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At the request of several Commissioners, in 2012 an independent review was conducted by an outside expert of the methodology and techniques used by the Commission staff in its assessment of dolphin populations in the eastern Pacific Ocean. The resulting report is presented below.

INDEPENDENT REVIEW OF THE IATTC'S EPO DOLPHIN POPULATION ASSESSMENT

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EXECUTIVE SUMMARY

- The types of models applied to eastern Pacific Ocean dolphin stocks are appropriate (and consistent with those used for stock assessments of other marine mammals). However, there has been no systematic evaluation of the basis for the assumptions underlying those assessments, and the sensitivity tests conducted (although fairly thorough) are not particularly closely linked to the hypotheses raised for the apparent lack of recovery of these stocks.
- If an estimate of trend is required, the most straightforward approach would be to fit a log-linear model to the most-recent few abundance estimates.
- A workshop should be conducted to identify (a) a broad set of hypotheses regarding the dynamics of these dolphin stocks, (b) a set of mathematical models which can (to the extent possible) represent them, and (c) what data are available to parameterize the models. A second workshop should be conducted to review the resulting assessment within a framework in which additional analyses can be requested by a Review Panel.
- Future reviews of assessments of dolphin stocks would be enhanced if a Terms of Reference document were to be developed.

1. INTRODUCTION

Population assessments of various dolphin stocks have been conducted by IATTC staff and other relevant scientists over several years. The outputs of these assessments have explored the state of the stock relative to the thresholds included in the U.S. Marine Mammal Protection Act (MMPA), the maximum and current rate of increase in abundance, and factors which might be hindering the rate of recovery. This review considers the assessment methodology applied to evaluate the status and trends of the eastern stock of spinner dolphin (*Stenella longirostris*) and of the northeastern stock of the spotted dolphin (*S. attenuata*) in the eastern Pacific Ocean (EPO).

The terms of reference for this review are listed in Appendix A, and the documents reviewed are listed in

Appendix B. The following sections provide reviewer comments in relation to each of the five terms of reference. The models are based on a variety of data sources, primarily catches and estimates of abundance from line-transect surveys. This review does not review the methods used to estimate catches and abundance.

2. ASSESSMENT METHODOLOGY AND ASSUMPTIONS

A variety of assessment techniques have been applied to data for the eastern stock of spinner dolphin and to those for the northeastern stock of spotted dolphin. The simplest analyses involved fitting exponential models (*e.g*., Wade *et al*. 2002) and smoothing functions (Anonymous 2006) to the abundance data (and testing for a change in exponential slope). Several population dynamics models have been applied to the data for these two stocks. Wade (1991, 1993) applied a "Hitter"-like approach to estimate stock size relative to carrying capacity, while most other assessments have been based on maximum likelihood, penalized maximum likelihood and Bayesian methods. The assessment methods applied to dolphin stocks can be categorized in a variety of ways, for example, by whether the population dynamics are modelled using an age-aggregated model (generally the theta-logistic model) or an age-(stage-)structured population dynamics model and by the method of parameter estimation (maximum likelihood, penalized maximum likelihood, or Bayesian techniques) (Table 1). The advantage of Bayesian (and arguably penalized likelihood) methods is that auxiliary (or prior) information can be included in analyses.

The basic versions of the population dynamics models assume that the population dynamics parameters have remained constant or have changed to a new value in a pre-specified year. As noted in Table 1, a variety of assumptions have been explored, although none of the models have explored sensitivity to stock structure. Taken together, the past analyses have explored a wide variety of assumptions. However, the exploration of assumptions has not been very systematic (Wade *et al*. (2002) provide the most comprehensive exploration of assumptions). Most of the assessments have used only catch and abundance data based on line-transect surveys. However, other data sources are available, and have been included in some of the assessments.

The most general model structure applied to the two stocks is outlined in Appendix A of Anonymous (2009) and by Hoyle and Maunder (2004). The model structure underlying Appendix A of Anonymous (2009) allows for a general production function, uncertainty [both bias and imprecision] regarding catches, and sampling error associated with the abundance estimates. However, the model in Appendix A of Anonymous (2009) is not fully documented and limited diagnostics are provided. Also, some of the results are unrealistic (*e.g*. Figure A-2 of Anonymous (2009)). The particular problems with Figure A-2 could have been overcome by placing a prior on the plausible extent of change in carrying capacity (that there was a problem with this scenario – a change in carrying capacity – was noted by Anonymous (2009)). Hoyle and Maunder (2004) based their analyses on an age- and stage [colour]-structured population dynamics model fitted to abundance estimates, catch age-composition data, and stage-structured data. The age data are, however, not particularly informative, except regarding the value for natural mortality. However, while allowance is made for process error in Hoyle and Maunder (2004), no allowance is made for uncertainty regarding historical catches (unlike Appendix A of Anonymous (2009)). In addition, only a subset of the biological parameters was considered by Hoyle and Maunder (2004) to be uncertain (the age-at-sexual-maturity was assumed known). Finally, additional variance was modelled as a multiplicative effect by Hoyle and Maunder (2004) (Equation 16), while additive additional variation is more common.

The fits of the baseline versions of the generalized logistic model to the data for eastern spinner dolphins (Figure 3 of Anonymous (2009)) seem adequate, but the fit to the data for northeastern spotted dolphins (Figure 1 of Anonymous (2009)) is mis-specified because the last five data points are all below the model predictions (although the model predictions are all included in the 95% confidence intervals for the data). This suggests that the models on which Appendix A of Anonymous (2009) is based are missing some key feature (or the extent of sampling variation associated with the abundance estimates is under-estimated).

The model of Hoyle and Maunder (2004) is able to fit the abundance estimates for northeastern spotted dolphins (their Figure 4), but the time-series used is not as long as that on which the analyses of Anonymous (2009) were based, so it is not possible to evaluate how this approach would have fit the most recent data.

Overall, the types of models applied are appropriate (and consistent with those used for stock assessments of other marine mammals). However (and as will be emphasized below), there has been no systematic evaluation of the basis for the assumptions.

3. ARE SENSITIVITY ANALYSES ADEQUATE?

As noted above, many combinations of factors have been explored, but to date: (a) several of the proposed hypotheses to explain the current rate of increase are not easily linked to aspects underlying the sensitivity analyses, and (b) sensitivity has not been explored within a single population dynamics model / statistical estimation approach. Furthermore, no sensitivity analyses have explored the implications of spatial- or stock-structure, and whether the postulated boundaries that define the stocks include only one stock of each species. Further comments regarding a way to more fully explore assumptions and the sensitivity of the model outputs to those assumptions are listed in Section E below.

4. IS THERE ADEQUATE INFORMATION TO ESTIMATE CURRENT POPULATION GROWTH RATE?

The most recent estimates of absolute abundance are available for 1998, 1999, 2000, 2003 and 2006, with sampling coefficients of variation (CVs) between 0.14-0.23 (northeastern spotted dolphin) and 0.22-0.33 (eastern spinner dolphin). There are two key ways to estimate the recent trend in abundance: (a) fit a population dynamics model over all years for which data are available, and (b) fit a model to recent abundance estimates. The former approach has the advantage that the current and maximum rates of increase, as well as the status of the stocks relative to their unfished levels, can be estimated. However, this approach could be subject to bias owing to model misspecification. Thus, if an estimate of trend is required, the most straightforward approach would be to fit a log-linear model to the most-recent five (or so) abundance estimates. Five abundance estimates is probably the minimum number which could lead to reliable trend estimates. However, sensitivity should be explored to the number of abundance estimates considered in such regressions. I **recommend** using a Bayesian approach in which allowance is made for variance about the abundance estimates in addition to sampling variance (if this is supported by the data), and expressing the rate of increase as a probability density function. Given their magnitude relative to the estimate of abundance, there is no need to account for the recent catches in such a calculation.

It is noteworthy that there have been no estimates of abundance since 2006. I **recommend** that analyses should be undertaken to evaluate the extent to which the posterior credibility intervals for the rate of increase will be reduced were a survey to be conducted during (say) 2012. Additional surveys would provide the best basis to address this question, especially if the population is indeed increasing.

5. ALTERNATIVE HYPOTHESES FOR THE PERCEIVED LACK OF INCREASE

Considerable care should be taken when comparing estimates of rate of increase with “expected” rates of increase at low population size because there is limited information to estimate the expected (rather than the theoretically maximum) rate of increase at low population size (in common with the situation for most other animals). Reilly and Barlow (1986) derive relationships between biological parameters and the maximum rate of increase (r_{max}) while Hoyle and Maunder (2004) implicitly impose a prior on the maximum rate of increase by placing bounds on some (but not all) of the biological parameters. However, none of these analyses represent the full range of uncertainty in the form of a prior distribution. This is particularly important because, while there are combinations of parameter values for which the maximum rate of increase could be as high as 9% (*i.e.*, when juvenile and adult survival are both very high), the likely prior probability of this would be fairly low. Ideally a prior distribution for the expected maximum rate of increase should be based on trends in abundance from observations of similar stocks/species at low population size, r_0 (see IWC (2011) for such data for baleen whales). Unfortunately, there do not appear to be observed data on rates of increase for dolphin populations not subject to anthropogenic impacts. Moreover, even the interpretation of observed rates of increase as estimates of r_{max} can be challenging because trends in abundance over short time periods may not reflect the expected maximum rate of increase (*e.g*. Cooke 2007).

Many hypotheses have been postulated why the estimated rate of increase does not match that expected from theoretical arguments.

- Dolphin bycatch is higher than reported (Gerrodette and Forcada 2005). Reasons postulated for this hypotheses include: (a) smaller boats which may sometimes set on dolphins, but not have observers; (b) observers do not see all of the net at all times during all sets; (c) some injured dolphins may die later; (d) dead dolphins, when observed, may not always be reported. Lennert-Cody *et al.* (in press) estimate the size of the catch by smaller (unobserved) boats and find that conclusions regarding the status and trends of the populations are robust to taking account of these catches.
- Historical dolphin bycatch has been overestimated so the estimate of *K* is an overestimate.
- Unobserved mortality of orphaned calves when lactating females are killed without their calves (Archer *et al*. 2004; Gerrodette and Forcada 2005).
- Chasing and capturing may increase mortality (Gerrodette and Forcada 2005).
- Productivity (generally quantified by the rate of increase in the limit of zero population size and carrying capacity) has declined for some unknown (anthropogenic or environmental) reason.

There is indirect evidence from observations of the proportion of females with calves (Cramer *et al*. 2008) that calf production for both eastern spinner and northeastern spotted dolphins has declined over time, which lends support to some of the above hypotheses. However, the data concerned have yet to be integrated into a model-based assessment.

Many analyses (see Table 1) have explored some of these hypotheses, but this has not been done in a systematic way. The ideal way forward is to develop a modelling framework that is capable of representing all of the various hypotheses. If I was to develop such a framework, I would start with an age- and stage-structured population dynamics model such as that of Hoyle and Maunder (2004) with the following features:

- The analysis would be based on Bayesian methods so that (a) the influence of the data can be quantified by the change between the prior and posterior distributions for key model outputs, and (b) the uncertainty associated with the model outputs can be quantified. Care needs to be taken when developing the prior distributions that they are coherent and that carrying capacity is a stable equilibrium point (see Brandon *et al*. (2007) for how these issues have been addressed in assessments for the Bering-Chukchi-Beaufort Seas stock of bowhead whales).
- Prior distributions would be imposed on the biological parameters of the model.
- The model would be able to fit to <u>all</u> available data sources (indices of abundance, catches, stage proportions, proportion of females with calves, tuna vessel observer data (TVOD)).
- The model would allow key parameters (*e.g*. carrying capacity, survival) to change over time.
- Process error in the dynamics would be considered. Possible ways to include process error are to impose it on natural mortality or fecundity/calf mortality (as is the case at present). Rather than assuming that fecundity/calf mortality is log-normally distributed, this mortality should be modelled using the approach of Taylor *et al*. (in press).

- The model would allow additional mortality to be related to effort or catches.

Analyses would be undertaken for a range of models which capture (to the extent possible) the identified hypotheses. Each analysis would be evaluated for model fit (*e.g*. using posterior predictive distributions) and the analyses which are not rejected on this basis considered as the basis for inference. Wade *et al*. (2002, 2007) and Brandon and Wade (2006) illustrate how Bayesian model selection and model averaging techniques can be applied to evaluate the evidence in favour of different population dynamic hypotheses. Given the limited data, it will also be important to consider retrospective analyses.

6. RECOMMENDATIONS FOR FUTURE ANALYSES

The following recommendations related to future analyses arise from this review:

1. The assessments provided by the IATTC staff (*e.g.* Anonymous 2006, 2009) seem to have been conducted very quickly and I found the methods poorly described and insufficient diagnostics provided. A Terms of Reference document for stock assessments should be developed. This document would outline the expectations for what should be included in assessment reports, including how data should be reported, what model outputs are to be provided, and the approaches used to evaluate model fit and model behaviour. Such documents have been developed for assessments of groundfish and coastal pelagic species off the US west coast, and these documents could form the basis for a Terms of Reference document for eastern Pacific Ocean dolphin assessments.
2. The current approach to evaluating possible hypotheses for the (possible) lack of recovery of the eastern stock of spinner dolphins and of the northeastern stock of the spotted dolphins has tended to be haphazard (see Table 1). The assessments have tended not to start from the set of available hypotheses and developed models to capture those hypotheses within a single modelling framework to allow model selection and model averaging approaches to be applied. A workshop should be conducted to identify (a) a broad set of hypotheses regarding the dynamics of these dolphin stocks, (b) a set of mathematical models which can (to the extent possible) represent them, and (c) what data are available to parameterize the models. A second workshop should be conducted to review the resulting assessment within a framework in which additional analyses can be requested by a Review Panel.
3. A modelling framework based on an age- and stage-structured population dynamics model should be developed within a Bayesian framework so that the available data and hypotheses can be represented in a single model structure.
4. If an estimate of trend is required, the most straightforward approach would be to fit a log-linear model to the most-recent few abundance estimates. Such an analysis should be conducted using a Bayesian approach in which allowance is made for variance about the abundance estimates in addition to sampling variance.
5. Analyses should be undertaken to evaluate the extent to which the posterior credibility intervals for the rate of increase will be reduced were a survey to be conducted during (say) 2012.

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Table 1. Overview of the scenarios [sensitivity tests] considered in the past

Scenario	Age-aggregated		Age-structured	
	ML	Bayes	ML	Bayes
Baseline*	X[a,e]	X[a,d,f]	X[b,c]	X[b,c,d]
Logistic production function (z = 1)	X[a]	X[a]		
Uncertainty in catch	X[a]	X[a]		
Random error in bycatch	X[a]	X[a]		
Alternative catch series based on accounting for mis-reporting by small vessels	X[a,e]			
Pre-specified bias in catch	X[a]	X[a,d,f]		
Estimated bias in catches	X[a]	X[a]		
Process error in surplus production	X[a]	X[a]		
Process error in surplus production & logistic production function		X[b]		
Pre-specified levels of *r*, the intrinsic rate of growth	X[a,e]	X[a]		
Change in *r* in some years (*e.g.* 1993)	X[a]	X[a,d,f]		
Change in *K* in some years (*e.g.* 1990)	X[a]	X[a,d,f]		
Annual mortality rate changes with sets		X[d]		

* Theta-logistic model, time-invariant parameters, known bycatch, no process error
a: IATTC (2009); b: IATTC (2006); c: Hoyle and Maunder (2004); d: Wade *et al*. (2002); e: Lennert-Cody *et al*. (in press); f: Wade *et al*. (2007)

Appendix A

TERMS OF REFERENCE

1. Review the population assessment model methodology, evaluate whether the model assumptions are appropriate, and identify alternative model assumptions.
2. Evaluate whether the sensitivity analyses are adequate and identify alternative sensitivity analyses.
3. Determine whether there is adequate information to estimate the current population growth rate.
4. Evaluate which hypotheses for the perceived lack of increase in abundance are supported by the data.
5. Recommend analyses that are needed to better understand the population assessment model and to evaluate the alternative hypotheses.

Appendix B

DOCUMENTS REVIEWED

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