The Commonwealth Small Pelagic Fishery: Review of Estimates of Jack Mackerel Biomass

26 August 2012

Dr Andrew Wadsley

Principal, Australian Risk Audit, consult@ariska.com.au

Summary

Estimates of 2002 jack mackerel spawning biomass given in the IMAS Neira 2011 Report, on which the increase in the 2012/2013 total allowable catch (TAC) is based, are inconsistent with the egg abundance-at-age data presented in the Report. Key parameters presented in Table 3.1 of the Report are not reproducible, casting serious doubt as to the validity of the analysis.

Reproducibility is the hallmark of good and reliable scientific analysis, all the more so in this case when the outcome of setting an unsafe TAC may seriously impact Australian jack mackerel stocks.

Because the calculation of these key parameters is not reproducible, the TAC Determination 2012 set by the AFMA of 10,100 t for jack mackerel is based on unreliable statistical analysis and is unsound. Based on the analysis in this report, the TAC should be less that 1/3rd of this; that is, 3,500 t. The current TAC exceeds the 20% maximum catch set by the SPF Harvest Strategy, implying that *the commercial stocks of jack mackerel are not being managed at ecologically sustainable levels,* as required under the Fisheries Administration Act 1991.

Simply, the calculation of spawning biomass given in the Neira 2011 report is wrong. Its results are false, and the setting of the jack mackerel TAC based on its results is not valid. A science-based approach to setting catch levels cannot rely on unsound science.

Introduction

The Total Allowable Catch (TAC) for 2012/2013 for jack mackerel in the East zone was increased from 5,000 t (in 2011/2012) to 10,100 t after taking into account newly available information based on 2002 egg survey data (Buxton *et al.* 2012, Neira 2011).

The Neira 2011 study estimated spawning biomass of jack mackerel in October 2002 to be approximately 114,900 to 169,000 t with a “best estimate” of 140,000 t quoted by Buxton *et al*., although Neira only refers to this number with the disclaimer “spawning biomass estimates reported here for the jack mackerel off southern NSW (~140,000 t) are largely imprecise and, as such, need to be taken with due caution”.

The TAC of 10,100 t is less than the Recommended Biological Catch (RBC) of 10,600 t which is 7.5% of the 140,000 t biomass estimate, 7.5% being the maximum allowable RBC under the Small Pelagic Fishery Harvest Strategy for Tier 2 stock.

Because the TAC for 2012/2013 is based on the spawning biomass estimate of Neira 2011 it is critical to the setting of a safe quota that this estimate be reliable.

This review does not look at the fishery science used to generate the data going into the estimate, but only the statistical analysis. Once fish stock parameters have been determined, the basic statistical analysis is simple using undergraduate-level mathematical concepts and can be carried out within MS Excel™.

Spawning Biomass Model

In his report, Neira estimates spawning biomass B (tonne) using the equation $B = P_0 A k / (R F S / W_f)$.

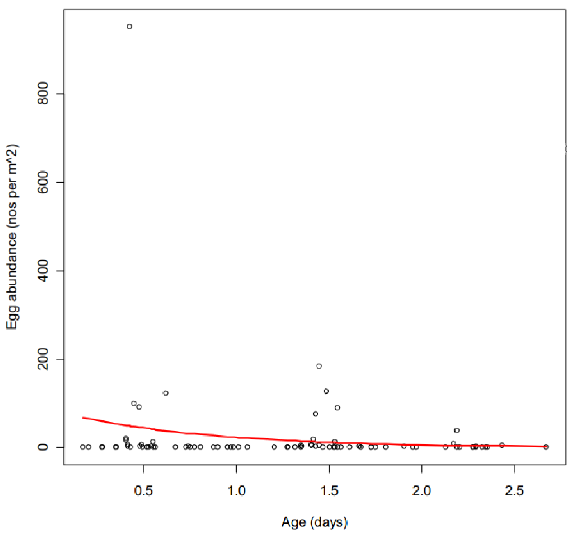
In this equation P_0 = egg production per unit of area per day (eggs / 0.05m2 / day), A = spawning area (km2), k = conversion factor (in this case k=20, to convert eggs / 0.05m2 / day to eggs / m2 / day), R =

fraction of mature females by weight (sex ratio), F = batch fecundity (number of oocytes released per mature female per batch), S = spawning fraction (proportion of mature females spawning each day), and W_f = mean weight of mature females in the population. [Note that Neira refers to the conversion factor k as a factor to convert grams to metric tonnes, but this is incorrect as a units analysis and the results of his calculations show that it is required only to convert areas from m2 to 0.05m2.]

Mean Daily Egg Production

The value P_0 = egg production per unit of area per day is calculated from a model that assumes all eggs to be spawned and instantaneously fertilized at a specific time, and affected by a constant exponential mortality rate, with daily egg abundance-at-age data in each sample to be independent observations from a population with a common P_0 and instantaneous mortality rate Z, $P_t = P_0\, e^{-Z\,t}$.

Neira calculated this value by fitting both a NLS (non-linear least squares model) and a GLM (generalized linear model with negative binomial error distribution) to jack mackerel eggs caught in 2002 off southern New South Wales for cohorts aged using two different temperature-dependent egg incubation models.



For one such incubation model, his results (Figure 8a) are reproduced above. In this figure, measured egg abundance (number of eggs per m2) is plotted against the estimated age of the egg cohorts (in days). The solid (red) line is a fitted mortality curve derived from GLM. The raw data values (egg abundance / cohort age) are not given in the report.

Spawning Biomass Estimate

From this data, Neira (Table 3.1) gives the following values for P_0 (in units eggs / 0.05m2 / day) where the incubation models are referenced by Figures 8a and 8b:

P_0 (eggs/0.05m2/day):	Incubation Model 8a	Incubation Model 8b
Non-linear regression (NLS)	**3.36**	**4.93**
Generalized Linear Model (GLM)	**3.80**	**3.92**

Using these values and estimates of spawning area (A = 23,934 km2), female weight (W_f = 311.4 g), fecundity (F = 62,947), sex ratio (R = 0.346) and spawning fraction (S = 0.20), estimates of 2002 spawning biomass were calculated (Table 3.1):

Spawning biomass (t):	Incubation Model 8a	Incubation Model 8b
Non-linear regression (NLS)	**114,943**	**168,817**
Generalized Linear Model (GLM)	**130,082**	**134,218**

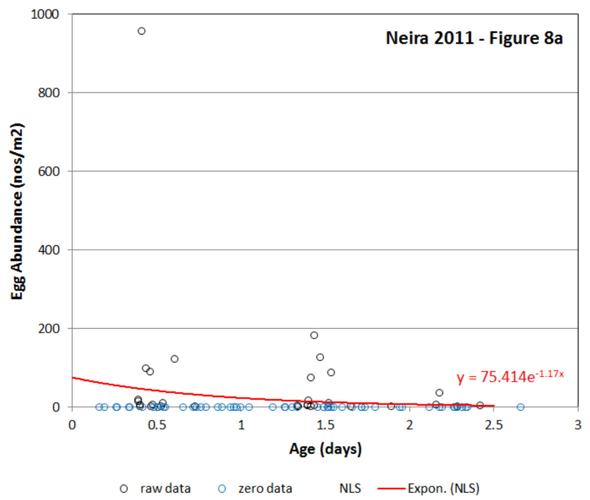
As a check, for the NLS model we have B = (3.36 x 23,934 x 20) / (0.346 x 62,947 x 0.20 / 311.4) = 114,980 which, to 4 figures, equals the table value of 114,943; and for the GLM model B = (3.80 x 23,934 x 20) / (0.346 x 62,947 x 0.20 / 311.4) = 130,037 which, to 4 figures, equals the table value of 130,082.

This calculation demonstrates that the estimates of jack mackerel biomass were derived from the values reported in Table 3.1, using the units presented in the table. In particular, the estimates of biomass depend on the value of P_0 derived from the daily egg abundance-at-age data.

Digitized Data

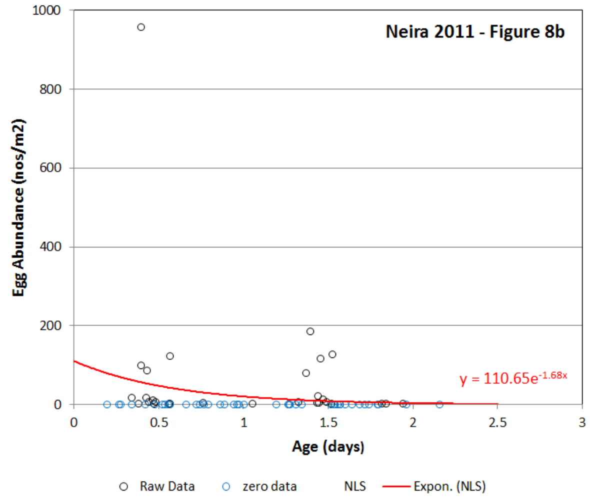
Because the raw numerical values plotted in Figure 8 were not given in the report, these values were extracted from the pdf (vector graphics) version of the report and scaled to the units shown in Figure 8. The zero egg abundance points appear to have been set to a value of 1 and the data was normalised to this; they are tabulated here in Appendix I. There is some discretization effect, and these values may differ from the actual values used in Neira's analysis but will agree to within the diameter of the markers used in Figure 8.

These values were plotted using MS Excel™ and are shown in the Figures below:

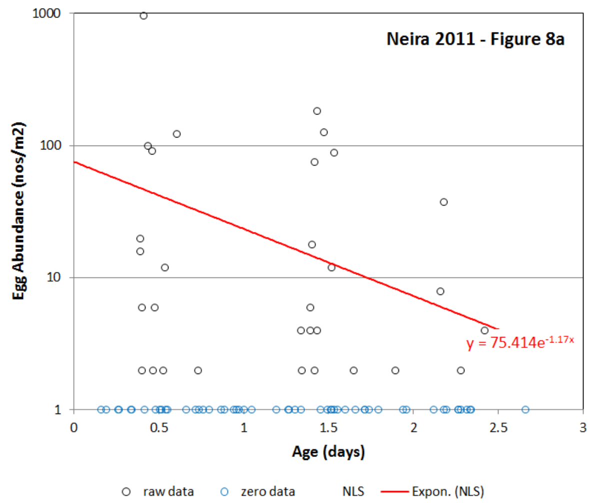


In these plots, we show the same data as Figure 8 of the Neira report, except here we show the NLS curves calculated from the values given in Table 3.1 of the report and scaled by the ratio 23,934 / 21,327 to account for the difference between the spawning area and the survey area (Neira and Lyle 2011) with units converted from eggs / 0.05m2 to eggs / m2.

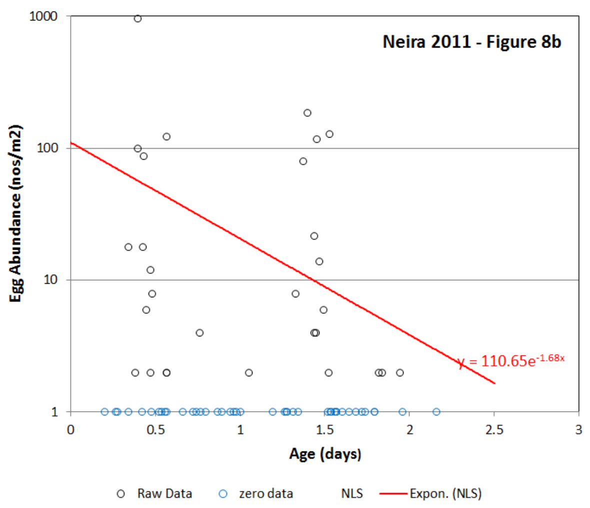
The equation is not a trend line fitted to the data, but the NLS curve presented in the report. Extreme data (which corresponds to eggs of age < 4 hr and eggs which would have hatched with probability > 98% at the mean station temperature, Neira and Lyle 2011) were not included in the original plot.



A linear scale is not appropriate for plotting data which follows an exponential decline as it visually masks the influence of low value points. Usually a log(x) or log(1+x) plot is used to display the data, the latter transform is used if zero value points are also displayed (Neira and Lyle 2011). Log(x) plots of the data are shown in the figures below (for clarity, zero values are plotted on the lowest vertical axis value):



The exponential decline trend plots as a linear curve on this log plot. Note that more than half of the data points (15) have egg abundances of less than10 eggs/m2.



Data Analysis

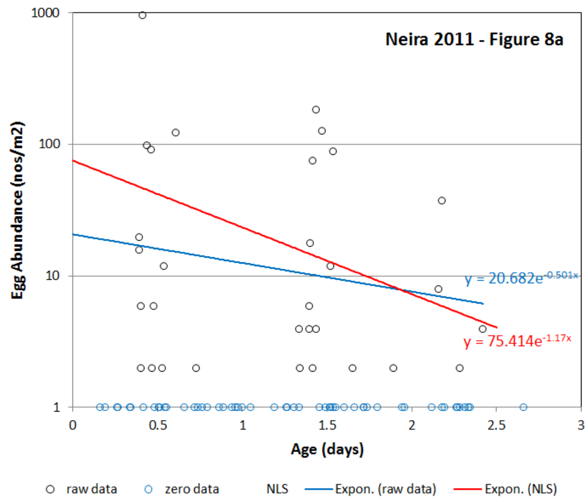
The Neira 2011 report refers to Neira and Lyle 2011 for details of how P_0 estimates were calculated from the data. Neira and Lyle in turn refer both to Picquelle and Stauffer 1985 and to Lo *et al.* 1996 with respect to fitting an exponential decline model to the data. There is an ambiguity here as Picquelle and Stauffer divide the samples into two strata: stratum 1 containing positive samples, and stratum 0 containing zero samples. For stratum 1 they use non-linear regression analysis over all samples and then weight the resulting P_0 value according to the area associated with each stratum; whereas Lo *et al.* group the egg cohorts into half-day categories (excluding eggs < 3 hrs old – here, Neira and Lyle exclude eggs < 4 hrs old) and regress against the mean days and mean egg abundance in each category, and then weigh the resulting P_0 values according to a positive area (which may include zero samples) and an area devoid of egg samples.

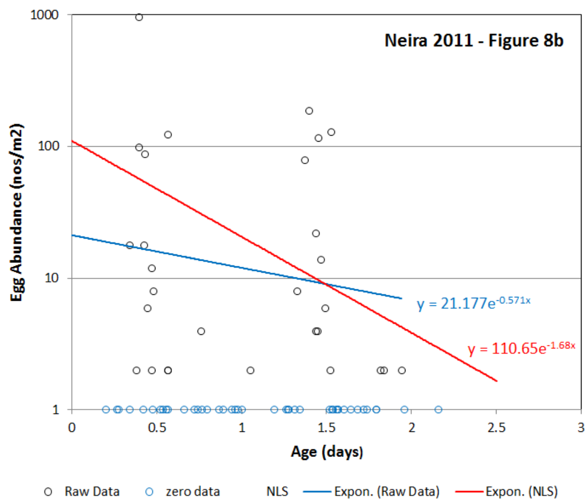
While Neira and Lyle appear to use the Lo *et al.* regression (because they explicitly state they include zero egg samples in the analysis) it was not possible to resolve the inherent methodological ambiguity from their published data. We could not distinguish between the Lo *et al.* and the Picquelle and Stauffer methods based on the data plotted in Figure 3 of Neira and Lyle – both methods gave similar trend lines. A brief survey of the literature showed that both methods have been used to analyse the results of DEPM surveys.

This ambiguity is also present in the Neira 2011 report. In our analysis we used both the Picquelle and Stauffer and the Lo *et al.* methods.

Non-Linear Least Squares – Picquelle and Stauffer Method

We used the inbuilt non-linear trend function in MS Excel™ to calculate NLS exponential trends fitted to the raw data of Figures 8a and 8b.





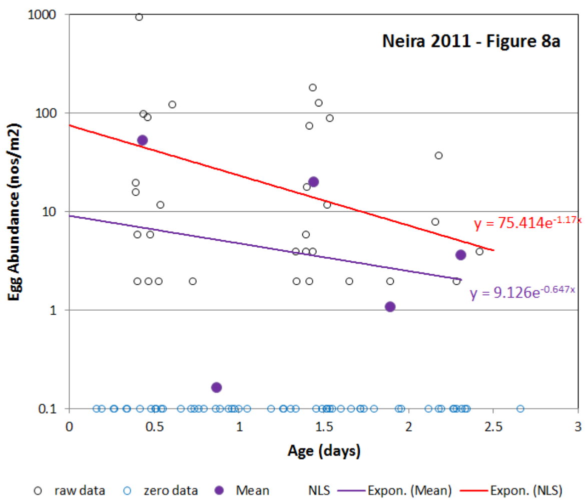
These trends (blue) and the corresponding equations are shown in the following figures. The trend lines were calculated using all of the positive data points shown in Figures 8a and 9b of the Neira 2011 report.

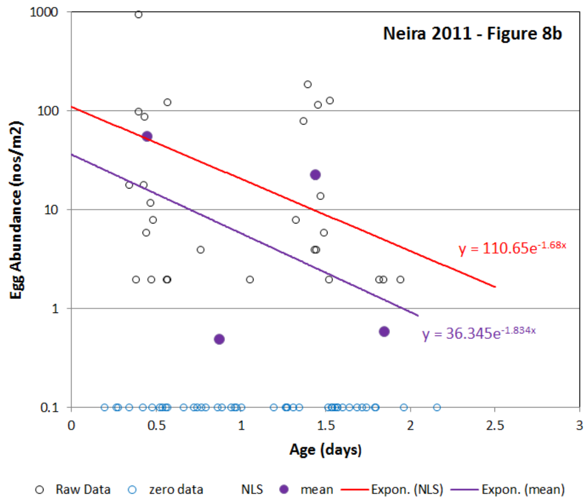
We expect these trends to be similar (within data tolerances) to the NLS trends presented in the report. However, they differ significantly. Either the results of the analysis presented in the report are incorrect, or the method used to analyse the data is not based on the Picquelle and Stauffer 1985 method.

Non-Linear Least Squares – Lo *et al.* Method

We followed the procedure of Lo *et al*. 1996 and took the mean of half-day age classes starting at 4 hours. [In the case of Figure 8a, the first data point was 3.8 hr in our dataset. This was included in the first age class even though this is less than 4 hr – the difference of 0.2 hr being likely related to the discretization of the values extracted from the pdf file.] The mean values per age and egg abundance class are given in the following table:

Figure 8a		Figure 8b	
Mean Age (days)	**Mean Abundance (eggs/m2)**	**Mean Age (days)**	**Mean Abundance (eggs/m2)**
0.430	53.47	0.448	55.70
0.867	0.16	0.873	0.49
1.439	20.33	1.442	22.81
1.892	1.10	1.844	0.59
2.308	3.63		





An exponential trend was fitted to these mean values, the resulting plots are shown in the following figures.

Again, we expect these trends to be similar to those reported in Neira 2011. However, they are significantly different with a large contrast between P_0 values between incubation models: that is, 9.13 eggs / m2 for Figure 8a data and 36.35 eggs m2 for Figure 8b data.

Inconsistency

The egg abundance / age data plotted in Figures 8a and 8b of the Neira 2011 report is not consistent with the weighted P_0 values presented in Table 3.1 using either the Picquelle and Stauffer or the Lo *et al.* regression methods, which are the methods referenced by the Neira and Lyle 2011 paper.

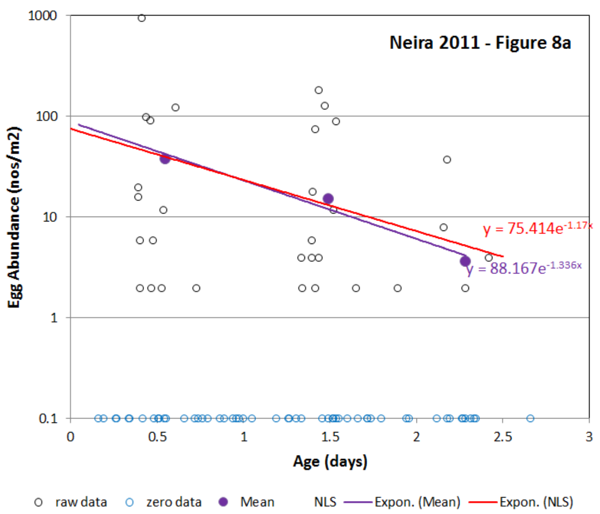
The weighted P_0 parameters given in Table 3.1 of Neira 2011 are not reproducible using the data given in the report and the methodologies cited.

Discussion

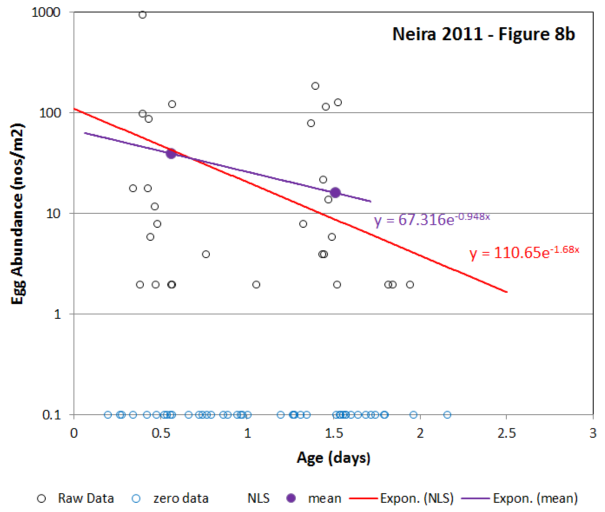
One problem with the Lo *et al.* 1996 regression method applied to the datasets is the low number of positive samples compared to the high number of zero samples included in the analysis. These zero samples dominate and lead to low egg abundance means, particularly for the 0.67 – 1.17 half-day period. This method is not statistically robust when applied to low counts of positive samples or clustered samples.

An alternative temporal collocation of the egg abundance data is to average egg abundance over 1 day rather than 0.5 day periods. The resulting trend curves are plotted below.

In this case, we see that there is a good match to the NLS trend curve for Fig 8a, but not for Fig 9a, where the trend has been fitted to only two data points (since the ages for all positive egg cohorts is less than 2 days). The Neira 2011 report gives a CV > 0 for the P_0 derived from this NLS trend line (Table 3.1); thus it must have been generated from more than 2 points – which is not consistent with averaging over 1 day periods. Moreover, the zero abundance-age points which have been included for each egg stage increasingly bias the analysis.



The egg abundances are clustered at approximately 0.4, 1.4 and 2.4 days, so not all egg stages are well represented in the sampled data – most likely because samples at each station were taken at similar times of the day [Zeldis and Francis 1998, Figure 2]. Statistically, inclusion of zero data points at times when sampling did not take place is not consistent with the spatially homogenous, exponential decline model: *absence of evidence is not evidence of absence.*



Use of the Picquelle and Stauffer 1985 method leads to a more consistent outcome between incubation models; however, the weighting of the calculated P_0 values may need to be revised to take into account the zero sample stations currently included in the positive station area. While the method is straightforward to apply, a potentially more rigorous approach is the maximum-likelihood model of Zeldis and Francis 1998.

Calculation of Weighted P_0 Values

Because the analysis based on the Picquelle and Stauffer method provides a more consistent estimate of P_0 values between both datasets, the results of this method were used in subsequent analysis. We use the average of P_0 = 20.9 eggs / m2 calculated from the MS Excel™ exponential trends fitted to the Figure 8a and 8b positive sample data.

Using the average unweighted P_0 value of 20.9 eggs/m2, we calculate a weighted P_0 = 0.05 x 20.9 x 21327 / 23934 = **0.93** which is less than 1/3rd of the value **3.36** eggs/0.05m2/day given in Table 3.1 of the report based on the same dataset and analysis method.

The value of 0.93 calculated here is consistent with the daily egg production of 0.8 (eggs/ 0.05m2 /day) reported for japanese mackerel, *Scomber japonicas,* by Watanabe *et al.* 1999 (cited by Neira *et al.* 2008), consistent with the range 0.6 – 2.1 for

blue mackerel, *Scomber australasicus,* given by Ward *et al.* 2009, and consistent with the value of 1.4 (eggs/0.05m2/day) reported by Dransfeld *et al*. 2005 for mackerel, *Scomber scombrus,* and horse mackerel *Trachurus trachurus* (referenced but not cited by Neira 2011).

The NLS trends presented above are independent of any interpretation of the data – whether one is a marine scientist or mathematician, the outcome will be the same.

Conclusion

We assume that the data presented in Figures 8a and 8b represents all of the (non-extreme) 2002 egg abundance / age data generated through the course of the Neira 2011 DEPM study and that this data can be relied upon to derive weighted P_0 values.

The implications of our analysis are significant for the spawning biomass estimates which are less than 1/3rd of the reported values. The "best estimate" of 140,000 t of spawning biomass should correctly be 47,000 t.

The 47,000 t estimate of spawning biomass is consistent with the decline in, and low level of, catches of jack mackerel taken in Commonwealth waters over the past 10 years [see Figure below].

Using correct estimates of weighted P_0, the 2012/2013 TAC of 10,100 t is 21.5% of the estimated spawning biomass of 47,000 t which exceeds the maximum 20% RBC for Tier 1 stock. Under the rules of the Small Pelagic Fish Harvest Strategy for Tier 2 stock the TAC should be no more than 3,500 t.

Reproducibility is the hallmark of good and reliable scientific analysis, all the more so in this case when the outcome of setting an unsafe TAC may seriously impact Australian jack mackerel stocks.

The estimates of weighted daily egg abundance P_0 given in the Neira 2011 report are not reproducible, as shown by the analysis presented above. This casts serious doubt as to the validity of the biomass estimates for jack mackerel on which the 2012/ 2013 TAC has been based.

Simply, the calculation of spawning biomass given in the Neira 2011 report is wrong. Its results give a false estimate of 2002 jack mackerel spawning mass, and the setting of the TAC based on these results is not valid.

References

1. Buxton *et al.* 2012: Colin Buxton, Gavin Begg, Jeremy Lyle, Tim Ward, Keith Sainsbury, Tony Smith, David Smith, *The Commonwealth Small Pelagic Fishery: General background to the scientific issues*, August 2012.

2. Dransfeld *et al.* 2005: Leonie Dransfeld, Oonagh Dwane, John Molloy, Sarah Gallagher, and Dave Reid, *Estimation of mackerel (Scomber scombrus L., 1758) and horse mackerel (Trachurus trachurus L., 1758) daily egg production outside the standard ICES survey area*, ICES Journal of Marine Science 62 (2005) 1705-1710.

1. Lo *et al.* 1996: Nancy Lo, Yanira Ruiz, Mercedes Cervantes, M.J., Geoffrey Moser and Ronald Lynn, *Egg Production and Spawning Biomass of Pacific Sardine (Sardinops sagax) in 1994, Determined by the Daily Egg Production Method*, CalCOFI Report 37 (1996) 160-174.

2. Neira *et al.* 2008: F.J. Neira, J.M. Lyle, G.P. Ewing, J.P. Keane and S.R. Tracey, *Evaluation of Egg Production as a Method of Estimating Spawning Biomass of Redbait Off the East Coast of Tasmania*, FRDC Project No. 2004/039, (2008).

3. Neira 2011: Francisco Neira, *Final Report, Application of daily egg production to estimate biomass of jack mackerel, Trachurus declivis - a key fish species in the pelagic ecosystem of south-eastern Australia*, Fisheries, Aquaculture & Coasts Institute for Marine & Antarctic Studies (IMAS) University of Tasmania (2011).

4. Neira and Lyle 2011: Francisco Neira and Jeremy Lyle, *DEPM-based spawning biomass of Emmelichthys nitidus (Emmelichthyidae) to underpin a developing mid-water trawl fishery in*

south-eastern Australia, Fisheries Research 110 (2011) 236–243.

5. Picquelle and Stauffer 1985: Susan Picquelle and Gary Stauffer (1985). *Parameter Estimation for an Egg Production Method of Northern Anchovy Biomass Assessment*. In R. Lasker (Editor), An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*, NOAA Technical Report NMFS 36 (1985) 7-15.

6. Ward *et al.* 2009: T.M. Ward, P.J. Rogers, L.J. McLeay and R. McGarvey, *Evaluating the use of the Daily Egg Production Method for stock assessment of blue mackerel, Scomber australasicus*, Marine and Freshwater Research 60 (2009) 112-128.

7. Watanabe *et al.* 1999: C. Watanabe, T. Hanai, K. Meguro, R. Ogino and R. Kimura, Spawning biomass estimates of chub mackerel Scomber japonicus of Pacific subpopulation off Central Japan by a daily egg production method, Nippon Suisan Gakkaishi 65 (4) (1999) 695-702.

8. Zeldis and Francis 1998: J.R. Zeldis and R.I.C.C. Francis, *A daily egg production method estimate of snapper biomass in Hauraki Gulf*, New Zealand, ICES Journal of Marine Science 55 (1988) 522-534.

Qualification

Professor Andrew Wadsley PhD, MSc, Bsc (Hons). Professor Wadsley received a BSc (Hons) and University Medal in Mathematics from the Australian National University in 1970, the Statistical Society of Australia Prize in 1969, an MSc from the University of Warwick (UK) in 1972, and a PhD (Mathematics) from the University of Warwick (UK) in 1974. He has more than thirty-seven years in the petroleum and steel industries, starting as a well-site petroleum engineer with Shell International in 1975. Professor Wadsley is a Principal of Australian Risk Audit, an Executive Director of Western Australia based Stochastic Simulation Limited, Director of Exploration and Production Consultants (Australia) Pty Ltd, Chairman of Optimiser Pty Ltd, a Western Australia based Digital Management Company, and adjunct associate Professor in Petroleum Engineering at the Curtin University of Technology. He is a member of the Society of Petroleum Engineers and the Society for Industrial and Applied Mathematics. Professor Wadsley has extensive experience in the auditing and uncertainty analysis of major resource projects including two recent carbon-dioxide sequestration projects in Australia, numerous oil and gas field developments both locally and internationally. He has been Umpire and Expert Witness for dispute resolution within the oil and gas industry. He is an expert in the numerical modelling and uncertainty analysis of multi-phase transport processes.

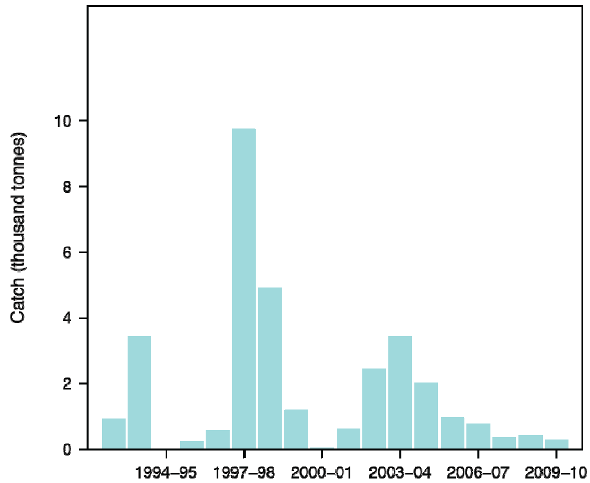


Figure 7.5 Commonwealth jack mackerel catch, 1992-93 to 2009-10
http://adl.brs.gov.au/data/warehouse/fishstatus20109abff00101/fishstatus20109abff00101_11a/07_FishStatus2010SmallPelagic_1.00.pdf

Appendix: Egg abundance-at-age data from Figures 8a and 8b from Neira 2011 pdf file.

Figure 8a		Figure 8b	
age	abundance+1	age	abundance+1
0.159	1.000	0.198	1.000
0.192	1.000	0.268	1.000
0.262	1.000	0.275	1.000
0.266	1.000	0.341	1.000
0.336	1.000	0.421	1.000
0.341	1.000	0.476	1.000
0.416	1.000	0.520	1.000

0.481	1.000	0.535	1.000
0.505	1.000	0.557	1.000
0.514	1.000	0.568	1.000
0.542	1.000	0.663	1.000
0.551	1.000	0.722	1.000
0.659	1.000	0.740	1.000
0.715	1.000	0.766	1.000
0.738	1.000	0.795	1.000
0.762	1.000	0.865	1.000
0.795	1.000	0.890	1.000
0.865	1.000	0.942	1.000
0.888	1.000	0.963	1.000
0.939	1.000	0.974	1.000
0.958	1.000	1.004	1.000
0.972	1.000	1.194	1.000
1.000	1.000	1.264	1.000
1.047	1.000	1.271	1.000
1.191	1.000	1.275	1.000
1.262	1.000	1.311	1.000
1.266	1.000	1.344	1.000
1.304	1.000	1.517	1.000
1.336	1.000	1.535	1.000
1.453	1.000	1.539	1.000
1.491	1.000	1.557	1.000
1.514	1.000	1.568	1.000
1.519	1.000	1.568	1.000
1.533	1.000	1.601	1.000
1.551	1.000	1.641	1.000
1.598	1.000	1.685	1.000
1.659	1.000	1.718	1.000
1.715	1.000	1.740	1.000
1.715	1.000	1.791	1.000
1.738	1.000	1.795	1.000
1.795	1.000	1.960	1.000
1.939	1.000	2.158	1.000
1.958	1.000	0.381	2.978
2.117	1.000	0.473	2.978
2.177	1.000	0.564	2.978
2.192	1.000	0.568	2.978
2.262	1.000	1.051	2.978
2.266	1.000	1.520	2.978
2.280	1.000	1.817	2.978
2.313	1.000	1.839	2.978
2.332	1.000	1.941	2.978
2.341	1.000	0.762	4.956
2.659	1.000	1.436	4.956
0.402	2.978	1.447	4.956
0.467	2.978	0.443	6.933
0.528	2.978	1.491	6.933
0.729	2.978	0.480	8.911
1.341	2.978	1.326	8.911
1.416	2.978	0.469	12.867
1.650	2.978	1.469	14.845
1.892	2.978	0.341	18.800
2.280	2.978	0.425	18.800
1.336	4.956	1.440	22.756
1.393	4.956	1.370	80.193

1.435	4.956	0.432	88.104
2.421	4.956	0.396	100.059
0.402	6.933	1.454	117.859
0.477	6.933	0.568	123.789
1.393	6.933	1.528	129.722
2.159	8.911	1.396	187.155
0.537	12.867	0.396	959.561
1.519	12.867		
0.393	16.822		
1.402	18.800		
0.393	20.778		
2.177	38.575		
1.416	76.237		
1.533	90.082		
0.463	92.060		
0.435	100.059		
0.607	123.789		
1.472	127.744		
1.435	185.178		
0.411	959.561		