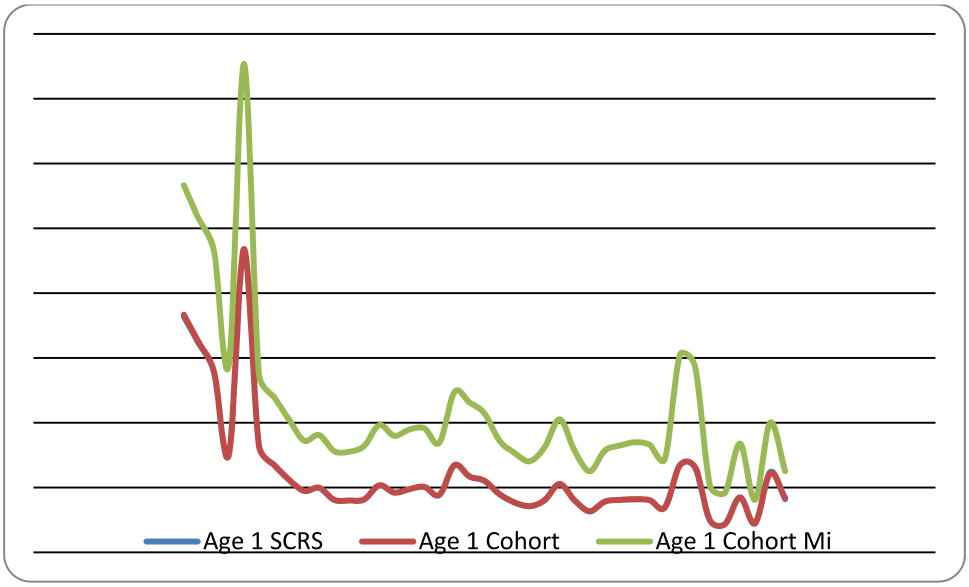


Figure 8. Reconstructed western Atlantic bluefin tuna population numbers at age 1 under assumed M=0.14 (red line) and under M at age equal to those used for east Atlantic and Mediterranean bluefin tuna (green line). Note that the SCRS estimates under M=0.14 are under the red line.

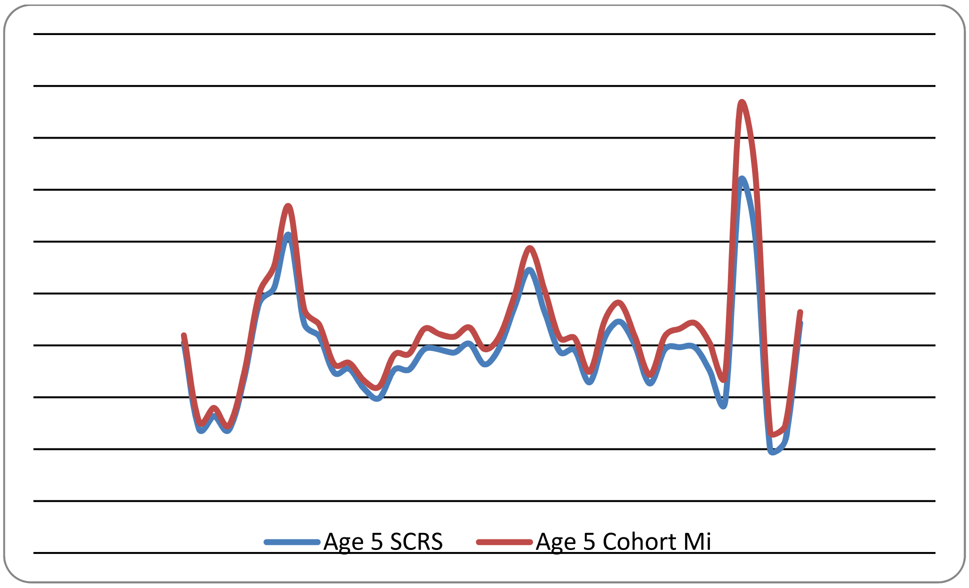


Figure 9. Western Atlantic bluefin tuna population numbers at age 5 in the SCRS assesment (blue line) or assuming M at age for the East Atlantic and Mediterranean (red line).