# APPENDIX R

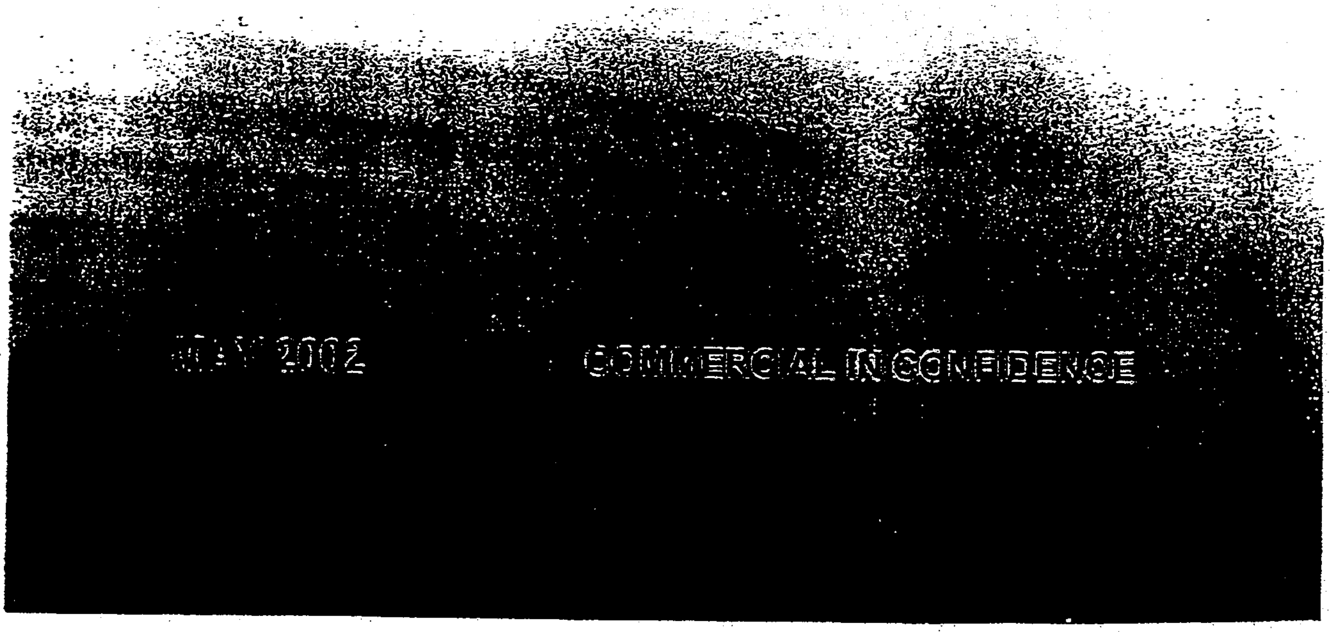
## Centre for Environment, Fisheries, and Aquaculture Science, *Review of Three Simulation Models for Sea Turtle Biology and Management in the Pacific*

CEFAS

The Centre for Environment,
Fisheries & Aquaculture Science

# REVIEW OF THREE SIMULATION MODELS FOR SEA TURTLE BIOLOGY AND MANAGEMENT IN THE PACIFIC

## FOR THE UNIVERSITY OF MIAMI INDEPENDENT SYSTEM FOR PEER REVIEW



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# 1. EXECUTIVE SUMMARY

## 1.1 Impetus and goals for the review

The consultant is required to provide a review of three simulation models examining sea turtle population biology. The reviewer shall analyze these reports, which examine loggerhead and leatherback sea turtles, focusing on the following:

1. Assumptions in defining the stock structures based on genetic or other information;
2. Application of the most recent biological, nesting beach, and fishery interactions data;
3. Underlying dynamics of the population models;
4. Applicability of the population models to the ongoing protected species recovery and fisheries management issues.

## 1.2 Main conclusions and recommendations

The models of Chaloupka are specifically designed for Pacific-wide turtle population analysis, and appear to require the least additional effort before they can provide the best information on which to proceed with protected species recovery and fisheries management analysis of relevance to the Hawaiian longline fishery and other U.S. interests. Wetherall's leatherback model concentrates on the Mexican leatherback population, and is likely to require considerable modification to incorporate the interactions of the other turtle meta-populations and anthropogenic impacts necessary to examine the wide range of issues of relevance to NMFS. The models of Chaloupka for leatherback and loggerhead turtle populations are perhaps biologically more realistic than that of Wetherall, and are certainly more complex. The values and functional forms of many of the parameters in the models of Chaloupka are unknown due to the paucity of suitable studies on the relevant turtle populations. This increases uncertainty in model outputs. Sensitivity analyses of the impact of the values and forms of these parameters on model outputs, assessments and perception of the population (recovery) need to be extended to identify those biological parameters which are important to the dynamics of populations. This will focus data collection on parameters which will best support the derivation of management. Wetherall's model is less data intensive, offers useful insights into the performance of the models of Chaloupka under uncertainty, and could be used to test the robustness of those models.

Scientific studies to populate the parameters will take a number of years to complete. It can be foreseen that management options will need to be developed in a shorter time frame. Chaloupka's models must therefore be used to derive management interventions which are robust to model uncertainties.

In their current form, Chaloupka's models will be useful for the identification of the likely causal factors of population decline. With development of management strategy simulation frameworks, for example, the models will be suitable for the examination of robust management interventions which halt declines in the short term, and result in long term stock recovery. They should also be used to inform the derivation of management targets for recovering turtle populations, and to develop practical early warning monitoring indicators for vulnerable sea turtle populations. The models should form the basis of discussion workshops examining potential management interventions.

A number of recommendations have been made throughout the text of this report. At present, the models of Chaloupka represent the best available information on which to proceed with species recovery and fisheries management in the Pacific. Consideration of the recommendations in this report will improve the models, and ensure that model outputs will provide suitable information of a quality sufficient for basing development of management strategies.

# 2. INTRODUCTION

Both leatherback turtle (*Dermochelys coriacea*) and loggerhead turtle (*Caretta caretta*) populations in the Pacific have been strongly affected by human activities. These activities include, for example, the loss of nesting habitat due to beach development, egg and female mortality on nesting beaches, hunting in coastal waters, and incidental mortality in fisheries. Declines in the numbers of female turtles returning to nesting beaches has led to considerable concern for the welfare of these populations. In the recent NMFS Biological Opinion (2001) leatherback turtles were listed as endangered, while loggerhead turtles were listed as threatened. As a result of the status of these populations, there is a need to develop appropriate strategies to halt declines and promote recovery.

## 2.1 Background

Simulation models have been developed by the U.S. National Marine Fisheries Service (Southwest Fisheries Science Center) to provide a quantitative foundation for assessing the impacts of the Hawaii-based pelagic longline fishery and other human activities on sea turtle populations. Two independent studies have been completed recently. In the first, two stochastic simulation models were developed under contract by a sea turtle modeling specialist, assisted by interactive workshops of invited experts. The first modeled Pacific leatherback sea turtles, with emphasis on western Pacific populations of this species. The second modeled the northwestern stock of Pacific loggerheads. In the second study, a simulation model of the Mexican leatherback population in the Pacific was developed.

An independent review of these models was requested, and forms the basis of this report.

## 2.2 Terms of Reference

The reviewer shall analyze the reports for loggerhead and leatherback sea turtles, focusing on the following:

1. Assumptions in defining the stock structures based on genetic or other information;
2. Application of the most recent biological, nesting beach, and fishery interactions data;
3. Underlying dynamics of the population models;
4. Applicability of the population models to the ongoing protected species recovery and fisheries management issues.

## 2.3 Description of Review Activities

The reviewer traveled to the NMFS Southwest Fisheries Science Center, Honolulu, Hawaii, for a two-day meeting with the model authors on the 2nd and 3rd May, 2002. During this useful meeting, the models were demonstrated and issues discussed. The green turtle workshop described in the Statement of Work did not go ahead, as work on that model is still underway.

Personnel met during the two-day meeting were from NMFS:
    Dr Mike Laurs
    Dr Jerry Wetherall
and the sea turtle modeling specialist:
    Dr Milani Chaloupka

Documentation made available to the reviewer is summarized in Appendix A.2.

## 3. REVIEW OF THE MODELS

The documentation for the three models was reviewed and discussed at the two-day meeting in Hawaii. The first two models were developed by Dr Chaloupka, and modeled populations of western Pacific leatherback sea turtle stocks and northwestern Pacific loggerhead sea turtle stocks respectively. These models are discussed together in Section 3.1. The third model was developed by Dr Wetherall, in collaboration with a number of Mexican scientists, and simulated the responses of Mexican Pacific leatherback populations to anthropogenic impacts. This model is discussed in Section 3.2.

### 3.1 Chaloupka turtle models

Dr Chaloupka developed two models which are similar in basic structure and approach. These stochastic simulation models were developed for the western Pacific leatherback sea turtle stock (which includes a sex- age class- and substock-structure) and northwestern Pacific loggerhead sea turtle stock (which comprises a sex- and age class-structure). In both cases the structure is linked by correlated time-varying habitat- density- and temperature-dependent demographic processes, incorporating environmental and demographic stochasticity.

#### 3.1.1 Assumptions in defining the stock structures based on genetic or other information

In this section, issues relating to assumptions in defining the stock structures based on genetic or other information which are unique to each model are discussed.

**Leatherback model**

Meta-populations are modeled as discrete sub-stocks, originating from Malaysia and Melanesia. Although current opinion is that there is no evidence of dispersal between leatherback substocks, the model is flexible enough to allow this capacity to be enabled if data are collected subsequently that prove otherwise.

The east Pacific population (Mexico stock) is not included currently in the model. However, there is genetic evidence that Mexican leatherbacks are caught in the Hawaiian longline fishery (NMFS Biological Opinion, 2001). Hence, this metapopulation should be included in the model. As a result of the model's formulation, it appears sufficiently flexible to allow this population to be added.

**Loggerhead model**

The model concentrates on the northwestern Pacific ('Japanese') loggerhead stock. This stock is known to interact with the Hawaiian longline fleet, and fisheries on the US Pacific and Mexican west coast. The southwestern loggerhead stock, with nesting sites around eastern Australia, is not currently included in the model since best information suggests that the two stocks do not mix. However, while the NMFS Biological opinion supports the fact that the vast majority of individuals caught in the Hawaiian fishery originate from the Japanese nesting stock ("nearly 100 percent"), it does state that that "the rest derived from Australia", referencing a personal communication with P. Dutton (Jan 2001). Consideration should be given on whether the Australian metapopulation should be simulated within the model or whether the level of interaction with fisheries of interest is sufficiently minimal for its impact to be ignored.

### 3.1.2 Application of the most recent biological, nesting beach, and fishery interactions data

In this section, issues related to application of the most recent biological, nesting beach, and fishery interactions data which are unique to each model are discussed.

**Leatherback model**

The model appears to be based on the latest knowledge of the biology of leatherback turtles. Limited biological information is actually available for western Pacific leatherback stock. As a result, the author sensibly used biological data from leatherback stocks from the Pacific, Atlantic and Indian Oceans to parameterize the model. Inevitably, this introduces uncertainty into the outputs from the model when attempting to simulate the western Pacific stock. The impact of this is discussed further in Section 3.1.4.

On page 12 of the manuscript, the assumption is made that there are no sex- or substock-specific differences in survival probabilities. However, it is noted in the next paragraph that clutch loss to tidal inundation or beach erosion is low for the Malaysian substock but quite significant for the Melanesian substock of the northern Papuan coast. Egg predation by veranids and pigs is also high in this area, but not for the Malaysian substock. The default assumption of no sub-stock differences in survival probabilities for eggs and hatchlings therefore appears unrealistic. Since the capacity to adjust survival probabilities for stocks is available within the model, the impact of stock-specific survival probabilities at various developmental stages should be examined.

Suarez *et al.* (in press, in NMFS Biological Opinion, 2001) noted that 40-60% of leatherback nests on Jamursba-Medi were lost to inundation and erosion, and that 90% of those nests not taken by poachers or the sea were destroyed by feral pigs (see above). This suggests that egg survival probability in specific locations may be significantly lower than the bounds currently operating in the leatherback model (for example). The effect on model performance of wider survival probability distributions should be examined. A related issue is raised in Section 3.1.3.

Discussion on the form of the probability of leatherback eggs hatching as a nonlinear function of nest temperature in the manuscript would be supported through reference to the form of this relationship for other turtle species. Based on the data available for leatherbacks presented in Figure 9a, there is little information to define the functional form selected. However, the choice of this form is supported by the greater data set available for loggerhead turtles.

In general, different populations in the model are appropriately affected by different area-specific hazards (be they natural or anthropogenic). However, recent evidence suggests that western Pacific turtles may suffer mortality in fisheries operating in Chilean waters (NMFS Biological Opinion, 2001). If correct, this additional interaction and source of mortality should be added to the model.

The y-axis in Figure 8b needs more explanation, since it implies that 'individual leatherback frequency' can be negative.

An explanation of the age class groupings for all age classes should be added to the legend of Figure 11.

**Loggerhead model**

Loggerhead turtles have a different biology and demography to that of leatherbacks. This is simulated appropriately within the model. A greater volume of biological information is available for loggerhead turtles in the Pacific compared to the leatherback stocks of interest. However, there is still relatively little information available on loggerhead turtle demography in the northwestern Pacific stock. As a result, the author sensibly used data available from stocks in the Atlantic Ocean and other areas of the Pacific Ocean, most notably from Australia (the 'southwestern' stock). It is unknown whether these data accurately reflect the demography of the northwestern stock, and further data collection and analysis is required to better parameterize the model.

It is difficult to reconcile the age classes in Table 2 with the growth patterns and age class divisions detailed in Figure 3 and the prose on page 10. For example, the prose indicates that loggerheads recruit to the benthic phase at around 70-80cm CCL, while in Table 2 benthic juveniles are 95cm+ and 10-14 years old (and are described as having just spent 10-15 years in the pelagic habitat). The comparison between Table 2 and Figure 3 a and b is also confusing. I suggest that a clearer explanation of the process is given. For example, a figure of the potential age distributions of each stage would be useful, to illustrate the degree of overlap.

The incidental capture of pelagics in the western U.S. coast fisheries is viewed as negligible in the model, based on the information available (23 leatherback and 24 loggerhead turtles since 1990, according to the NMFS Biological Opinion, 2001). Since data on loggerhead mortality is limited, it would be prudent to ensure that additional sources of mortality can be easily added on the relevant age class stage in the event that further information changes the current opinion.

### 3.1.3 Underlying dynamics of the population models

In this section, issues relating to the underlying dynamics of the population models which are specific to each model are discussed first. Issues common to both models are then detailed.

**Leatherback model**

In the leatherback model report, Figure 16 shows considerable fluctuations in the proportion of age classes/stages for one realization of the model. This appears to result largely from the use of stock proportion to display trends. Low recruitment levels of the year 1 age class result in warmwater juveniles representing a higher proportion of the stock, despite the fact that their numbers may be little different from previous years. To allow easier interpretation of the dynamics, it would be better to show the numbers or biomass of each stage in such graphs. This should provide a clearer indication of the interactions between age groups.

**Loggerhead model**

Figure 17 presents the relative age class proportions in the stock for one realization of the model. However, if this is a measure of the proportion of total stock, these proportions add up to more than 1. While the sum of the pelagic and benthic substocks in Figure 17a may equal 1, what is the proportion of the year 1 age class relative to? This needs further explanation.

**Issues common to both models**

A number of issues were identified relating to the underlying dynamics, which are common to both the leatherback and loggerhead models. These are detailed below.

It was interesting to note that demographic stochasticity does not appear sufficient to recover a population from low levels. Density dependence, the existence of which is controversial for turtles (as noted in the model documentation), is relied upon to recover depleted populations. Currently, the model does not incorporate random events which may stimulate stock recovery (e.g. favorable environmental conditions) Conversely, catastrophic events (e.g. random events such as hurricanes which may increase the levels of mortality in many age classes) are also not simulated. The incorporation of these events in the model, through conditional distributions (defining the probability of an event occurring, and if that event occurs, the likely magnitude), and the option to 'switch' events on or off, should be considered.

Variability in the number of nesting individuals has been shown to decrease at low population sizes (Chaloupka, pers. comm.). This may be a useful indicator against which to parameterize and tune the model. For example, superficial examination of model performance suggests that the level of density dependence set in the model may influence the level of fluctuation in simulated nester abundance relative to population size. However, it should be noted that there will be many parameters interacting in this dynamic, which may render the causal relationships unclear. A more thorough test of the model performance should be made before tuning goes ahead.

Empirical derivation of the survival probability values for the majority of age classes is done through tuning of the model (required due to the lack of data to define the values and distributions). The survival probabilities are within very narrow distributions. Since the model is likely to be highly sensitive to these values and distributions, further examination of their forms is appropriate to examine their impacts on model performance (e.g. examine the use of correlated normal distributions, log-odds). Further data collection and experimental analysis to improve these estimates, and hence reduce the requirement for tuning, is important.

Given uncertainty over the value for initial population size used to seed the model, robustness of the model to changes in initial population abundance estimates should be examined. Particularly where density dependence is operating, model performance under changing initial estimates may not be straightforward.

A factorial experimental design was used to examine the influence of particular variables on model outputs. The parameters examined were not sampled over a particularly large range. Multiple equilibria may result if a larger range is examined. This would be an important finding for the model in its current form, and something users should be made aware of, since it could be misconstrued as evidence for phase-shifts. It would also assist in the identification of areas where data collection and analysis should be focused. It is therefore recommended that wider parameter ranges are examined in the factorial experimental design.

### 3.1.4 Applicability of the population models to the ongoing protected species recovery and fisheries management issues

In this section, all issues on applicability of the population models to ongoing protected species recovery and fisheries management issues were common to both models.

The models of Chaloupka have identified a number of biological parameters which are important to the dynamics of populations. The values and distributions of these parameters are often unknown, due to the paucity of studies which have been performed on study populations. This renders model outputs open to uncertainty. However, as noted in Section 3.1.3, these models are useful tools to identify those parameters and processes own which data collection and analysis should be concentrated.

Studies required to populate many of these important model parameters are likely to take a number of years to produce; answers to management questions will undoubtedly be required in a shorter timescale than this. The models must therefore be used to identify management interventions which will lead to population recovery, and are also robust to uncertainties in the model.

The models already allow simple management analyses to be performed, by setting the level of stock abundance assessment error in harvesting strategy evaluations. Currently the perceived stock level is selected as a random value around the true stock level, as defined by a lognormal probability density function with an adjustable coefficient of variation. However, this is not very realistic. In general, one might expect that if stock size is overestimated in one year, it is more likely to be overestimated in the following year as well. Therefore, it is strongly recommended that the level of error is correlated between years in these simulations.

A more realistic approach would be to perform management strategy simulations. Here, the manager's perception of stock status is determined by the stock assessment methodology (rather than as a random variable around the true stock level). Management action (determined by management control rules) is then applied to the actual stock through a harvest strategy (e.g. reduction in effort if stock shows a decline). Stock status following management intervention is then re-assessed after a particular time period, and the action cycle repeated. Monte Carlo simulations can then assess the likely impacts of management over time. Management strategy simulation has become relatively common in fisheries (e.g. Kell *et al.*, 1999; Punt, 1995; 1997). Incorporation of a management strategy simulation structure within the models would allow the impact of interventions such as the closure of the fishery, (the models are already capable of modeling this action), gear modifications (which might be simulated through a reduction in mortality in fishery or catch rates, for example, although this must realistically relate the level of mortality reduction to the modification made) or conservation efforts leading to a decrease in juvenile mortality, as seen in Mexico (perhaps initiated through a modification of the egg or juvenile survival probabilities) to be assessed. The feasibility of incorporating management strategy simulations should be examined.

Management strategy simulations, and management action in general, require a goal against which the performance of management interventions can be related. However, no goals or targets appear to exist currently for sea turtles. Without such goals, it is difficult to state whether there are deficiencies in the current model structure and outputs. Wetherall *et al.* (2002) provide an excellent discussion of the need to quantify recovery objectives and the reductions in human-caused mortality necessary to achieve it.

The models currently have the facility to measure the performance of interventions through quasi-extinction curves, which provide managers with a measure of the likelihood of adult population abundance falling below a set level of initial abundance within a particular time scale. This is a sensible measure, but is most useful in a situation where the aim is sustainable exploitation. For many of the stocks in question, what is desired is a recovery of population numbers to a sustainable level (whatever that level may be). Recovery targets are very different from those of steady-state management.

Some suggestions for recovery targets are:

- the recovery of the stock to level X over Y years (examined within the model as the probability of the population achieving this);
- a particular increase in survivorship of mature adults (which may be practically identified through tagging);
- an increase in the percentage of first time breeders (although this would be open to variations in the number of experienced nesters returning each year, and would also require a time series of data collection to confirm trends).

Recovery plans will involve reductions in the anthropogenic impacts on stocks. The impact of plans must also be examined from the socio-economic/fleet perspective. This could be examined either within or outside the model (using model outputs).

Management strategy simulations also require the development of performance criteria, so that the relative success of different management approaches can be judged. Examples of management performance criteria include:

- the time taken for the population to achieve the management target;
- the ratio between biomass at the end of a management period (e.g. 20 years) and unexploited levels.

An appropriate set of performance criteria need to be identified so that they can be added to the model, as necessary.

Once a turtle population has recovered, there is a need to identify further, practical, early warning monitoring indicators for management. These need to allow suitable mitigation approaches to be put into effect in good time if a recovered stock shows signs of decline. These indicators are frequently different from those used as recovery goals. Potential indicators may include:

- number of females on nesting beaches (but see discussion below);
- number of juveniles successfully hatching;
- for loggerheads specifically, the number of 'clean' recruits to the benthic phase.

The Chaloupka models appear to be suitable and valuable tools to identify these practical recovery and monitoring indicators for management.

The number of females nesting on beaches has been suggested as a criteria with which to monitor population status (see above). However, since beach nesting numbers fluctuate considerably in healthy populations, its use as an indicator may be reduced. Short term trends provided by most monitoring studies may give incorrect impressions of the population; downward trends in a healthy population which arise merely due to random variation may lead to management action when it is not required. However, the recovery signal may be stronger if the population is recovering from extremely low levels (or is crashing). This should be examined through simulations where management decision rules are based upon the monotonous increase or decrease in the number of individuals breeding (e.g. a decrease over three years leads to management intervention).

As noted, the models are excellent discussion tools. They can form the focus of workshops discussing the use of selected management interventions, using the simulations suggested above (as well as others). It is essential that structured conclusions to workshops be produced. These may include handouts to be taken away by participants. Handouts should present the findings graphically, showing trends of decline or recovery resulting from particular interventions for example (e.g., 95% of runs achieve performance measure if a particular intervention is initiated). An alternative suggestion is the basic traffic light approach (Caddy and Mahon, 1995; Caddy, 1998). Given the development of a battery of suitable indicators, a system of red/green lights for these indicators for a given situation/intervention can be produced. Each indicator can then be weighted for 'desirability' by the workshop participants to identify the most appropriate outcomes.

### 3.1.5 Specific items

In this section, issues specific to each model are discussed first. Issues common to both models are then detailed.

**Leatherbacks**

There are a number of mis-spellings and grammatical errors in the manuscript, the majority of which will be picked up by a spell-check or grammar search.

On Page 11, the second paragraph refers to benthic recruitment, which is not a stage of the leatherback lifecycle.

**Loggerheads**

There are a number of mis-spellings and grammatical errors in the manuscript, the majority of which should be picked up by a spell-check or grammar search.

In the introduction, the common species name referred to in the first line should be leatherback, not loggerhead.

**Issues common to both models**

These comments focus on the issue of handing over the models to other users. Methods to assist the handover process are suggested.

These complex models offer a potentially bewildering array of parameters for adjustment. Most of these parameters are referred to by acronyms, which give little insight into the processes they control. It is recommended that a list of parameters available within the model is developed, listing the acronyms, full names, what they represent, and suitable ranges for these parameters based on the available data. These lists or tables should be broken down into sections, with related parameters grouped together (e.g. under reproduction, dispersal, fishery related parameters etc). Also, the acronyms presented in graphs in the documentation are not transparent – for ease of model use, these variable names should be spelt out in full.

The problems encountered when running the model (required screen resolution in IBM PCs, for example) should be documented for other users.

There needs to be some simple diagnostics within the model (including the capacity to add statistical fitting routines for a time when sufficient data are available) to identify and highlight unrealistic changes or pathological model behavior. Considerable training will be required for users new to the model, and even simple diagnostics would enable them to identify poor or unrealistic model performance, and examine or discuss the likely causes.

Given that the processes modeled contain considerable uncertainty, the focus on single model runs in the documentation can be highly misleading. I would suggest focusing on runs with uncertainty displayed in the outputs, to avoid the impression that users can rely on single runs to identify trends. In turn, it would be useful to be able to set the level of uncertainty to be displayed around the output trends (e.g. be able to set probability levels for each output).

## 3.2 Wetherall Mexican leatherback model (TURTSIM)

The TURTSIM model allows discrete-time simulation of marine turtle population dynamics and human-caused mortality on nesting beaches and oceanic habitat. The model assumes populations are structured by carapace length, sex, and state of maturity, and incorporates biological details pertaining to egg and hatchling production, somatic growth, natural and human-caused mortality, maturation and remigration. Density-dependence is incorporated into growth, remigration and hatchling production functions.

### 3.2.1 Assumptions in defining the stock structures based on genetic or other information

In its current form, the model concentrates on the Mexican leatherback population, as a population which is independent of other stocks. Based on the available genetic information, this appears appropriate. However, if this model were to be used to examine the impact of mitigation measures in the Hawaii longline fishery, other stocks would need to be included (e.g. those from Malaysia and from Melanesia). This is discussed further in Section 3.2.4.

### 3.2.2 Application of the most recent biological, nesting beach, and fishery interactions data

Growth parameters for the leatherback population are based on 15 individuals aged from a dump in Peru. This represents a limited data set on which to base estimates of von Bertalanffy growth parameters, although the data do appear to produce a reasonable von Bertalanffy growth curve. It would be interesting to see how estimates of growth for this stock compare with those for other leatherback stocks.

The estimation of variability in growth ignores length-at-age data from the diseased individuals, since these individuals show low growth rates compared to those sampled from Peru. However, these diseased individuals may represent a natural extreme in the level of individual growth variability. Since information suggests that these diseased individuals could still reproduce, their length-at-age data should be included in estimates of individual variability.

Growth in the model is density dependent. This is modeled through changes to the von Bertalanffy growth parameter K. However, the majority of density dependent growth models (e.g. Beverton and Holt, 1957; Lorenzen, 1996) have related changes in population density to changes in the von Bertalanffy growth parameter $L_\infty$ (or the related asymptotic weight $W_\infty$), rather than to changes in K. The von Bertalanffy growth function describes growth as the net result of anabolism (the build up of body materials, related to $L_\infty$) and catabolism (the breakdown of existing body materials, related to K). Catabolism (K) is presumed to be affected by the amount of body material to be broken down (weight of the organism, level of metabolic activity) and therefore independent of population density. Anabolism ($L_\infty$) is dependent on the food resources available to individual fish, and therefore population density. While density dependent growth has been modeled in K in the past, the author should be aware of the current convention.

The model does not have implicit relationships between the action of density dependent growth and natural mortality (the ratio between M and K has a significant influence on the theoretical maximum yield and optimum effort levels in calculations of the yield-per-recruit type) or density dependent growth and fecundity. At present density dependence acts on these characteristics via its effect on growth. This may lead to unexpected model behavior. These interactions should be investigated, and the development of relationships between these parameters considered.

Since little data exists on density dependence, assumptions on the form of its relationship with parameters are arbitrary. Quite frequently, however, a sigmoid form is selected, which may be more biologically realistic than those presented in Figure 8 of the manuscript. In this form, levels close to the maximum density have little effect on a parameter, while further decreases in density have an increasing effect. This effect decreases to a biological asymptote at very low densities. It would be interesting to examine the effect of this form of density dependent relationship on model outputs.

On page 10, the assumption of 85% survival for adults does not appear to match with the calculation of 30% for M in section 4.4 of the manuscript. This needs explanation.

On page 19, the calculation that 1/8th of Hawaii longline mortalities were from Mexico needs explanation; ¼ of mortalities are from the eastern Pacific, and there is a 50:50 split assumed between Mexico and Costa Rica populations, hence the value of 1/8th .

### 3.2.3 Underlying dynamics of the population models

Initially, survivorship levels in the model are tuned based on the adult natural survivorship levels, to achieve equilibrium. This has led to a 10-fold increase in the survivorship levels for the youngest age group where there is low adult survival, compared to the situation where adult survival is high (Table 1 of the manuscript). This is unlikely to be biologically realistic, and may explain the surprising and somewhat contradictory differences in recovery times between low and high survivorship simulation runs (page 23 of manuscript) where higher rates of recovery were predicted under assumptions of low natural survivorship and nonlinear density dependence. A situation where low survivorship achieves recovery goals more quickly represents a problem for conservation. If correct, mitigation measures increasing the survivorship of populations would slow the rate at which the population recovered, an effect which may also be found where density dependent growth is operating (increasing population size decreasing growth rates, and therefore biomass recovery). To confirm whether this is a result of model tuning, it would be appropriate to attempt tuning the model with survivorship in each developmental group constrained within likely bounds.

### 3.2.4 Applicability of the population models to the ongoing protected species recovery and fisheries management issues

In the documentation, the model of Wetherall *et al.* is used to examine the influence of various anthropogenic influences on the Mexican leatherback population specifically. Following examination of the points detailed in previous sections, this model appears suitable for this purpose.

However, extensive work would be required to modify the model to realistically focus on the impacts of the Hawaiian longline fishery on Pacific leatherback populations. As shown by the model of Chaloupka, there are a number of meta-populations which interact with that fishery, with varying biological and anthropogenic characteristics. The dynamics of these would need to be incorporated into the model of Wetherall, if a focus on the Hawaii fishery were the ultimate goal.

While management studies can be performed, as are examined in the manuscript, the model contains no stochasticity, besides the influence of density dependence on growth and related factors. This limits simulations to less realistic deterministic studies.

One of the advantages of the approach taken in this model is that it is less data intense. This lower complexity offers a useful opportunity to compare outputs with the more complex leatherback model of Chaloupka. This is discussed in Section 4.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The models of Chaloupka are specifically designed for Pacific-wide turtle population analysis, and appear to require the least additional effort before they can provide the best information on which to proceed with protected species recovery and fisheries management analysis of relevance to the Hawaiian longline fishery and other U.S. interests. Wetherall's leatherback model concentrates on the Mexican leatherback population, and is likely to require considerable modification to incorporate the interactions of the other turtle meta-populations and anthropogenic impacts necessary to examine the wide range of issues of relevance to NMFS.

The models of Chaloupka for leatherback and loggerhead turtle populations are perhaps biologically more realistic than that of Wetherall, and are certainly more complex. The values and functional forms of many of the parameters in the models of Chaloupka are unknown, due to the paucity of suitable studies on the relevant turtle populations. This increases the uncertainty in model outputs. Sensitivity analyses of the impact of the values and functional forms of these parameters on model outputs, assessments and perception of the population (recovery) need to be extended to identify those biological parameters which are important to the dynamics of populations. This will focus data collection on parameters which will best support the derivation of management. Wetherall's model is less data intensive, offers useful insights into the performance of the models of Chaloupka under uncertainty, and could be used to test the robustness of those models.

Scientific studies to populate the parameters will take a number of years to compete, and it can be foreseen that management options will need to be developed in a shorter time frame. Chaloupka's models must therefore be used to derive management interventions which are robust to model uncertainties.

In their current form, Chaloupka's models will be useful for the identification of the likely causal factors of population decline, and provide the best information on which to proceed with protected species recovery and fisheries management in the Pacific. With the development of management strategy simulation frameworks, for example, the models will be suitable for the examination of robust management interventions which halt declines in the short term, and in the longer term result in stock recovery. They should also be used to inform the derivation of management targets for recovering turtle populations, and to develop practical early warning monitoring indicators for vulnerable sea turtle populations. The models should form the basis of discussion workshops to examine potential management interventions.

A number of recommendations have been made throughout the text of this report. The main recommendations were:

**Chaloupka models:**

- add the east Pacific (Mexico) metapopulation to the leatherback model;
- consider whether the Australian metapopulation should be added to the loggerhead model;
- examine the impact of stock-specific survival probabilities at various developmental stages in both models;
- support the choice of nest temperature relationship for leatherbacks with information from other turtle species;
- add potential mortality arising from mid/south American fisheries to the western Pacific leatherback metapopulation;
- add the capability to simulate random favorable and catastrophic events to the models;
- examine alternative distributions (form and value) for age class specific survival in both models;

- examine the robustness of models to changes in the initial population abundance estimates;
- examine wider ranges for the parameters tested in the factorial experimental design;
- correlate the level of stock abundance error in the harvesting strategy evaluations;
- examine the feasibility of expanding models to incorporate more realistic management strategy simulations;
- use the models to identify suitable recovery and monitoring criteria for turtle populations (which may not be the same);
- use the models as discussion tools within workshops to develop management strategies based on such criteria.

Issues and recommendations relating to the handover of the models were also discussed (Section 3.1.5), including the inclusion of simple diagnostics within the models to assist new operators in model use and interpretation.

**Wetherall model:**

- consider whether the model should be expanded to include other leatherback stocks in the Pacific of relevance to the Hawaii longline fishery, or whether the model should concentrate on analysis of the Mexican stock only;
- the length-at-age data from diseased individuals should be included in the estimates of individual variability;
- consider whether density dependence should be changed to act on the von Bertalanffy growth parameter $L_\infty$, rather than K;
- examine and consider implicit relationships between the action of density dependent growth and both natural mortality and fecundity;
- consider different forms of density dependence in the model;
- tune survivorship of each developmental group to eliminate the compensatory shifts in that of the youngest age group when adult survival is modified;
- examine the addition of further stochasticity to the model to render it more realistic.

At present, the models of Chaloupka represent the best available information on which to proceed with protected species recovery and fisheries management in the Pacific. Consideration of the recommendations in this report will improve the models, and ensure that model outputs will provide suitable information of a quality sufficient for basing development of management strategies.

## 5. OTHER ISSUES OF POTENTIAL INTEREST TO NMFS

Comments in this section do not fall under the information required by the terms of reference. They are raised as they may be of interest to NMFS staff.

CEFAS have been collaborating with NMFS Southeast Fisheries Science Center (Miami) to develop specific models and methodologies to improve the estimates of bycatch (in particular of dead bluefin tuna discards) in the U.S. pelagic longline fishery in the Atlantic, and the calculation of uncertainty about these estimates. The methods may prove effective in improving estimates of turtle bycatch from the Hawaii longline fishery, and may identify related factors (e.g. areas, time periods, fishing methodologies or characteristics) that could suggest potential mitigation measures.

The issue of seabird bycatch in longline fisheries was noted as an important factor in the EIS. The problem of seabird (in particular albatross) incidental mortality in longline fisheries has been noted in the fisheries operating under the auspices of CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources; www.ccamlr.org), of which the USA is a member. A number of mitigation measures have been developed, some of which may be adaptable for fisheries in the Pacific.

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## APPENDICES

A.1 Report Generation and Procedural Items
A.2 Review and Background Documents
A.3 Center for Independent Experts Statement of Work

## A.1 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.

## A.2 Review and Background Documents

Chaloupka, M. (2002). Development of a stochastic metapopulation model for the western Pacific leatherback sea turtle stock. Report prepared for the US National Marine Fisheries Service, Southwest Fisheries Science Center, Honolulu Laboratory, Honolulu, Hawaii. 109p.

Chaloupka, M. (2002). Stochastic simulation model of western Pacific leatherback sea turtle metapopulation dynamics – User's Guide. For the US National Marine Fisheries Service, Southwest Fisheries Science Center, Honolulu Laboratory, Honolulu, Hawaii. 41p.

Chaloupka, M. (2002). Development of a stochastic population model for the western Pacific loggerhead sea turtle stock. Report prepared for the US National Marine Fisheries Service, Southwest Fisheries Science Center, Honolulu Laboratory, Honolulu, Hawaii. 102p.

Chaloupka, M. (2002). Stochastic simulation model of northwestern Pacific loggerhead sea turtle population dynamics – User's Guide. For the US National Marine Fisheries Service, Southwest Fisheries Science Center, Honolulu Laboratory, Honolulu, Hawaii. 37p.

Chaloupka, M. (2002). Stochastic simulation modeling of southern Great Barrier Reef green turtle population dynamics. *Ecological modeling* **148**, 79-109.

Chaloupka, M. and Limpus, C. (2001). Trends in the abundance of sea turtles resident in southern Great Barrier Reef waters. *Biological conservation* **102**, 235-249.

Chaloupka, M. and Limpus, C. (2002). Survival probability estimates for the endangered loggerhead sea turtle resident in southern Great Barrier Reef waters. *Marine Biology* **140**, 267-277.

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National Marine Fisheries Service, 2001 final Environmental Impact Statement (EIS) on the western Pacific pelagic fishery. http://swr.ucsd.edu/piao/eisdocs.htm

Wetherall, J., Sarti, L., Dutton, P. and Garcia, D. (2002). Status of Mexican leatherbacks in the Pacific Ocean: A simulation of human impacts. Draft manuscript, 62p.

## A.3 Center for Independent Experts Statement of Work

Consulting Agreement Between The University of Miami and Dr. Graham Pilling

May 29, 2002

### General

Simulation models have been developed to provide a quantitative foundation for assessing impacts of the Hawaii-based pelagic longline fishery and other human activities on sea turtle populations. Two independent studies have just been completed. One study involved the development and application of a stochastic simulation model of Pacific leatherback sea turtles, with emphasis on western Pacific populations of this species, and a second simulation model of Pacific loggerheads. These models were developed under contract by a sea turtle modeling specialist assisted by interactive workshops of invited experts. The other study involved the development and application of a simulation model of the Mexican leatherback population in the Pacific by a NMFS modeler in collaboration with two Mexican leatherback experts, using a different modeling approach. These analyses, which evaluate the dynamics of sea turtle populations and their sensitivity to longline fishing and other human-caused mortality factors, need to be reviewed independently. The reviews should examine the assessment methods, models, and findings.

These reports are expected to play an important role in the development of mitigation and recovery efforts by the NMFS Southwest Region through fishery management regulations and other measures, likely in the context of an ESA biological opinion on the Hawaii longline fishery. As a result, the review should consider not only the basic population science underlying these models, but also the applicability of the models to evaluation of mitigating effects and the analyses' use of the best available information on both population modeling and sea turtle biology.

The reviewer shall analyze the reports for loggerhead and leatherback sea turtles, focusing on the following:

1. Assumptions in defining the stock structures based on genetic or other information;
2. Application of the most recent biological, nesting beach, and fishery interactions data;
3. Underlying dynamics of the population models;
4. Applicability of the population models to the ongoing protected species recovery and fisheries management issues.

### Specific

The reviewers duties shall not exceed two weeks – several days to review the reports (two of which are parallel in structure and simulation methodology); participation in a two-day workshop in Honolulu, Hawaii, on May 2-3, 2002, which will focus on the use of the first (stochastic simulator's) approach for developing a model of the Hawaiian green sea turtle population; and several days to produce a written report of the findings. Finally, no consensus, pre-final review, or rejoinder comments are required.

The itemized tasks of the review include:

1. Analyzing the following documents provided to the consultant by the NMFS Honolulu Laboratory:

   a. Leatherback turtle stock assessment simulation report by Dr. Milani Chaloupka, including narrative description, workbooks, and model code;
   b. Loggerhead turtle stock assessment simulation report by Dr. Milani Chaloupka, including narrative description, workbooks, and model code;
   c. Mexican leatherback simulation model report by Dr. Jerry Wetherall, Laura Sarti, and Dr. Peter Dutton.

2. Reading (no commentary required) the following background documentation provided to the reviewer by the NMFS Honolulu Laboratory:

   a. 2001 Biological Opinion on the western Pacific pelagic fishery;
   b. 2001 final Environmental Impact Statement (EIS) on the western Pacific pelagic fishery; and,
   c. Materials for the green sea turtle workshop provided by the consultant.

3. No later than May 20, 2002 submitting a written report of findings, analyses, and conclusions concerning the three sea turtle stock assessment simulation reports. This report must address the utility of the population simulation models and methodology to answer questions concerning the status of Pacific leatherback and loggerhead sea turtle populations and the assessment, mitigation and reduction of human-caused mortality. The report must include the following elements:

   a. Executive summary of findings and recommendations.
   b. Main body consisting of background; description of review activities; findings and conclusions; and recommendations. The conclusion must contain a statement as to whether the analyses represent the best available information on which to proceed with protected species recovery and fisheries management, and whether the information quality is sufficient for basing development of management strategies.

The report should include as separate appendices the bibliography of all materials referenced in the review, including those documents provided by the Center for Independent Experts and the Southwest Fisheries Science Center; and a copy of the statement of work.

Full photocopies (or PDF files) and citations of all papers, reports or other written materials cited by the review should be provided separately.

The final report[1] should be addressed to the "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via email to ddie@rsmas.miami.edu.

Reviewer name: ______________________

Signature: ______________________ Date: ______________

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[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.