Report on the "Assessment of the Population Dynamics of the northeast offshore spotted and the eastern spinner dolphin populations through 2001".

Malcolm Haddon
Marine Research Laboratory
Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Nubeena Crescent
Taroona, TAS 7053
Australia
Malcolm.Haddon@utas.edu.au

Executive Summary

The determination of whether purse seine fishing in the Eastern Tropical Pacific is hampering the recovery of the northeastern offshore spotted dolphin and eastern spinner dolphin populations is a difficult problem. The question was not answered satisfactorily by a simple consideration of population abundance estimates, despite these estimates being made using innovative methods and great care and effort. The three population estimates made in 1998-2000 did not differ statistically from the five estimates made in 1986-1990. In order to determine if recovery were occurring the available data needed to be assessed using a population dynamics model.

Three different models were investigated, a simple exponential growth model, a generalized logistic model (that included a non-linear density dependent term), and a more realistic age-structured model based on age-specific schedules of survivorships and fecundity (a Leslie matrix). The use of multiple models, having intrinsically different designs, provides for a more thorough investigation of the information contained within the data available for linking the models to reality.

The data available is limited to 12 fishery independent population abundance estimates made over 21 years. This data has been collected using standardized methods with the addition of innovative methods (in this context) of correcting for differences between observers. This data is the best available for describing the dynamics of the affected dolphin populations. However, there are only 12 data points and all of these were collected after the major period of dolphin depletion had occurred. A result of this limitation is that the data provide little insight into how the dolphins respond to changes in their population density (i.e. there is little information about density dependent effects). In addition to the fishery independent data, there is a fishery dependent series of Tuna Vessel Observer Data (TVOD), but these population estimates have received a persuasive critical treatment pointing out that there have been major changes to the way in which the information was collected through time (binoculars being replaced by radar and helicopters). This, along with other biases (and changing trends in those biases),

"make use of this index in population growth models ill-advised." Despite this limitation, this data should be re-examined to determine whether there are sub-sets within the data time-series that are less heterogeneous in how the information was collected, especially from before the fishery independent estimates were made. Any valid data from earlier in the fishery might assist in characterizing the density dependent dynamics. The inadvisability of using the fishery dependent population estimates (the TVOD) reinforces the value of conducting the fishery independent assessments. Without the line-transect information, assessment of the dolphin stock status in a defensible way would be extremely difficult or impossible.

The optimal fits of the exponential, the generalized logistic, and the age-structured models appeared to produce equivalent predictions of the state of the population of northeastern spotted dolphins over the period 1978 to 2000. All of these models differed in terms of the precision of the estimates they provided over this period with no single model appearing to be superior to the others. The generalized logistic and age-structured models differed in their predictions of the equilibrium unfished populations (and therefore of the depletion levels). However, the equivalence in the model predictions through the 1980s and 1990s was brought about by a failure of the data (only available after depletion had occurred) to provide information about density dependent processes. In effect, the density dependent terms in the models were redundant over the period 1978-2000. This means that the back projections from the first population estimate in 1979 back to 1958, when the dolphin populations were assumed to be in an unfished equilibrium, are greatly influenced by the very poorly determined non-linearity parameter used in the density dependent terms of the main models. This implies that the estimation of the unfished population size will be highly uncertain, as will be the estimate of the population depletion level. An important part of this uncertainty would derive from model uncertainty (which model best suites the data/system being described). The different models used should be compared directly (using the Akaike's Information Criterion – AIC, or Bayes' factors), to determine which model best matches the data. Alternatively, the outcomes from the two models should be combined in a Bayesian analysis to give an indication of the uncertainty around the depletion level that includes model uncertainty.

The models need to be amended to include unaccounted nursing calf mortality that derives from purse seine operations bringing about separations between mothers and calves, as well as the death of nursing mothers leaving the calves uncared for. This influence could also affect the estimates of dolphin kills right through the history of the fishery, so the kill data also needs review from that point of view. It is possible that a review of the photographic records of dolphin schools through time will enable an annual estimate of the proportion of juveniles to adults to be made. If such data is available in sufficient amounts to be representative of the different stocks then it should be included in the fitting process for the age-structured model.

There were attempts made to fit models that treated the 1979-1990 data separately to the 1998-2000 data (needing two gradients). This required two extra parameters, the year of the split and the new gradient. While in the case of the eastern spinner dolphin the 2-slope model provided a better fit it must be remembered that at least the extra gradient parameter is being fitted to only three data points. The amendments for the unaccounted for kill of nursing juveniles should be made and the comparisons between the 2-slope and the 1-slope models should be made again.

Given the constraints of the analyses listed above, the models predict that the northeastern offshore spotted dolphin stocks are growing at less than 2 % per annum. At that rate the population will take a further 20 years to reach a size of one million animals. The eastern spinner dolphin appears to be growing at an even slower rate (or possibly is continuing to reduce in numbers). The highest priority now should be given to reviewing the available data in a search for more information regarding the unaccounted mortality of juvenile dolphin and for information about either stock size or age-structure from before 1979, the first of the fishery independent abundance estimates.

Background

Statement of the Problem

In the eastern tropical Pacific Ocean, the tuna purse seine fishery has used the association between tuna and dolphins to target large yellowfin tuna (*Thunnus albacares*) for just over five decades. Unfortunately, once encircled by a large purse seine, if nothing is done to ameliorate the situation, a large number of the trapped dolphins can be drowned or crushed as the purse seine is hauled in. In fact, three stocks of dolphins were depleted by high historical levels of dolphin mortality in tuna purse seine nets, with approximately 4.9 million dolphins killed during the fourteen year period 1959-1972 (Wade, 1995). The species involved were the northeastern offshore spotted dolphin (*Stenella attenuata*), the eastern spinner dolphin (*Stenella longirostris*), and the coastal spotted dolphin (*Stenella attenuata graffmani*). This level of destruction led to a tuna consumer backlash and intense lobbying by conservation groups, eventually leading to the passage of the Marine Mammal Protection Act (MMPA) in 1972. In turn, this led to changes in the fishery with regard to which fleet actually did the fishing and also the procedures used to capture yellowfin tuna. These new procedures, designed to prevent dolphin deaths, decreased the bycatch mortality during the late 1970s and 1980s to reach such low levels in the 1990s that everyone considered that they should be biologically insignificant.

Changes to the net design and the introduction of backing down the net to allow the dolphins to escape, dramatically reduced the observed mortality of dolphins. The International Dolphin Conservation Program Act (IDCPA), introduced in 1997, amended the MMPA. This required the National Marine Fisheries Service (NMFS) to conduct research consisting of three years of population abundance surveys and stress studies in an attempt to answer the question set by the Secretary of Commerce about whether the “intentional deployment on, or encirclement of, dolphins by purse-seine nets is having a significant adverse impact on any depleted dolphin stock”. An alternative version of this question deriving from the advent of the IDCPA and given in a Report to Congress (SouthWest Fisheries Science Center, 1999) was “In the period since 1991, has there been for any depleted ETP dolphin stock a failure, attributable to fishery activities, to grow at the expected rate?“ In effect, NMFS must determine whether the depleted dolphin stocks are recovering, and if so, at what rate and with what level of certainty. Determining “the expected rate” of recovery is also difficult given a lack of biological information.

This review is to focus upon the most recent assessment (Wade, 2002) paying particular attention to the data used, the models developed, and the processes used to estimate the population growth rates, particularly of the northeastern offshore spotted dolphin and the eastern spinner dolphin.

History of the Problem

The following is an attempt at a brief synthesis of the historical sequence and driving forces behind the problem and its related research. It derives from all the literature cited in the bibliography but, in addition, from my interpretation of many of the comments made during the formal review meetings at La Jolla at the start of April 2002.

Before 1950, Yellowfin tuna was taken in the Eastern Tropical Pacific (ETP) region using the classical pole and line method. It was sometime in the 1950s that the fishers discovered that the biggest Yellowfin tuna tend to swim directly under schools of dolphins, especially large schools. Apparently, it was in 1959 that the fishing fleet began to switch to using purse seines. During the 1960s, large numbers of dolphins (in some years totalling more than 600,000 across all species) were crushed or drowned in the fishing process using the new purse seines. This began the serious population depletions seen in the affected stocks.

In the 1970s, a fisher, personally concerned at the level of dolphin mortality, raised an alarm that was taken up by numerous conservation groups. This led directly to a consumer boycott of canned tuna in an effort to change the behaviour of the fishery. In addition, the U.S. Congress was encouraged by public pressure to pass the Marine Mammal Protection Act (MMPA) in 1972. This led to observers being required on U.S. tuna boats as well as changes to fishing practices being required with the aim of minimizing dolphin kills. Through the late 1970s and the 1980s, U.S. purse seine boats tended to leave the fishery and fish elsewhere, leaving the fishing to foreign boats from Mexico and other southern countries, which, at that time did not have to adhere to the provisions of the MMPA.

Continuing mortality of dolphins through purse seine fishing activities in the 1980s led to a new round of protests and consumer pressure, which led to the introduction of the 'dolphin-safe' tuna can label (implying that no dolphins had been killed, either intentionally or through neglect; accidental kills were still allowed). In 1992, following growing concern about dolphin mortality rates, there was a meeting held leading to what has become known as the La Jolla Agreement. This led to the tuna fleets, primarily composed of foreign vessels, adopting more conservative capture methods (releasing any dolphins before hauling in the purse seine). A further meeting, leading to what has become known as the Panama Agreement or Declaration, led to some significant changes in how dolphin kills were managed. All purse seine tuna vessels fishing in US waters were required to carry observers, who have been active in determining remaining rates of dolphins killed and producing a fishery dependent estimate of the number of dolphins. In addition, each vessel became responsible for its own dolphin kills. Once a vessel's limit had been reached it had to stop setting on dolphins. The Panama Agreement also helped lead to the IDCPA being passed by Congress in 1997, which amended the MMPA to require the research discussed in this review.

The fact of stock depletion was easily demonstrated but whether stock recovery has occurred is more difficult. The most recent abundance estimates made in 1998, 1999, and 2000 all show that the populations of offshore eastern spotted dolphins and eastern spinner dolphins remain at a relatively low level. The Report to Congress (SWFSC, 1999, p.vi) was referring only to the 1998 estimates for the two species but their statement can now stand for all three recent estimates: "These estimates are not statistically different from estimates based on research vessel surveys conducted during the 1986-1990 Monitoring of Porpoise Stocks (MOPS) and require the context of a population model to determine if recovery is taking place." This lack of recovery was unexpected. It appears that during the 1990s, when no fishery independent surveys were conducted, it was believed that the dolphin stocks would be showing signs of recovery after a number of years of very low fishery induced mortality. However, if recovery is taking place then a population model is required to detect it.

The present assessment (Wade, 2002) derives from the previous assessment reported in the Report to Congress (SWFSC, 1999). The modelling was conducted by Dr Paul Wade, who used a variety of different models in an attempt to describe the dynamics of the populations.

Review Activities

The dates for the review at La Jolla were finally confirmed on the 26th April 2002. Most of the review documents were placed on a web site for download by the reviewers on Friday 29th April, 2002. Unfortunately, from Australia, I was only rarely able to open the web site and completely failed to get a positive response when trying to download the required documentation. Manoj Shivlani, in Florida, who arranged the review contract details, was kind enough to download the review documents (see references) and email them to me. These documents and other supporting material found elsewhere were read in the days immediately prior to the review meeting held at La Jolla in San Diego over the 3rd and 4th of April. Other material, such as the Report to Congress and an unpublished paper describing the methodology used by Dr Wade, was kindly provided during the review meeting. I would recommend that future reviews be arranged with more of a lead in time for the reviewers. I am sure that both the reviewers and those whose work is being reviewed would appreciate that.

On Wednesday 3rd April, Dr Murdoch McAllister and myself arrived at the South West Fisheries Science Centre laboratory of the National Marine Fisheries Service, at La Jolla, to begin the review of the assessment of northeast offshore spotted and eastern spinner dolphins. We met with members of the research team in the large conference room at the Science Centre. Those present for one or both days of the review were:

- Dr. Paul Wade – who gave a presentation on his assessment model.
- Dr. Steve Reilly – the IDCPA research coordinator, described the development of the problem under consideration and of the research program.
- Dr. Tim Gerrodette –gave a presentation and further information on the processes used in generating the dolphin abundance estimates.
- Dr. Wayne Perryman - dolphin photogrammetry specialist
- Dr. Paul Fiedler - ecosystem specialist, oceanographer
- Dr. Lisa Ballance - ecosystem specialist
- Dr. Bill Perrin - ETP dolphin specialist
- Dr. Dave Bratten – representing IATTC
- Dr. William Fox – Chief Scientist, NMFS, Washington Office
- Dr. Michael Tillman, Director of SWFSC
- Dr Frederick Archer – SWFSC, addressed the meeting on the mother-calf relationship.
- Ms. Nicole le Boeuf – NMFS, Washington Office
- Ms Megan Donahue, SWFSC
- A few other observers, such as research assistants involved in the various projects.
- Dr Murdoch McAllister, Imperial College London, Reviewer
- Assoc. Prof. Malcolm Haddon, University of Tasmania, Reviewer

After introductions a tentative agenda was agreed upon and involved:

- A presentation by Dr Steve Reilly introducing the context in which the assessment had been conducted and some of the background information.
- A presentation by Dr Paul Wade on the assessment he had most recently written.

- A presentation by Dr Tim Gerrodette on the 12 abundance estimation surveys.

While the presentations were formal, the speakers encouraged the audience to ask questions at any time throughout their talks. In this way we quickly covered the main points of the assessment, grasping the models used and the data the models were based upon.

At the end of the first day of the review Dr McAllister and myself discussed options for the following day and requested the following:

- A presentation regarding the estimates of age-selectivity used to project the dolphin populations backwards.
- A presentation on the alternative hypotheses being suggested to account for the modelling results.
- A review of actual effort, in terms of numbers of sets on dolphins.

During the day, these presentations and the questions they led to generated discussion concerning the age-selectivity and its influence on the modelling. In addition, the discussion of stress, induced through dolphins being set upon, was stimulated by the graph of numbers of dolphin sets. The assumption, as stated in SWFSC (1999, p.4), had been that the average number of sets was about 8,000 a year. The updated diagram of number of dolphin sets showed there had been a large increase above this level after about 1985 (see later, p. 17). This, combined with the impact of setting on dolphins that could arise through separating calves from their mothers (Archer *et al*, 2001) led to revising the model structure to add a fishery effect to the calf survival rate (already in the model) combined with the number of sets on dolphins through time. The evidence for a regime shift in the ETP was also considered.

The review required the meeting with the scientists involved in the research because the final report from the project has yet to be completed. Indeed, we could see that the modelling continues to be refined and tested. Some of the suggestions the reviewers presented have already been adopted into the model so parts of the review report relates to material already accepted. The review process was conducted in a positive and friendly atmosphere with intense enthusiasm being expressed for anything that might lead to either improving the model or providing a test of the information.

I would like to thank the research team at La Jolla for making the review such a positive experience. Their helpfulness and speed of response to questions or requests for data and information has been greatly appreciated.

Summary of Findings

In the formal review process we focussed on three main questions:

1. Were the modelling approaches adopted appropriate?
2. What more should be done?
3. Has appropriate data been used as an input to the models?

Each of these main questions led to their own set of sub-questions that provided the foundation for the academic review of the assessment.

Were the modelling approaches adopted appropriate?

During the review, we were presented with the latest draft of the final report on the modelling (Wade, 2002); the final report to the project is only due in the middle of 2002. Despite this document only being a draft, when it was combined with the presentation made by Dr Wade during the review at La Jolla, along with published literature describing the structure of the various models (SWFSC, 1999; Wade, 1999; Wade, *In Press*) we were able to comment thoroughly on the modelling approaches adopted. The details of the most recent results were not given in detail in the draft report because these are still being produced.
When conducting assessment modelling, the strategy of developing more than one model, with each being structurally or conceptually different from the other, is now standard and best practice. Each modelling approach adopted places emphases on different aspects of the available data. If there are differences between the outcomes of the different models then this can provide more insights about the dynamics of the system under study than only using a single model. If the models used provide similar results then because they are conceptually different one gains more confidence in the model outcomes (Hilborn and Walters, 1992).

The principal source of data with regard to the purse seine induced mortality on the dolphin populations was discussed and reviewed by Wade (1995) and SWFSC (1999). The data used in the modelling of the eastern spotted dolphin was kindly provided to the reviewers on request and this data was used in the following investigations (Fig. 1). The 12 population estimates made on research cruises through the eastern Tropical Pacific (Fig. 2) were provided in Gerrodette and Forcada (2002). These data will be considered in the next section. Of critical importance is the fact that while some biological information is used, the modelling is based only upon the 12 data points describing the population sizes in the years of fishery independent survey. Despite the good quality of the population estimates this is still only a limited dataset to which the models used are to be fitted. It puts an upper limit on the number of independent parameter estimates that are possible.

As stated by Wade (2002) "Two types of population growth rate will be estimated: (1) the productivity of the population from 1979-2000 and (2) the maximum population growth rate (R_{max} or λ_{max}) under the assumption of a density-dependent model where pre-exploitation population size in 1958 is considered carrying-capacity. Both a simple (aggregated) population model and an age-structured model are used."

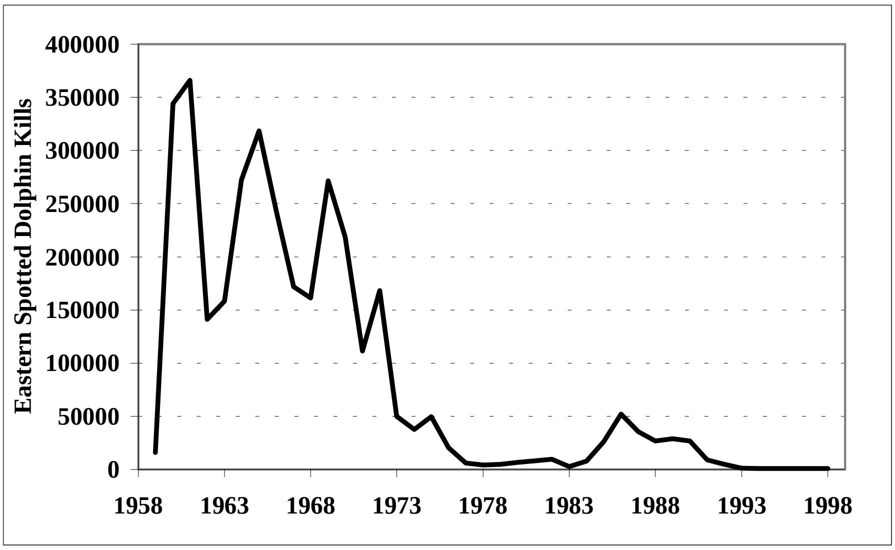

Figure 1. The history of northeastern spotted dolphin purse seine induced mortality since 1959 (data from Wade, 1995; SWFSC, 1999; and provided to the review team as a text file).

Initially, Wade (2002) uses an Exponential model to provide a simple estimate of the productivity over the period 1979 – 2000. This model would have the structure:

(1) $$N_{t+1} = N_t e^r - H_t$$

where r is a measure of the productivity of the population, N_t is the population size in year t, and H_t is the purse seine bycatch kill of dolphins in year t. The residual error structure used when fitting this to the available population estimates is log-normal. Natural mortality is not included explicitly because that is included implicitly in the productivity term r. This model has no density-dependent term and represents exponential growth, which is modified by known levels of bycatch mortality. It is used to reflect the simplistic expectation of exponential population growth once excess mortality (the bycatch kill) is removed.

I was able to replicate this model and the simple least squared residuals analysis that I used (equivalent to the maximum likelihood estimate when using normal or log-normal residual errors) produced essentially identical results to Wade’s (2002) Bayesian analysis of the exponential model and data (Fig. 2). The least squared analysis suggested that the productivity of the population in the absence of density dependence was approximately 1.975 % per annum. The 95% probability limits around this estimate obtained using a Bayesian analysis are reported as being –0.5 % to 4.0 %. When the log-normal residuals around the optimal fitted model are bootstrapped 10,000 times (Haddon, 2001), the central 95% of the estimates of the production parameter r were 0.18 % to 3.85 % (Fig. 3), which agrees very closely with the assessment given in Wade (2002).

The reason that the exponential model analysis has been repeated and the details given is that there is a remarkable resemblance between the outcomes of this model with those of the generalized logistic model (Fig. 2), which was also fitted to the data provided.

Figure 2. The optimal fit of the exponential model (Eq. 1). The predicted population productivity was 0.01975 (1.975% per annum). The points are the research vessel abundance estimates (data from Gerrodette and Forcada, 2002). If the optimal fit from the generalized logistic were also shown on this graph the predicted lines would not be visually distinguishable.

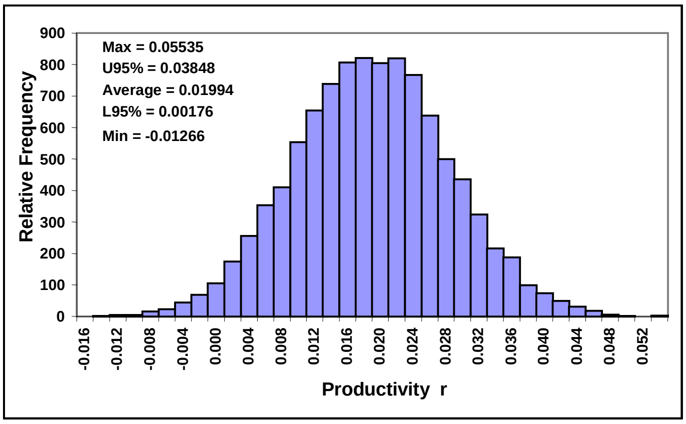

Figure 3. 10,000 bootstraps of the exponential model (Eq. 1) illustrated in Fig. 2. The 95 % central interval appears slightly tighter than the Bayesian analysis presented in Wade (2002). Interestingly, the distribution is essentially flat between values of 0.016 and 0.022. It took 10,000 bootstraps to remove an obvious dip at the 0.02 bin. It is possible that the lack of population estimate data in the 1990s makes this productivity slightly less likely than values immediately either side of it.

The more complex generalized logistic model implements a non-linear density-dependent term, with the non-linearity being introduced by the parameter *z*. The model equation has the form:

(2) $$N_{t+1} = N_t + N_t R_{MAX}\left(1 - \left(\frac{N_t}{K}\right)^z\right) - H_t$$

where *K* is the unfished equilibrium population and the other terms are as previously described. To convert an estimate of the population production parameter *r* to an estimate of R_{MAX} one uses the following relation:

(3) $$R_{MAX} = e^r - 1$$

Using the full time series of northeastern spotted dolphin kills with the 12 population estimates, the model (Eq. 2) was fitted using a least squared residuals method on log-normal residuals between observed population sizes and model estimates. Because of the addition of the density dependent term in Eq. 2, the expectation was that the results from the two models would be different. However, the optimum fit, which was very stable for R_{MAX} (Fig. 4), produced an estimate of R_{MAX} of 0.019944, which is what one obtains when one converts the optimum estimate from the exponential model of the population production parameter r = 0.0197474 using Eq. 3. In addition, both models predict a population size of 667,377 in 1978. These values are very robust to the initial starting values in the search for the optimum, while the K estimate adapts to whatever value of z is settled upon.

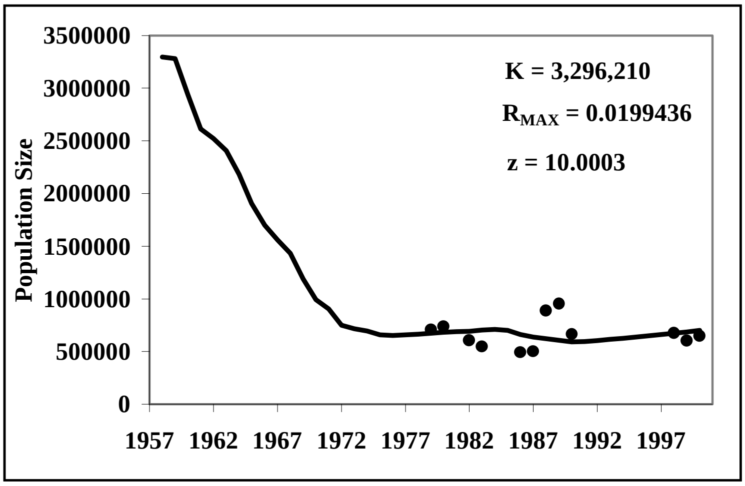

Figure 4. Optimal fit of the generalized logistic (Eq. 2) to the northeastern offshore spotted dolphin population data. The optimum predicted population trajectory line is effectively coincident with that obtained from the exponential model.

The coincidence between the two models should not be seen as surprising. The only data being used to fit each model are the fishery-independent abundance estimates. The effect of this is to force the generalized logistic to mimic the simpler exponential model. Because the available population estimates all occurred after the major depletion period, the fitting process forces the non-linear production term z to take on a value sufficiently large such that there is no effective density dependence operating at the depleted population densities predicted for the 1980s and 1990s (Fig. 5).

In effect, the generalized logistic model is telling us no more than the simpler exponential model over the years 1978-2000. However, because of a lack of data the exponential model cannot validly be back projected into the years prior to 1978. The generalized logistic model, on the other hand, as a somewhat more realistic model of population dynamics, provides a description of events prior to 1978. This is sufficient reason to prefer the generalized logistic model over the exponential model, making the exponential model redundant. . However, the inability of the generalized logistic model to produce a precise estimate of z implies that any estimate of the unfished population, K, will be highly uncertain, as will the subsequent estimate of the population depletion level. Clearly, care must be taken in using this approach when estimating or interpreting this latter statistic. The available information can only provide a weak insight into the density dependent reactions of the dolphin populations so even a Bayesian analysis will only provide limited insight into the actual depletion levels.

If a means can be found of using the Tuna Vessel Observer Data then one would expect the two models to provide somewhat different results. Unfortunately, there are major problems involving determining the relative weights to give to the two series of data during the model fitting process and, more critically, the validity of the TVOD has been called into question by Lennert-Cody *et al* (2001). These issues are dealt with in the section relating to whether the data selected was appropriate.

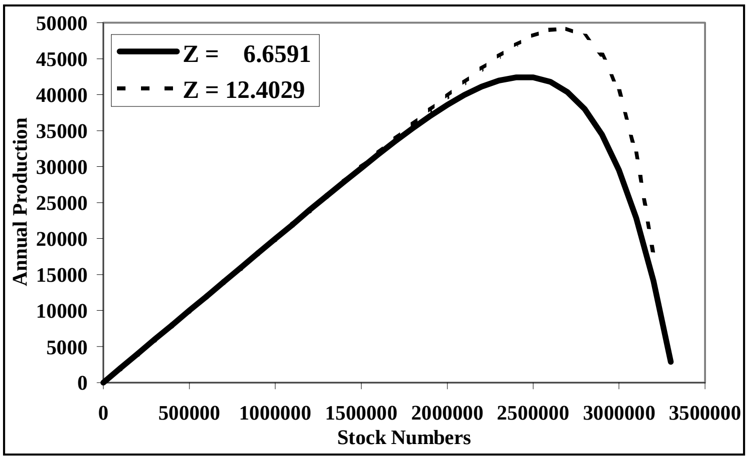

Figure 5. A comparison of the Annual Production at different population sizes for different values of the non-linear parameter from the density dependent term in the generalized logistic. Note that the *z* parameter is very poorly determined by the available data (*cf.* Wade, 1999). An increase in the *z* parameter leads to a higher productivity at the higher population levels but for populations below about 1.7 million the annual productivity increases as a constant proportion of population size (*i.e.* there is no density dependence, as in the exponential model). Depending on the starting value of the *z* parameter the initial population size *K* varies to account for the changing productivity at high population levels. In all cases the R_{MAX} value, the population size in 1978, and the subsequent time series of predicted population sizes remains closely similar across model fits.

Without additional data of some kind, the use of the generalized logistic provides no additional benefit beyond that provided by the exponential model. It is recommended that the use of the exponential model can be stopped for the northeastern offshore spotted dolphins. The analysis can be repeated for the eastern spinner dolphins (this was not done here because the exact data was not available), but because they also only have data after the main depletion has occurred then once again the generalized logistic can be expected to perform like the exponential model. The generalized logistic is the preferred model because it provides some predictions about the state of the populations before the large increase in mortality caused by purse seining.

Age-Structured Leslie Matrix Model

Given the limitations of the generalized logistic, more emphasis needs to be placed upon the age-structured Leslie Matrix model. To make the final report a stand-alone document the full set of equations describing the model, especially the full form of the density dependent term, needs to be included (presently one aspect of it is only explained by referring to a different publication). There have been a number of small variations on the model structure, so to avoid any confusion the whole model should be described explicitly, possibly in an appendix. The equations below are my interpretation of the structure that I have assumed was used in the modelling. If the actual structure deviates from this, it should not alter the conclusions about the various parameters.

The age-structured Leslie Matrix model has the most realistic structure of the models considered, however, its implementation is hampered through a lack of adequate biological information about age-specific survivorship and fecundity. The solution adopted of assuming a single survivorship for juveniles and another for adults is a reasonable solution. The transition matrix used, **A**, is a classic Leslie matrix, and the whole model uses a total of seven directly estimable parameters (plus a vector of age-specific selectivity independently derived from other data). It must be stated that seven parameters from 12 data points is pushing the bounds of what is reasonable, although it appears from Wade (2002) that *a* was set to a constant in the fitting process. These parameters identify the critical assumptions of the model and are:

(a) S_j the rate of juvenile survivorship,
(b) S_a the rate of adult survivorship,
(c) f_m the maximum fecundity rate,
(d) K the unfished, equilibrium population size,
(e) *ASM* the age at sexual maturity, used to determine where in the Leslie matrix the fecundity terms should enter,
(f) z the non-linearity term used in the density dependent influence on fecundity,
(g) a age of transition between juvenile and adult survivorship,
(g) **s** the age-specific selectivity of the purse seine mortality.

The population dynamics are simply described by:

(4)
$$\mathbf{N_{t+1}} = \mathbf{AN_t} - \mathbf{H_t}$$

where $\mathbf{N_t}$ is a vector of population numbers in each of the n age classes (the age-structure; for the northeastern spotted dolphin population n was assumed to equal 40), **A** is an n x n matrix (the Leslie matrix) describing the dynamic relations between age classes, and $\mathbf{H_t}$ is a vector of purse seine induced mortalities by age-class. The vector $\mathbf{H_t}$ would be formed from:

(5)
$$\mathbf{H_t} = h_t\mathbf{s}$$

where h_t is the total number of dolphins killed in purse seines in year t, and **s** is a vector describing the age-specific selectivity of the purse seine mortality. In Wade (*In Press*), **s** was assumed to equal the proportional age distribution for each year. In the latest assessment (Wade, 2002) an estimate of the age-specific selectivity was obtained from aged samples of dolphins killed in the 1980s, and this was assumed to apply for all years. This assumption may be weak and the equilibrium age-structure should be compared to the one that was used to generate the age-specific selectivity values. If they are markedly different then the assumption of the same age-selectivity through time would be incorrect. The survivorship terms for adults and juveniles were estimated directly. The fecundity, however, contained a density-dependent with a form similar to the generalized logistic (Wade, *In Press*):

(6) $$f_t = f_0 + \left(f_m - f_0 \right) \left[1 - \left(\frac{N_t}{K} \right)^z \right]$$

where f_t is the fecundity rate in year t (assumed identical for all mature age classes), f_0 is the fecundity at a net recruitment of zero – the replacement level of fecundity (a closed form estimate of this in terms of other model parameters exists; this should be included explicitly in the model description instead of just pointing to a reference).

Once again the non-linearity parameter in the density-dependence term is a source of uncertainty. If this value is large (meaning z >5) then the fecundity term becomes constant up to relatively large population sizes (Fig. 6).

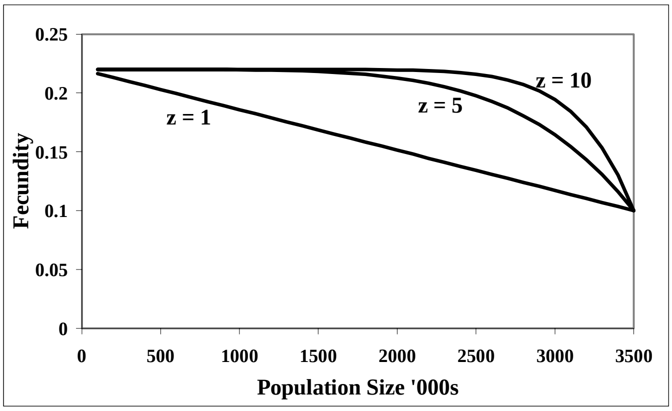

Figure 6. The relationship between fecundity, population size, and the non-linearity parameter z, as in Eq. 6. In this example, K has been set to 35000, f_m set to 0.22, and f_0 set to 0.1. The same pattern of an effectively constant fecundity for population sizes below 1.5 million exists for other reasonable values of these variables.

When this density dependent relationship for fecundity is combined with constant survivorships for juveniles and adults, then at the depleted population levels exhibited by the northeastern spotted dolphin, the Leslie matrix represents a constant rate of population growth, akin to the exponential and the generalized logistic models. The time delays inherent in the age-structured form of the Leslie matrix may be expected to provide some variations away from the predictions of the generalized logistic. However, when Figs 3 and 4 from Wade (2002) are overlaid (on a light table) the predicted optimum lines from both the age-structured and generalized logistic, from about 1978 to 2001, appear visually coincident. This suggests that the intrinsic rate of increase from the Leslie matrix would also be equivalent to that produced by the exponential and generalized logistic models. The precision of the population estimates differs between the models, as does the projection back to the unfished equilibrium population size. Selection between the different model predictions of unfished equilibrium population size remains a real issue. An AIC comparison between the generalized logistic and the age-structured model should be conducted. I have suggested using the AIC but the comparison could be made using Bayes' factors instead. The AIC, being based solely on the maximum likelihood estimates will not be influenced by any other the priors, which because of the difficulty of generating uninformative priors, may affect the comparison. For this reason the AIC comparison may have advantage. An alternative would be to attempt a combined Bayesian analysis using both the age-structured and generalized logistic models so that the uncertainty around the unfished equilibrium size and the resulting depletion level would include model uncertainty as well as other sources.

There were attempts made to consider models that exhibited a change in regime between the 1979-1990 and the 1998-2000 sampling periods. A justification for doing this is that there was a correlated regime shift in the oceanographic conditions at about the same time (Hare and Mantua, 2000; McPhaden and Zhang, 2002). The new model fits were based upon the models having two gradients of population growth rate (2-slope models were compared with 1-slope models). This actually required two extra parameters, the year when the gradient changes and the new gradient. In the case of the northeastern offshore spotted dolphin the 1-slope model remained the optimum. However, with the eastern spinner dolphin, the AIC comparison indicated that the 2-slope model provided a better description of the abundance estimates than the 1-slope model (see Figs 14 and 15 in Wade, 2002). It must be remembered, however, that at least the extra gradient parameter is effectively being fitted to only three data points (the 1998-2000 abundance estimates). In the exponential model, the 2-slope model predicts an initial population increase of 9.5% while the density dependent model had the eastern spinner dolphins expanding in the early years at 8 % per annum. These rates of increase appear high in terms of dolphin biology. The 2-slope model has both unlikely and uncertain aspects that mean it should be regarded with great caution. If these populations are only increasing at a rate between 1 and 3 % then it would be very hard to detect over a short time interval. A good model fit does not constitute a test of an hypothesis (Haddon, 2001). While the 2-slope model provides a better fit to the 12 data points for the eastern spinner dolphin, further evidence that such a regime shift has occurred in the dolphin populations is required independently of the model fit.

What more should be done?

During the discussion of the alternative possibilities regarding the perceived slow recovery rate of the two main dolphin species, we considered both the idea of a regime shift in the Eastern Tropical Pacific, and whether there was some other source of significant mortality that was not yet included in the modelling.

With regard to regime shifts there does appear to be some evidence of shifts in abundance of both yellowfin tuna (significant increase in abundance since 1987) and bigeye tuna (more variable numbers but a big decrease in numbers between 1986 and 1991, which has since reversed). The oceanographic evidence of potentially influential shifts in temperature regime and circulation turnover changes (Hare and Mantua, 2000; McPhaden and Zhang, 2002) appears convincing but remains only as a correlation with the failure of the dolphins to recover as quickly as was hoped. The yellowfin tuna populations increased significantly following 1987 despite increased fishing pressure. However, there is no explanation for why there was no equivalent increase in the associated dolphin populations despite a significant reduction in bycatch mortality. Rather the 2-slope models suggested that the two dolphins species were both negatively affected by such a regime shift, so that if the model were true then the northeastern offshore spotted dolphin was declining at 1.6% per annum and the eastern spinner dolphin by 5.6 %.

These studies, attempting to relate the population dynamics of major components of the Eastern Tropical Pacific remain interesting but are, as yet, based primarily on correlation studies. They constitute the addition of a qualitative increase in the amount of uncertainty around the modelling of the affected populations. Without this reminder that there may be trends in the population data being environmentally driven it might be possible to forget that a model is only a model of the data and ideas that is put into it. However, at present it is unknown how the dolphins may respond to any change in oceanographic regime. If the results of the 2-slope modelling are followed they suggest that the two species have responded differently.

Of more direct significance to the modelling were the discussions held over the potential unreported loss of nursing calves occurring during the chase and encirclement of dolphin schools (Archer *et al*, 2001). There is a close association between mothers and calves for up to two years after birth. Unweaned calves, especially, swim in literal close proximity to the mother’s shoulder. During the chase involved in preparing a dolphin school for encirclement by a purse seine it is likely that there will be some separation of mother calf pairs, which will at least increase the likelihood of the calf dying in the absence of the mother. In addition, in past estimates of dolphin mortality, there will have been cases where mothers were purse seined after separation from their calves. If the mother was killed in the operation then it is highly likely that the calf will also die, but this mortality will go unrecorded. Archer *et al* (2001) estimate that this phenomenon would lead to an increase in the mortality of spotted dolphins of between 10 – 15% and 6 – 10 % for spinner dolphins. In the review meeting, it was also reported that in photographs of dolphin schools the percent of calves (identifiable by their shorter length) was only 6 – 7% when it should be closer to 12 %; in recent years the numbers have been even less than 6 - 7 %. Such a deficit in calves will greatly effect stock dynamics. If effort had remained stable at about 8,000 sets on dolphins (SWFSC, 1999, p. 4) then the modelling would have absorbed this relatively constant mortality into the estimates of overall population production. The reviewers requested that a literal plot of sets on dolphins against years be produced as a check on this assumption of relatively constant effort directed at dolphins. In addition the data was sent to us (Fig. 7).

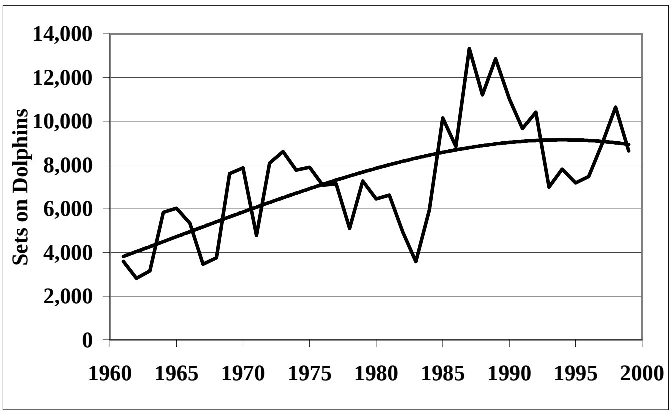

Figure 7. The number of purse seine sets made upon dolphin schools (source: IATTC annual reports). Note this is the number of sets for all dolphin stocks, not by stock. The line is a third order polynomial put there to indicate the trend. The more extreme variation in numbers of sets in the 1980s and 1990s indicate a continuing relatively high level of setting on dolphins.

The available data indicate that the number of sets on dolphins has neither stayed stable nor decreased (Fig. 7). It is possible that, with the improving success at releasing dolphins without killing them, purse seiners have even increased their targeting of dolphin schools. If there is a continuing, inadvertent and unreported mortality of calves associated with schools being targeted (as seems extremely likely, Archer *et al*, 2001) then this source of mortality should be explicitly modelled. It should certainly be included in the early estimates of mortality. Once the amendments for the unaccounted for kill of nursing juveniles are made, the comparisons between the 2-slope and the 1-slope models should be made again.

The unaccounted kill could be included in the generalized logistic as an additional term of number of successful dolphin sets x rate of calf loss (perhaps $-H_t^j$) beside the bycatch levels already accounted for in the model. The data should really be segregated as dolphin sets per species/stock. Thus:

(7) $$N_{t+1} = N_t + N_t R_{MAX}\left(1 - \left(\frac{N_t}{K}\right)^z\right) - H_t - H_t^j$$

In the age-structured model one could modify the calf survival rate s_j directly by the increase induced by the calf loss (or it could be included more simply as above). This is such a significant source of additional non-constant mortality that is needs to be included in the modelling. If there is information in early photographs concerning the relative proportions of the different age-classes represented in the age-structured model, then this could provide an additional data source against which to fit the model. This would also be an important addition. However, it would require that the photographs were representative of the population and this would need to be assessed.

Has appropriate data been used as an input to the models?

There were a number of sources of data including:

- Catch history of dolphins killed in the purse seines (e.g. Wade, 1995).
- Fishery independent line-transect surveys of dolphin population abundance (1979-80, 1982-83, 1986-90, and 1998-2000; Gerrodette and Forcada, 2002).
- Fishery dependent estimates of dolphin abundance – Tuna Vessel Observer Data (TVOD; Lennert-Cody *et al*, 2001).
- Biological information concerning the dolphin species concerned (various sources).

The catch history of dolphin bycatch kills in the ETP purse seine fishery has been reviewed a number of times (Wade, 1995; SWFSC, 1999). However, these data will need a further revision to take into account the unrecorded mortality of nursing calves (Archer *et al*, 2001). If the level of calf mortality has always been as high as recently estimated this would have been highly significant and have had important effects on the depletion and the present rate of recovery of the different dolphin stocks. This will certainly have an impact on the estimates of unfished equilibrium population and hence the present level of depletion. It would certainly be slowing the rate of recovery of the present stocks. In addition the age-selectivity vector taken from kills in the 1980s will have been constructed incorrectly.

The fishery independent line-transect population abundance estimates provide the main data source for relating the dolphin populations to the models used to characterize their dynamics. These have been conducted in a standard way since their inception. Where they have improved is in the analysis and through developing methods for correcting for observer bias in school size estimates. This latter was difficult but very necessary and innovative work. It involved comparing observer counts with aerial photographs of schools taken from helicopter, developing statistical models that described the relative performance of each observer and then producing correction factors for each observer. The attention to detail and success of the technique are to be commended. One unfortunate problem, about which nothing can or could be done, is that these fishery independent surveys only began after the dolphin populations had suffered most of the depletion they were going to experience. Nevertheless, without this data, the modelling exercise would not have been possible.

Despite the abundance surveys being executed about as well as possible, the results deriving from them provide an ambivalent signal as the 1980s turned into the 1990s. Whether the model results are equally sensitive to each of the data points could be determined by an analysis analogous to a Jacknife (Haddon, 2001). This would involve fitting the model to subsets of 11 data points at a time, sequentially omitting each data point in turn. The objective would be to test the relative influence of each of data point (Fig. 8). As it happens, for the northeastern offshore spotted dolphins, with the generalized logistic the trend through time is hardly affected by removing each data point in turn although the exact location on the population size axis is affected (Fig. 8). This suggests than no single point has excessive influence over the predicted population trajectory.

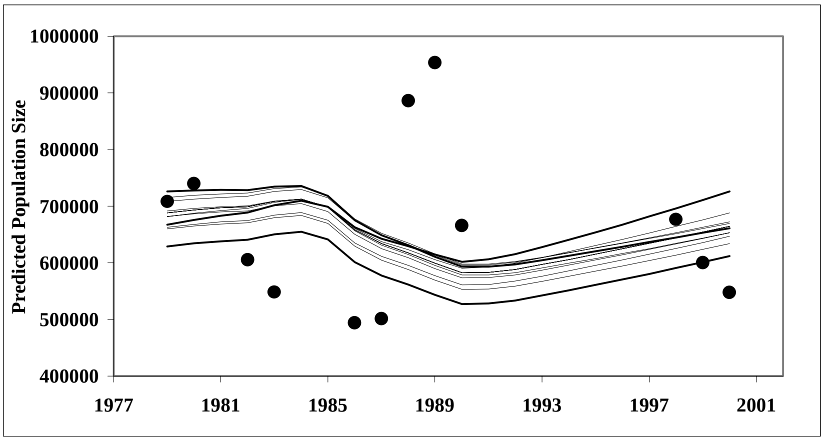

Figure 8. A plot of the predicted population sizes from the generalized logistic model fitted to the data from the northeastern offshore spotted dolphin. Each of the 12 lines derives from omitting one of the 12 data points. The principal effect of this jacknife-like process is to alter the vertical location of the curve and not the pattern of the trend (i.e. most lines run roughly parallel to each other).

The Tuna Vessel Observer Data (TVOD) provides fishery dependent estimates of population abundance. However, serious doubts have been raised about its relative accuracy and subsequent usefulness (Lennert-Cody, *et al*, 2001). Unfortunately, they found that the methods used to estimate abundance indices were not without problems, and that there were other biases in the estimates and these had not been constant through the years. Since Lennert-Cody *et al* (2001) there have been further reappraisals of the TVOD conducted by Goodman and a student. They have found that group size estimates were wildly different between those made by Tuna Commission observers and the National Fisheries Marine Service observers. There have been fewer differences found between the separate estimates of mortality. The TVOD data (from SWFSC, 1999) need to be multiplied by approximately 0.626 (Fig. 9) to scale them to match the fishery independent abundance estimates (from Gerrodette and Forcada, 2002). After scaling to make the estimates comparable, they differ markedly in 1983, and the last three years, where the TVOD data indicates the population of spotted dolphins has declined severely.

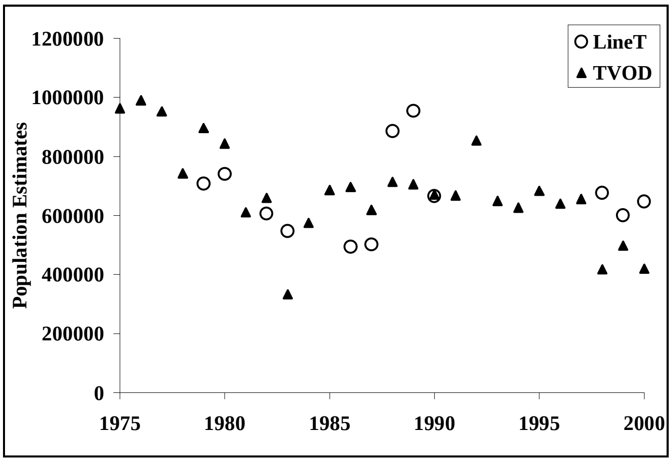

Figure 9. Comparison of the Tuna Vessel Observer Data (TVOD) with the fishery independent population estimates (LineT). The TVOD data have been multiplied by 0.626 to scale them as closely as possible to the line-transect estimates. To appreciate the scale, note that the difference between the two estimates in 1990, where the points appear to overlap, was about 5,300.

It would certainly be useful if the early data, from when there were no fishery independent data, were available and useful. For this to happen it would be necessary to show that any biases did not change significantly during the pre-1979 period and that assessment methods did not change in those years. If that data is more consistent than the whole data series it may prove useful in helping to define the density dependent behaviour of the stock. The same can be said for any sub-set of this data where the biases were stable and the methods were acceptable. Such a review, looking for sub-sets of useful data within the TVOD should be made as it would assist the modelling greatly to have more data points against which to fit the models.

During the review in La Jolla, it was suggested that the sensitivity of the models to including the TVOD into the process be considered. Until the review and searching for sub-sets has been completed, I would suggest that this data not be included. The criticisms leveled are serious and would weaken any conclusions drawn from the modelling rather than strengthen them. For the spotted dolphins, the two data series appear inconsistent, so the results will depend upon the relative weight given to each data series.

Conclusions/Recommendations

Through the text there are a number of aspects of the models and data that should be taken into account when attempting to interpret the results of the modelling. These include:

- The limited number of data points available to which to fit the models. This will limit the number of parameters that can be estimated with confidence.
- The inability of the data to provide information concerning any expected density dependent effects. This makes the density dependent terms effectively redundant at current population sizes.
- That the dynamics of the different models be considered as they are expressed at current population densities, and whether each type is telling the same things for each species being considered.
- That the uncertainty around the estimates of unfished equilibrium dolphin population abundance and the related estimates of current depletion rates is poorly determined when only one model is included in the analysis. The different density dependent models need to be compared or both included in a single Bayesian analysis so as to include model uncertainty into the estimates.
- That calf mortality has not been taken into account in the modelling nor in the estimates of total mortality. Both of these things (combined with the actual number of sets on dolphins) will have a marked effect on the modelling outcomes.
- That the TVOD data be reconsidered to determine whether there are any sub-sets that could be taken from it and included in the model. These would need to be more homogenous in how the estimates were made than in the complete data set.
- That the comparisons between the 1-slope and 2-slope models be treated with great caution because of the lack of data and lack of a mechanism for the regime shift (other than a correlation with oceanography).

DISCLAIMER

This information has been provided by way of review only. The author makes no representation, express or implied, as to the accuracy of the information and accepts no liability whatsoever for either its use or any reliance placed on it.

References

Allen, R. (2000) Inter-American Tropical Tuna Commission Scientific Working Group. Review of Dolphin Abundance Estimates. 19-20 October 2000, La Jolla, California, USA. *Chairman's Report.* 9 p.

Anon. Assessment of the population dynamics of the northeast spotted and the eastern spinner dolphin populations through 2001. *Unpublished report from the NMFS website*.

Archer, F., Gerrodette, T., Dizon, A., Abella, K. and S. Southern (2001) Unobserved kill of nursing dolphin calves in a tuna purse-seine fishery. *Marine Mammal Science* **17**: 540-554.

Forcada, J. (2002?) Multivariate methods for size-dependent detection in conventional line transect sampling. *Unpublished report from NMFS website.*

Gerrodette, T. and J. Forcada (2002) Estimates of abundance of dolphin stocks affected by the tuna purse-seine fishery in the Eastern Tropical Pacific ocean. *SWFSC Administrative Report LJ-01-* 23p.

Gerrodette, T., Perryman, W. and J. Barlow (2002) Calibrating group size estimates of dolphins in the eastern tropical Pacific Ocean. *SWFSC Administrative Report LJ-01-* 21p.

Haddon, M. (2001) *Modelling and Quantitative Methods in Fisheries.* Chapman & Hall/CRC. London. 406 p.

Hare, S.R. and N.J. Mantua (2000) Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography* **47**: 103-145.

Hilborn, R. and C.J. Walters (1992) *Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty*. Chapman & Hall, London.

Lennert-Cody, C.E., Buckland, S.T. and F.F.C. Marques (2001) Trends in dolphin abundance estimated from fisheries data: A cautionary note. *Journal of Cetacean Research and Management* 3: 305-319.

McPhaden, M.J. and D. Zhang (2002) Slowdown of the meridional overturning circulation in the upper Pacific Ocean. *Nature* **415**: 603

Perkins, P.C. and E.F. Edwards (1999) Capture rate as a function of school size in pantropical spotted dolphins, *Stenella attenuata*, in the eastern tropical Pacific Ocean. *Fishery Bulletin* **97**: 542-554.

Reilly, S.B. and J. Barlow (1986) Rates of increase in dolphin population size. *Fishery Bulletin* **84**: 527-533.

Southwest Fisheries Science Center (1999) Regarding whether the intentional deployment on or encirclement of dolphins with purse seine nets is having a significant adverse impact on any depleted dolphin stock in the eastern tropical Pacific Ocean. *Report to Congress* 60p.

Taylor, B. and D.P. DeMaster (1993) Implications of non-linear density dependence. *Marine Mammal Science* **9**: 360-371.

Taylor, B.L. (1999) Incorporating uncertainty in management models for marine mammals. *Proceedings 5th NMFS NSAW. NOAA Technical Memo, NMFS-F/SPO-40.*

Wade, P.R. (1995) Revised estimates of incidental kill of dolphins (Delphinidae) by the purse-seine tuna fishery in the eastern tropical Pacific, 1959-1972. *Fishery Bulletin* **93**: 346-354.

Wade, P.R. (1999) A comparison of statistical methods for fitting population models to data. Pp 249-270 *In:* Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.F.J., McDonald, L.L., and D.G. Robertson (*eds.*) *Marine Mammal Survey and Assessment Methods* Balkema, Rotterdam.

Wade, P.R. (In Press) A Bayesian stock assessment of the Eastern Pacific gray whale using abundance and harvest data from 1967 to 1996. *Report of the International Whaling Commission (Special Issue)* **17** : 23p.

Wade, P.R. (2002) Assessment of the population dynamics of the northeast offshore spotted and the eastern spinner dolphin populations through 2001. *Draft report provided in the Review Meeting on April 3rd at La Jolla, California.* 25p.

Appendix 1: Bibliography of All Material Provided For the Review

Archer, F., Gerrodette, T., Dizon, A., Abella, K., and Southern, S. 2001. Unobserved kill of nursing dolphin calves in a tuna purse-seine fishery. Mar. Mam. Sci. 17(3): 540-554.

Forcada, J., 2002. Multivariate methods for size-dependent detection in conventional line transect sampling. Report prepared for the Southwest Fisheries Science Center, National Marine Fisheries Service. La Jolla California.

Gerrodette, T., and Forcada, J., 2002. Estimates of abundance of dolphin stocks affected by the tuna purse-seine fishery in the eastern tropical Pacific Ocean. Report LJ-01- prepared for the Southwest Fisheries Science Center, National Marine Fisheries Service. La Jolla California.

Lennert-Cody, C.E., Buckland, S.T. and Marques, F.F.C. 2001. Trends in dolphin abundance estimated from fisheries data: a cautionary note. J. Cetacean Res. Manage. 3(3):305-319.

Perkins, P.C. and Edwards, E.F. 1998. Capture rate as a function of school size in pantropical spotted dolphins, *Stenella attenuata* , in the eastern tropical Pacific Ocean. Fish. Bull. 97: 542-554.

Reilly, S.B. and Barlow, J. 1986. Rates of increase in dolphin population size. Fish. Bull. 84: 527-533.

SWFSC. 1999. International Dolphin Conservation Act. Report to Congress. Available from SWFSC, P.O. Box 271, La Jolla CA 92038.

Taylor, B.L., and DeMaster, D.P. 1993. Implications of non-linear density dependence. Marrine Mammal Science 9(4): 360-371.

Wade, P. 1995. Revised estimates of incidental kill of dolphins (Delphinidae) by the purse-seine tuna fishery in the eastern tropical Pacific, 1959-1972. Fish. Bull. 93: 345-354.

Wade, P. 1999. A comparison of statistical methods for fitting population dynamics models to data. Marine Mammal Survey and Assessment Methods. GAmer et al. (eds) Balkema, Rotterdam, ISBN 90 5809 043 4.

Wade, P. 2002. Assessment of the population dynamics of the northeast offshore spotted and the eastern spinner dolphin through 2001. Doc. prepared for the Southwest Fisheries Science Center, National Marine Fisheries Service. La Jolla California.

Wade, P. In press. A Bayesian stock assessment of the eastern Pacific Gray whale using abundance and harvest data from 1967 to 1996. SC/48/AS8.

Appendix II: Statement of Work

STATEMENT OF WORK

Consulting Agreement Between The University of Miami and Dr. Malcolm Haddon

Background

The tuna purse seine fishery has used the association between tuna and dolphins to fish in the eastern tropical Pacific Ocean for over five decades. Three stocks of dolphins were depleted by high historical levels of dolphin mortality in tuna purse seine nets, with an estimated 4.9 million dolphins killed during the fourteen year period 1959-1972. After passage of the Marine Mammal Protection Act (MMPA) in 1972 and the increased use of fishing equipment and procedures designed to prevent dolphin deaths, mortality decreased during the late 1970s, 1980s and 1990s to levels that are generally considered biologically insignificant.

While changes in the fishery have greatly reduced the observed mortality of dolphins dramatically, the MMPA, as amended by the International Dolphin Conservation Program Act, requires that the National Marine Fisheries Service (NMFS) conduct research consisting of three years of population abundance surveys and stress studies to form the basis of a determination by the Secretary of Commerce regarding whether the “intentional deployment on, or encirclement of, dolphins by purse-seine nets is having a significant adverse impact on any depleted dolphin stock”. Specific to this review, NMFS must essentially determine whether or not the depleted dolphin stocks are recovering, and if so, at what rate and at what level of certainty.

The topic of this review is the overall framework that will be used to estimate the growth rate of two dolphin populations of interest, the northeastern offshore spotted dolphin and the eastern spinner dolphin. The framework uses growth rates estimated by fitting a population model to the three-year survey estimates and other available estimates of abundance. Estimates from research vessel surveys using line transect methods are available for three periods: 1979-83 (four estimates), 1986-90 (five estimates), and 1998-2000 (three estimates), for a total of twelve estimates over twenty-one years. Reviewers will also be asked to evaluate the inclusion or exclusion of a set of fishery-dependent indices of abundance, resulting from data collected by observers onboard tuna vessels. Two types of population growth rate will be estimated: (1) exponential rate of change from 1979-2000 and (2) intrinsic rate of increase under the assumption of a density-dependent model where pre-exploitation population size in 1958 is considered carrying-capacity. Both an aggregated population model and an age-structured model will be used. Bayesian statistics, using a numerical integration method, will be used to estimate a probability distribution for the population growth rate.

Specific Reviewer Responsibilities

Expertise needed to review these analyses will include familiarity with population dynamics and assessment models, including estimation of trend and estimation of status (depletion level) using density-dependent models. Additionally, familiarity with

Bayesian and likelihood estimation, including numerical methods, will be essential. Documents supplied to reviewers will include draft manuscripts, and a number of background papers (relevant publications and reports). The raw data and software used in the analysis will be made available to the reviewers upon request during the review.

The reviewer's duties shall not exceed a maximum total of two weeks, including several days to read all relevant documents, two days to attend a meeting with scientists at the NMFS La Jolla Laboratory, in San Diego, California, and several days to produce a written report of the reviewer's comments and recommendations. It is expected that this report shall reflect the reviewer's area of expertise; therefore, no consensus opinion (or report) will be required. Specific tasks and timings are itemized below:

1. Read and become familiar with the relevant documents provided in advance;

2. Discuss relevant documents with scientists at the NMFS La Jolla Laboratory, in San Diego, CA, for 2 days, from 3-4 April 2002;

3. No later than May 3, 2002, submitting the written report[1] addressed to the "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via email to ddie@rsmas.miami.edu.

Signed______________________ Date____________

[1] The written report will undergo an internal CIE review before it is considered final. After completion, the CIE will create a PDF version of the written report that will be submitted to NMFS and the consultant.

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The report should also include as separate appendices the bibliography of all materials provided and a copy of the statement of work.