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REPORT OF THE SCIENTIFIC RESEARCH PROGRAM UNDER THE INTERNATIONAL DOLPHIN CONSERVATION PROGRAM ACT

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REPORT OF THE SCIENTIFIC RESEARCH PROGRAM UNDER THE INTERNATIONAL DOLPHIN CONSERVATION PROGRAM ACT

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NOAA Fisheries
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EXECUTIVE SUMMARY

The tropical waters of the Pacific Ocean west of Mexico and Central America, an area known as the eastern tropical Pacific (ETP), support one of the world's largest fisheries for yellowfin tuna with between 100,000 and 300,000 metric tons caught each year. A primary basis for this fishery's success is an ecological association in the region between tunas and dolphins in which large yellowfin tuna regularly swim together with several species of dolphins. In the 1950s, a fishery method was developed whereby fishermen look for the surface-schooling dolphins to locate the tuna and use speed boats to herd these dolphins into large purse-seine nets. Because of the strong association, the co-schooling tunas followed and were also captured. This method rapidly became the predominant tuna fishing method in the ETP although many dolphins would die in the nets before they could be released. Since the fishery began, an estimated six million dolphins have been killed, resulting in three stocks of dolphins being declared "depleted" under the Marine Mammal Protection Act (MMPA): the northeastern offshore spotted dolphin, the eastern spinner dolphin, and the coastal spotted dolphin. In the last decade, however, technological and procedural improvements and the increasing skills of captains and crews have reduced reported mortality to very low levels relative to dolphin population sizes; currently ship-board observers report fewer than 3,000 dolphins killed per year.

With this dramatic reduction in mortality, indications of the initial stages of a recovery of the affected populations to near pre-exploitation abundance levels would be expected. However, despite considerable scientific effort by fishery scientists, there is little evidence of recovery, and concerns remain that the practice of chasing and encircling dolphins somehow is adversely affecting the ability of these depleted stocks to recover.

In response to these concerns, the International Dolphin Conservation Program Act of 1997 (IDCPA) directed the NOAA Fisheries to conduct a program of scientific research to address the question of 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 ETP. The research program was specified in subsection 304(a) of the MMPA, as amended by the IDCPA, to include population abundance surveys and stress studies.

In 1997, a research program was designed by the NOAA Fisheries' Southwest Fisheries Science Center (SWFSC) in consultation with the U.S. Marine Mammal Commission, the Inter-

American Tropical Tuna Commission and others. The research was conducted between 1997 and 2002, also with consultation of the Commissions and others. The program was broadly structured to include four components: abundance estimation, ecosystem studies, stress and other fishery effect studies, and stock assessment.

Abundance Estimation

What is the population size of each depleted dolphin stock? Current abundance estimates were derived from research vessel surveys conducted in the ETP during 1998, 1999, and 2000, using improved analytical methods for abundance estimation. Survey data from nine earlier abundance surveys dating back to 1979 were also re-analyzed using these new methods. This time series of abundance estimates provided the core information for subsequent evaluations of trends, population growth rates, and ultimately stock assessment analyses.

The average of the abundance estimates for the years 1998, 1999, and 2000 are 641,153 (CV[1] = 16.9%) for northeastern offshore spotted dolphins, 448,608 (CV = 22.9%) for eastern spinner dolphins, and 143,725 (CV = 35.7%) for the coastal spotted dolphins. Although the coastal spotted dolphin is presented here as a single value, recent genetic analyses indicate multiple coastal stocks are likely, making the single abundance estimate of limited relevance.

If the Potential Biological Removal (PBR) system under the MMPA were applied as a standard, mortality limits for these stocks would be 1,298 for eastern spinner dolphins, 2,367 for northeastern offshore spotted dolphins and 1,073 for coastal spotted dolphins (but note that this would apply to a single coastal spotted dolphin stock, which is no longer considered likely). The stock mortality limits (SML)[2] for these stocks, if computed using this updated information (i.e., the mean abundances from the 1998, 1999, and 2000 surveys), would be 371 eastern spinner, 557 offshore spotted dolphins and 107 coastal spotted dolphins (same caveat applies for coastal spotted

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[1] The coefficient of variation, CV, is a measure of the variability of the estimate and is the ratio of the standard error to the mean. The smaller the value, the greater the precision of the estimate. For estimates of cetacean abundance, CVs typically range from 20% to 50%.

[2] The nations fishing in the ETP have established under the International Dolphin Conservation Program a system for calculating annual limits on the allowable fishery mortality level for each stock.

dolphins as noted for PBR above).

Ecosystem Studies

Has the ecosystem changed substantially since the dolphin stocks were depleted? For a long-lived animal such as a dolphin, carrying capacity[3] is more likely to be affected by long-term (over decades) changes rather than those occurring short-term (interannual or seasonal). Therefore, ecosystem studies focused on investigations of temporal variation in as many parts of the ecosystem as possible. These included physical and biological oceanography, a range of trophic levels from the lowest (phytoplankton) to the highest (top predators), and as many species within each trophic level as possible.

All investigations indicated that variability associated with El Niño-Southern Oscillation (ENSO) events is the predominant variability throughout the ecosystem. Longer, decadal-scale variability was also evident, but the magnitude was much smaller than that recorded during the 2-7 year ENSO cycles.

Historical evidence related to long-term patterns included a time series of sea surface temperature data beginning in 1901, which indicated that a number of shifts have occurred. Notably, a shift in temperature of surface waters occurred in the late 1970s that was detected throughout the Pacific Ocean. Changes at that time in the physical environment and in biological communities were clearly documented in the North Pacific. In the ETP, this shift resulted in a warming of less than 1°C. Coincident with this, there was a weakening of trade winds and a small increase in surface chlorophyll content of the ETP, indicative of an increase in the amount of phytoplankton that forms the base of the entire food chain. A contrasting decrease of these properties was observed along the equator, south of the principal habitat of the depleted stocks of primary interest here. No other responses to this late 1970s shift have been reported for the ETP, but biological data prior to 1976 are sparse or currently unavailable in a form that would allow comparisons with more recent data.

Stock assessment models (discussed below) indicated that, in the absence of any other effect,

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[3] The maximum size of a particular population that can be sustained within a given area or habitat. For ETP dolphins this population level is thought to have existed in the late 1950s before the onset of purse seining on dolphins.

a three- to five-fold decline in carrying capacity of the ecosystem would be required to explain the low growth rates currently estimated for the depleted dolphin stocks. If such a dramatic change in the ecosystem occurred, it is unlikely that the only animals affected would be dolphins. It is conceivable that the small physical changes observed have had some effects on carrying capacity of the ecosystem for these dolphins, but the paucity of directly relevant data precludes a determination of either the direction of such an effect or its magnitude. However, it appears unlikely that carrying capacity of the ETP has declined by three- to five-fold.

Data on a wide range of habitat variables and species were collected beginning in 1986 as part of the NOAA Fisheries dolphin assessment cruises. No dramatic shifts were detected, but this series of data do not cover the period before the late 1970s shift.

Stress and Other Fishery Effects Studies

Do chase and encirclement adversely affect dolphins? Stress studies were required by the IDCPA to address the concern that chase and encirclement of dolphins during fishing operations might affect dolphins, but not necessarily result in their immediate, and observable, death in the nets. Four related research projects, broadly categorized as stress studies, were required: a stress literature review, a necropsy[4] study, a review of historical data, and a field study involving the repeated chasing and capturing of dolphins. Research was completed by the SWFSC under all four items. The key lines of investigation included research on potential separation of mothers from their calves, measurement of acute and chronic physiological effects that could result in injury or death, observation of behavioral responses to fishing activities, and estimation of the average number of times a dolphin might be chased and encircled per year per stock.

A review of scientific literature on stress in mammals indicated that tuna purse seine operations involve well-recognized stressors in other wild mammals, and it is plausible that stress resulting from chase and capture could compromise the health of at least some of the dolphins involved. The stress studies included a combination of field experiments, retrospective analyses, direct observation, and mathematical modeling, to address a broad range of stress-related effects and other factors that potentially could lead to unobserved dolphin mortality associated with tuna purse-

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[4]A necropsy or postmortem examination is generally equivalent to an autopsy in human medicine.

seine operations. In the aggregate, the findings support the possibility that purse seine fishing involving dolphins may have a negative impact on the health of some individuals. Several lines of research suggested potential physiological mechanisms of stress effects, but larger sample sizes and baseline data for the affected species are needed to fully interpret the findings. In particular, cow-calf separation and potential muscle injury leading to delayed death warrant future study. Sample sizes for both the necropsy program and the field studies were insufficient to estimate potential population-level impacts or to determine whether population recovery of the depleted stocks may be delayed by these effects.

Analyses of over 1,800 purse-seine sets from 1973 to1990 in which all dolphins that died in the net were examined led to the conclusion that there is some separation of calves from their mothers. Based on reasonable assumptions about length of nursing dependency, it was estimated that total mortality was underestimated by 10-15% for spotted dolphins and 6-10% for spinner dolphins in this sample. More importantly, unobserved calf mortality potentially could be large, and continuing at the present time, if mother-calf separation occurs during the chase portion of the fishing operation. Whether, and if so how often, such separations occur during the chase is unknown. Given these uncertainties, only a minimum estimate of unobserved calf mortality is possible, with the caveat that the actual mortality is likely to be larger by an unknown amount. Although there are insufficient data to resolve the upper limit of this effect, a simple evaluation of potential calf separation effects was included in the quantitative stock assessment model in the form of additional mortality.

In addition to reported mortality and any inferred additional mortality, it is important to consider how many times the fishery interacts with dolphins individually and with the populations as a whole each year. The number of interactions is large relative to the population sizes. For northeastern offshore spotted dolphins, there are over 5,000 dolphin sets per year, resulting in 6.8 million dolphins chased per year and 2.0 million dolphins captured (encircled in the purse-seine nets) per year (numbers are means for 1998-2000). For eastern spinner dolphins, there are about 2,500 sets per year, 2.5 million dolphins chased per year, and 300,000 dolphins captured per year. For coastal spotted dolphins, there are about 150 sets per year, 280,000 dolphins chased per year, and 40,000 dolphins captured per year. When divided by the mean estimated abundances during the same years, a northeastern offshore spotted dolphin is chased 10.6 times per year and captured 3.2 times per year on average, an eastern spinner dolphin 5.6 and 0.7 times per year, and a coastal spotted dolphin 2.0 and 0.3 times per year.

Stock Assessments

How do current population levels compare to historical population levels? The final component, the stock assessment modeling, provided quantitative estimates of growth rates and depletion levels, and a framework for testing hypotheses about changes in carrying capacity and potential fishery effects. Of primary interest was an evaluation of the current population size relative to the population size that can be sustained by the ecosystem in the absence of human-induced mortality (i.e., carrying capacity). This question has a direct bearing on the potential rate of recovery for these depleted stocks, and provides a means of evaluating the observed population growth rate in the context of the ecosystem and uncertainties associated with the estimates of abundance and mortality. This question cannot be addressed for coastal spotted dolphins because historical estimates of mortality and abundance are not available for this stock.

A trend analysis of annual abundance estimates for northeastern offshore spotted and eastern spinner dolphins did not show any statistically significant change (either an increase or a decrease) during 1979 - 2001, the period covered by NOAA Fisheries research vessel abundance surveys. However, if the stocks were growing very slowly (below about 2%), a trend would be difficult to detect with this approach; therefore, additional, more sophisticated population modeling exercises were performed.

The most striking result from the trend and assessment analyses for both northeastern offshore spotted dolphins and eastern spinner dolphins is that their population growth rates are very low. Depending on the model used, estimates of population growth rates ranged from -2% to 2% per year. For eastern spinner dolphins, analyses indicating a decline during the past decade were slightly more probable. Taking all the assessment analyses together, the results are not consistent with recovery from depletion for either stock. This conclusion is not dependent upon a specific model or subset of analyses. These rates appear too low overall and suggest some process is acting to suppress population growth. The extent to which this suppression of growth might be related to the fishery, the environment, or other factors is considered in the next section. Regardless of the source of depression, these low rates are a conservation concern given the depleted state of the populations.

Under the MMPA, a marine mammal population is considered depleted when its abundance is less than 60% of carrying capacity. Northeastern offshore spotted dolphins are currently estimated to be at 20% of their pre-fishery abundance, and the 95% probability interval[5] on this estimate is from 11% to 35%. Eastern spinner dolphins are currently estimated to be at 35% of their pre-fishery abundance, with a 95% probability interval on this estimate from 18% to 75%. Thus, for both of these stocks, there is a high probability that they remain at a depleted level.

The assessments indicated about equal weight for models with and without changes in carrying capacity or maximum potential increase rates since the onset of the fishery, but the ability to resolve these issues with the available data is limited, and such changes should not be dismissed from consideration.

A factor was also included in some models that accounted for the possibility that when an individual dolphin encounters more sets, it is less likely to survive. Inclusion of this factor, represented as the number of sets made per individual dolphin in each year, resulted in an increase of maximum growth rates to approximately 3%, closer to but still lower than the 4% generally expected for small cetaceans. However, models including this survival factor were modertely less probable. Similarly, models with mortality scaled up by 50% and 100% performed moderately worse than models with the reported mortality levels. (These models were run to reflect potential effects of either unobserved/unreported mortality, or additional mortality from cow-calf separation that might occur in proportion to reported fishery mortality). So, while such additional mortality should be regarded as moderately less likely as a result of this assessment modeling, it should not be dismissed from consideration due to the generally weak ability of the data to discriminate between competing models.

Analyses that allowed for a change in increase rates during recent decades suggested the stocks were increasing at reasonable rates until about 1990, then decreasing throughout the past decade. Inclusion of the abundance indices from tuna vessel observer data in addition to research vessel abundance estimates made this scenario appear moderately more likely than the case of a flat trend through recent decades. However, use of abundance indices based on the tuna vessel observer data is controversial (see "Scientific Findings" section).

When population sizes were projected forward, the low growth rates led to long estimated

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[5] Ninety-five percent of the time, the "true" value will fall within the stated probability interval.

times to recovery from depletion for these stocks. The best supported models predicted recovery in 78 years for northeastern offshore spotted dolphins and a decline (no recovery) for eastern spinner dolphins. A second set of models, slightly less well supported by the data, predicted recovery times greater than 200 years for northeastern offshore spotted dolphins and 64 years for eastern spinner dolphins. If the populations were to recover at the expected 4%/year, the recovery times would be 29 and 18 years, respectively. These estimates of time to recovery assumed no change in carrying capacity has occurred since the late 1950s.

The differences between the observed growth rates and the generally expected rate of about 4%/year are 2.3% and 2.6% per year for northeastern offshore spotted and eastern spinner dolphins, respectively, for the models with the shortest (most optimistic) recovery times. Given recent population estimates, these percentages correspond to about 14,400 and 11,300 dolphins per year, respectively. Given the number of interactions with the fishery, these numbers correspond to 2.8 dolphins per set, 2 dolphins per thousand chased and 7 dolphins per thousand captured for northeastern offshore spotted dolphins. For eastern spinner dolphins, the corresponding numbers are 4.5 dolphins per set, 5 dolphins per thousand chased and 39 dolphins per thousand captured. In other words, because of the intensity of the fishery, a relatively small number of animals affected per interaction (2-5 per set or 2-5 per thousand chased) would be sufficient to explain the low growth rates and long recovery times.

Summary

Research conducted under the IDCPA has produced many important, substantial new results: current estimates of abundance for depleted dolphin stocks as well as for other cetaceans in the ETP, with advances in analytic methods for abundance estimation; extensive contributions to understanding the oceanography and ecology of the region; sharpening the focus on likely mechanisms of stress effects on individual dolphins; and an improved understanding of the likely effects of chase and encirclement on the cow-calf bond.

For the two depleted dolphin stocks for which we have sufficient information, the primary results are: (1) northeastern offshore spotted dolphins are at 20% and eastern spinner dolphins at 35% of their pre-fishery levels; and (2) neither population is recovering at a rate consistent with these levels of depletion and the reported kills.

There are three general explanations (hypotheses) for the lack of recovery. The hypotheses are not mutually exclusive; more than one may be operating. The leading hypotheses are:

(1) The environment has changed, and the current sizes of the northeastern offshore spotted and eastern spinner dolphin populations are already at, or near, their carrying capacities.

> Since the late 1950s, the environment might have changed in such a way that it would no longer support the same numbers of these dolphins as it did before. However, physical and biological data do not support such a large-scale environmental change in the ETP. Although environmental change such that the carrying capacity has come down to match the fishery-induced depletion levels appears unlikely, the hypothesis of some degree of reduction cannot be rejected because relevant data are sparse, and the complicated relationships among species and their environment are so poorly understood.

(2) After bycatch due to the purse-seine fishery has been reduced or eliminated, there is a lag period before recovery begins.

> There are no data to support or reject this hypothesis for ETP dolphins. Studies of apparent lags in other species are discussed in the "Scientific Findings" section of this report.

(3) The purse-seine fishery has effects on the dolphin populations beyond the reported bycatch.

> Research conducted under the IDCPA has evaluated some possible fishery effects, including separation of mothers from calves and physiological effects of chase and encirclement ("stress") that could affect subsequent survival and reproduction. In addition, there are other fishery effects for which investigation was not feasible. There are several reasons to think that the actual bycatch could be larger than the reported kill: (a) some mortality is not observed, simply because the fishery observer cannot see all of the net at all times on all sets; (b) dolphin sets made by boats smaller than Class 6 are not observed; and (c) some mortality is observed but not reported by the fishery observer.
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> There are numerous plausible effects of the fishery on the dolphin populations beyond the reported kill. Is the sum of all of these fishery effects sufficient to account for the lack of recovery? Unfortunately, the answer to this central question is not clear. It is probable that

all of these effects are operating to some degree, and it is plausible that in sum they could account for the observed lack of growth of the dolphin populations. If the sum of the fishery effects were a few dolphins per set or a few dolphins per 1000 dolphins chased, it would be sufficient to account for the lack of recovery. However, without comprehensive quantitative estimates for any of these effects, it is not possible to reach more definitive conclusions.

The final determination of whether or not the purse seine fishery is having a significant adverse impact on these dolphin stocks should be made in consideration of the evidence for adverse fishery effects beyond reported mortality and the lack of evidence for substantial ecosystem change.

INTRODUCTION

The tropical waters of the Pacific Ocean west of Mexico and Central America, an area known as the eastern tropical Pacific (ETP), support one of the world's largest fisheries for yellowfin tuna (*Thunnus albacares*) with between 100,000 and 300,000 metric tons caught each year (Fig. 1). A major basis for this fishery's success is an ecological association in this region between tunas and dolphins in which large yellowfin tunas regularly swim together with several species of dolphins. The reasons for this association between tunas and dolphins are not well understood. Nevertheless, since the 1950s, a predominant tuna fishing method in the ETP has involved intentionally capturing tunas and dolphins together using nets called purse seines. In the early history of the fishery, many of the dolphins died in the nets, but now the vast majority of dolphins captured during fishing operations (more than 99%) are released alive owing to numerous technological and procedural improvements and the skills of the experienced captains and crews. It is estimated that 6 million dolphins have been killed since the fishery began and that this mortality resulted in three stocks of dolphins in the ETP being declared "depleted"[6] under the Marine Mammal Protection Act (MMPA). The three dolphin stocks most affected by fishery are the northeastern offshore spotted dolphin (*Stenella attenuata*), the eastern spinner dolphin (*S. longirostris oreintalis*), and the coastal spotted dolphin (*S. attenuata graffmani*). In recent years, the reported number of all species of

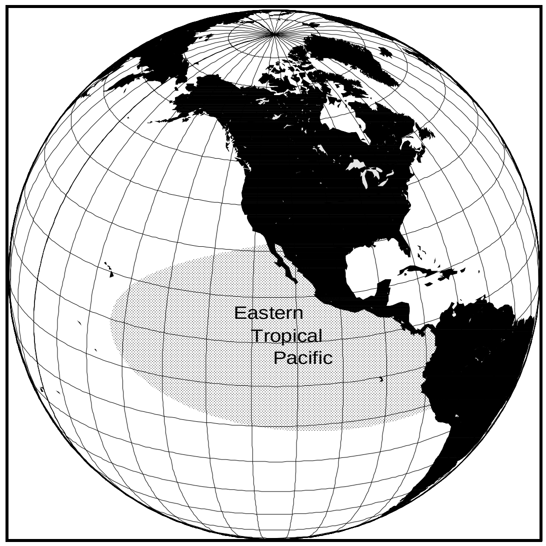

Figure 1 The eastern tropical Pacific (ETP).

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[6] Under the Marine Mammal Protection Act (MMPA), a species is designated as depleted when it falls below its optimum sustainable population. The MMPA defines optimum sustainable population (OSP) as "the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the optimum carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element" (16 U.S.C. 1362). NOAA Fisheries regulations have further defined optimum sustainable population as "a population size which falls within a range from the carrying capacity of the ecosystem to the population level that results in maximum net productivity." The population level that results in maximum net productivity is considered to be 60% of population size at carrying capacity.

dolphins killed in this fishery has declined significantly to fewer than 3,000 dolphins per year. Despite this substantial reduction in reported dolphin mortality in the fishery, there is concern that the practice of setting on dolphins is affecting the ability of depleted stocks to recover. Consequently, the research reported here was conducted to assess whether or not depleted dolphin stocks in the ETP are recovering and to examine the effects of chasing and encircling dolphins during purse seine fishing.

In addition to using dolphins, there are other ways in which tuna are caught in the ETP purse seine fishery. Purse seine nets can be set around schools of tunas unaccompanied by dolphins ("school sets") and around tunas associated with logs or other objects floating in the ocean ("log sets" or "fish aggregating device sets"). Sets on dolphins comprise approximately 45% of the 15,000-20,000 purse seine sets made by large vessels in the ETP every year. The U. S. fleet dominated the fishery in the early decades, but over the last 20 years the vast majority of U.S. vessels transferred to foreign flags or moved to the western Pacific Ocean where sets made are exclusively non-dolphin sets. As the U.S. component of the fishery steadily has declined in the ETP, the number of foreign vessels has steadily increased since the early 1980s. In 2002, only three U.S.-flagged large purse seine vessels were fishing in the ETP, and their sets are exclusively non-dolphin sets. Non-U.S. vessels fishing in the ETP numbered 204 in 2001 with the largest fleets from Mexico, Venezuela, and Ecuador.

This report summarizes the results of the multi-year IDCPA research program conducted by the Southwest Fisheries Science Center (SWFSC) of the NOAA Fisheries to assess the status of depleted dolphin populations in the ETP and to determine the effect of purse seine fishing operations on these stocks. These research efforts provide a substantial body of information including dolphin abundance data, fishery mortality estimates, a review of scientific literature on stress in marine mammals, results from a necropsy study of dolphins killed in the fishery, a review of historical demographic and biological data related to dolphins involved in the fishery, results from an experiment involving the repeated chasing and capturing of dolphins, and information regarding variability in the biological and physical features of the ETP ecosystem over time. The results of this research are summarized in the section below titled "Scientific Findings." A more detailed presentation of each research component and its results can be found in a series of appendices at the end of this report. The most detailed and technical information on each research component can be found in the numerous scientific papers and reports supporting this document (see Appendix 1 for a list). A list of acronyms used in this report is provided in Appendix 2.

Legislative Background and Required Research

In 1997, Congress amended the Dolphin Protection Consumer Information Act (DPCIA) and the MMPA with the IDCPA, adding specific provisions for studying the impact of the fishery on the ETP depleted dolphin stocks. These amendments require the Secretary of Commerce to conduct specified scientific research and to make a finding, based on the results of that research, information obtained under the IDCP, and any other relevant information, as to 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 ETP. This finding will determine the dolphin-safe labeling standard for tuna sold in the United States.

The research specified under subsection 304(a) of the MMPA, established by the IDCPA, required three years of dolphin population abundance surveys and studies on stress in dolphins. The stress studies required were: (1) a review of relevant stress-related research and a 3-year series of necropsy samples from dolphins killed in the fishery; (2) a 1-year review of relevant historical demographic and biological data related to the depleted dolphins; and (3) an experiment involving the repeated chasing and capturing of dolphins by means of intentional encirclement.

The IDCPA Scientific Research Program

In order to fulfill the research mandates of the IDCPA, the SWFSC of NOAA Fisheries further developed its existing ETP dolphin research program to address the specific research activities required in the IDCPA (as detailed above). The IDCPA research program is structured as follows: abundance estimation, ecosystem studies, stress and other fishery-related studies, and stock assessment. The SWFSC has conducted research in the ETP for over three decades. In 1986 a long-term, large-scale research program was initiated to monitor trends in the abundance of ETP dolphin populations (the Monitoring of Porpoise Stocks program, or MOPS). The SWFSC again conducted abundance surveys in the ETP in 1992 in a more limited area off Central America, focusing on the stock of common dolphins there. However, there was a lapse of eight years before comprehensive abundance surveys were conducted again covering the known range of northeastern offshore spotted and eastern spinner dolphins, resulting from the IDCPA mandate. During this history of research activity the SWFSC regularly conducted studies of the region’s physical and biological characteristics, in order to place its dolphin studies within an ecological context.

Although the SWFSC has conducted a large amount of management-related research on the life history of dolphins affected by this fishery, research on dolphin stress and related issues has not been a regular or major component of research by the SWFSC. Therefore, in order to appropriately address the research requirements of the IDCPA mandates for stress-related research, it was necessary to initiate new types of sampling in collaboration with experts from academia and other governmental and inter-governmental organizations.

As mandated by the IDCPA, the research program was conducted in consultation with the Marine Mammal Commission (MMC) and Inter-American Tropical Tuna Commission (IATTC). These consultations, as well as meetings with scientific experts selected by NOAA Fisheries scientists to comment on specific technical topics, took place as a part of the planning, implementation, and evaluation of research conducted under subsection 304(a). See Appendix 3 for a list of consultations held with the MMC and IATTC and other important planning events. To further ensure the highest caliber of these research results and analyses, NOAA Fisheries utilized a formal system for independent peer review through the Center of Independent Experts (CIE), administered by the University of Miami, Cooperative Institute for Marine and Atmospheric Sciences. The CIE draws experts for its independent peer reviews from a pool of qualified scientists from outside NOAA Fisheries. These scientists typically are internationally recognized experts from countries around the world. To ensure independent peer review, and to avoid perceptions of improper influence, the CIE has a Steering Committee composed of tenured academics and senior researchers who are charged with the program's oversight. The CIE Steering Committee selects reviewers and secures written assurances from them that they have no conflicts of interest. NOAA Fisheries held five CIE reviews: four to evaluate the major topics of study and one to review this report (see Appendix 4).

Dolphin Stocks in the Eastern Tropical Pacific Ocean

In the region known as the ETP there are 20 stocks of 14 species of small cetaceans (whales and dolphins) known to have suffered at least some mortality in the ETP purse seine fishery for tuna. The cetacean stocks predominantly affected by the fishery are the northeastern offshore stock of spotted dolphin, the eastern stock of spinner dolphin, and the coastal spotted dolphin. A number of other species also have been killed in the fishery, including common dolphins (*Delphinus delphis*), striped dolphins (*S. coeruleoalba*), Fraser's dolphins (*Lagenodelphis hosei*), rough-toothed dolphins (*Steno bredanensis*), bottlenose dolphins (*Tursiops truncatus*), and short-finned pilot whales (*Globicephala macrorhyncus*).

The MMPA requires that marine mammal populations be managed so that each is maintained at an optimum sustainable population (OSP) level, a level defined as a population size that falls within the range between carrying capacity and the maximum net productivity level, which is defined as 60% of the carrying capacity. In other words, the MMPA requires that an exploited population be managed such that its population size falls within the range between the largest size the ecosystem can sustain and the size at which the population's or stock's net productivity is maximized. Stocks are defined as depleted if their population levels are below OSP. Three ETP stocks have been classified as depleted under the MMPA: the northeastern offshore spotted dolphin, the eastern spinner dolphin, and the coastal spotted dolphin. Two of these stocks, the northeastern stock of offshore spotted dolphins and the eastern stock of spinner dolphins were designated depleted under the MMPA, most recently on 26 August 1993 (58 FR 45066) and 1 November 1993 (58 FR 58285), respectively. At that time the eastern spinner dolphin was estimated to be at approximately 44% of its pre-exploitation population size (Wade 1993a), that is, 44% of the number of dolphins estimated to have comprised the stock prior to the onset of purse seine fishing in the late 1950s. The northeastern offshore spotted dolphin was estimated to be between 19% and 28% of its pre-exploitation population size (Wade 1993).

There is less certainty regarding the status of the depleted coastal spotted dolphins, which are found within 185 km of the coast in the ETP. During the early years of the purse seine fishery, fishing effort was concentrated near the coast. Therefore, coastal dolphin stocks that associate with tunas may have experienced high mortality. The coastal spotted dolphins are sufficiently distinct to be classified as a separate subspecies, and recent genetic studies suggest there are multiple stocks along the coast (Escorza-Trevino *et al.* 2002). In a 1980 Federal Register notice the NOAA Fisheries declared that the 1979 population size was estimated to be 193,200 (45 FR 72178-72196). This was estimated to represent 42% of its pre-exploitation population size and was therefore considered depleted under the MMPA. The limited information available for coastal spotted dolphins is presented and evaluated to the extent possible in this report.

Reported Mortality in the Purse Seine Fishery

Since 1959, when fishing with purse seines began to dominate the tuna fishery in the ETP, the number of purse seine sets made on dolphins has been recorded in skipper logbooks and reported to the IATTC. These records provide reasonably accurate information on the number of sets made on dolphins by year and location for the preponderance of the fishery's history. However, information from logbooks is insufficient for determining dolphin mortality, species composition of the dolphin mortality, and other important information, such as the use of dolphin rescue methods (e.g., backdown method) over the course of the fishery (Barham *et al.* 1977, Wade 1994). It is known that the proportion of encircled dolphins killed was higher in the early part of the fishery relative to later years (Joseph and Greenough 1979).

In 1971, NOAA Fisheries began placing observers on U.S.-registered vessels to record information on dolphin sets and mortality. This program was formalized in 1972 (Edwards 1989). In 1979, the IATTC instituted a similar observer program on non-U.S. vessels that also continues presently. In 1991, Mexico initiated its own national observer program and a portion of its vessels' trips are observed through this program, with additional trips being covered under the IATTC program. By 1990, the NOAA Fisheries mandated that 100% of fishing trips involving dolphin sets by U.S. vessels be observed. Soon after, the IATTC and Mexican observer programs implemented their programs to have 100% observer coverage on non-U.S. class 6 vessels. More recently, Venezuela and Ecuador initiated national observer programs, and a portion of those nations' trips are now covered by their own observers, with the remaining portion covered under the IATTC program.

For the past several years, a simple enumeration of reported dolphin mortalities has been used by the IATTC in order to summarize dolphin mortality in the fishery. In the years before 100% observer coverage was implemented, dolphin mortality in the fishery was estimated for unobserved fishing trips using reported mortality from observed trips. Estimates of dolphin mortality in the fishery for 1959-2001 can be found in Wade (2002). These mortality estimates were used in analyses of the northeastern offshore spotted dolphin and eastern spinner dolphin stocks presented below.

SCIENTIFIC FINDINGS

Abundance of the Depleted Stocks

We used a method called line-transect sampling to estimate the abundance of dolphins in the ETP. This method is the most widely used for estimating the abundance of biological populations (Buckland et al., 2001). In line-transect sampling, observers perform standardized visual surveys along a series of lines, searching for objects of interest (i.e., groups of dolphins) and recording each animal or group detected, its perpendicular distance from the transect line, and the group size. From this information, the abundance of the animals in the survey area is estimated.

The SWFSC has conducted line-transect sampling surveys on research vessels in the ETP for nearly three decades. Marine mammal surveys in the ETP have been conducted by the SWFSC in the following years: 1974, 1976-77, 1979-80, 1982-83, 1986-1990, 1992, and 1998-2000. Surveys in 1974 and 1976 were primarily feasibility studies, and data collected on those surveys were inappropriate for estimating abundance using current line-transect sampling procedures. Since 1977, data collection on surveys has followed line-transect sampling protocols and allowed abundance estimation of dolphin stocks in the ETP (Wade 1994). However, surveys in 1977 and 1992 did not have sufficient survey effort in the areas of the ETP occupied by northeastern spotted and eastern spinner dolphins, so abundance estimates for these survey years are not available, resulting in a gap during the 1990s.

To fulfill the research requirements under the IDCPA, research cruises to estimate the abundance of dolphin stocks affected by the tuna purse seine fishery were carried out in 1998, 1999, and 2000. Prior to the surveys, a technical meeting to review the survey design for estimating abundance of ETP dolphins was held at the SWFSC; attendees included experts in line-transect sampling and abundance estimation and scientists representing the IATTC, MMC, Mexico, and Ecuador (see Gerrodette *et al.* 1998). After the completion of the 1998 survey, another technical meeting was convened to review the methods for analysis of the data collected during the first survey. Many of the same experts participated in this second meeting, as well as scientists from the IATTC, Mexico and Peru (see Olson and Gerrodette 1999).

As part of the IDCPA research program, the SWFSC developed improved analytical methods of estimating abundance to account for factors such as dolphin group size, sea state, swell height, sun glare, and other conditions that affect the probability that a dolphin school will be detected (Forcada 2002). These covariate methods are a significant improvement over traditional univariate methods, which model the probability of detection as a function only of distance from the transect line. These methods also deal with the bias that arises because large schools of dolphins are more likely to be seen than small schools and with the problem that the dolphins occur in mixed-species schools.

These new analytical methods were applied to data collected in 1998-2000 as well as to data collected on nine earlier cruises dating back to 1979. Thus, northeastern offshore spotted and eastern spinner dolphin abundance was estimated in each of 12 years over a 21-year period using these methods (Fig. 2) (Gerrodette and Forcada 2002). These new series are used in the assessment modeling (see Appendix 8).

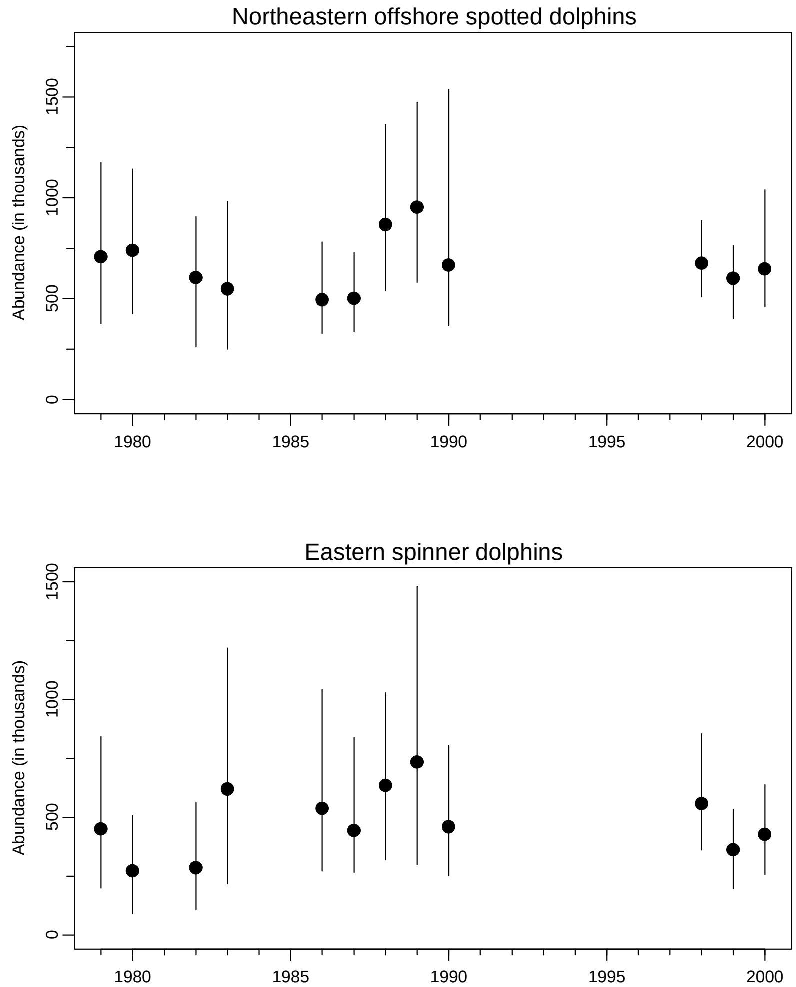

Figure 2 Estimates of abundance for northeastern offshore spotted and eastern spinner dolphins, 1979-2000, with 95% confidence intervals on the point estimates.

The average of the abundance estimates resulting from the new surveys for the years 1998, 1999, and 2000 are 641,153 (CV = 16.9%) for northeastern offshore spotted dolphins, 448,608 (CV = 22.9%) for eastern spinner dolphins, and 143,725 (CV = 35.7%) for the coastal spotted dolphins. Although the coastal spotted dolphin is presented here as a single value, recent genetic analyses (discussed below) indicate multiple coastal stocks are likely, making the single abundance estimate of limited relevance.

Please see Appendix 5 for more detail on Abundance Estimation.

The Environment and Ecosystem

Carrying capacity, or the maximum equilibrium population size for a given animal that the environment will support, is a fundamental concept in population ecology and the ideas used to manage exploited populations. When a population is reduced in abundance by external factors (human or otherwise), it should recover to its carrying capacity once those factors are removed. This increase in abundance is referred to as recovery from depletion. Recovery is dependent upon an environment that is relatively stable. If the environment has changed such that the resources needed to support the population have either increased or decreased enough to change the carrying capacity, our expectation for recovery should be modified. That is, we should expect the population to stabilize at a new level, which may be either higher or lower than that prior to the change. We also should modify our concern with respect to mortality due to human activities. For instance, if a population has been depleted and we suspect that the environment has changed in a manner that supports fewer individuals, then resource managers should consider taking a more conservative stance when evaluating potential impacts of future human effects.

The rate with which recovery is achieved will be a function of both the population's intrinsic ability to grow and the current carrying capacity. Consequently, the relevant ecosystem issue is whether there have been changes in carrying capacity of sufficient magnitude to explain the lack of recovery toward pre-exploitation levels.

If carrying capacity had increased, or had not changed substantially, this would be indistinguishable in terms of growth rates achieved by stocks that have been depleted: in either case these populations should be growing at or near their maximum intrinsic rates. Our knowledge of the value of this maximum rate is limited, but it is generally assumed to be approximately 4% per year for dolphins, which is also the default value established by the U.S. system for managing cetacean populations under the MMPA's PBR system. For the two stocks of concern here, carrying capacity would have to be substantially reduced, by approximately 80% and 65% for northeastern offshore spotted and eastern spinner dolphins, respectively, to explain their low and unchanging abundances (see below, Figure 2 and "Stock Assessments" section). Are such large reductions consistent with the information available about the ETP environment and ecosystem? This is a central question to be addressed when we evaluate the available information on fishery effects.

The dominant source of variability in the ETP is related to the El Niño/Southern Oscillation (ENSO), and occurs on 2-yr to 7-yr periods. This conclusion is based on analysis of a lengthy time series of physical and biological oceanographic data (approximately 100 years). Analyses of data on prey fishes, squids, and seabirds, collected aboard NOAA Fisheries dolphin surveys since 1986, also support this conclusion (Appendix 6), though it should be noted that there are no data for these groups currently available prior to the early 1980s.

There have been longer-term changes throughout the Pacific Ocean, with the best-known change occurring in the late 1970s when the North Pacific clearly shifted from one physical and ecological state to another. This climate shift also was detected within the ETP, in the form of a small increase in sea surface temperature, a weakening of trade winds, and moderate changes in surface chlorophyll levels (increase in the core of the ETP occupied by the stocks of interest here, decrease along the equator). If carrying capacity for dolphins is changed simply as a result of changes in basic production as indexed by surface chlorophyll, one would expect small increases in carrying capacity as a result of the late 1970s shift. The core ecosystem questions here are whether these small changes have for some reason caused reductions of carrying capacity, and further whether any possible reductions were large enough to explain the low abundance of dolphin populations. As detailed below in the section on Stock Assessment, these populations have remained essentially unchanged since earlier depletion to 20% (northeastern offshore spotted dolphins) and 35% (eastern spinner dolphins) of their pre-exploitation levels. Such dramatic reductions in carrying capacity are considered unlikely, but they cannot be dismissed entirely from consideration. This is due to a combination of our general lack of knowledge about what specifically constitutes carrying capacity for these dolphins, our lack of data on the ecosystem prior to the late 1970s shift, and the possibility that small changes in background physical conditions can have large ecological effects.

In conclusion, the available data are insufficient to clearly resolve the matter of whether or not there have been substantial ecosystem changes in the ETP that would inhibit or enhance these populations' ability to recover. Nonetheless, the information available indicates it is unlikely that the carrying capacity has been reduced to the degree required to explain the low growth rates of the depleted dolphin populations.

Please see Appendix 6 for more detail on the Ecosystem Studies.

Fishery Effects: *Mortality, Stress and Other Effects*

Reported mortality levels from the fishery have been reduced substantially, especially within the past decade. In 2001 (the most recent year for which annual mortality estimates are available) the total reported mortality was 2,027, with 466 eastern spinner dolphins, 656 northeastern offshore spotted dolphins, and 2 coastal spotted dolphins killed. If the Potential Biological Removal (PBR) system under the MMPA were applied as a standard, mortality limits for these stocks would be 1,298 for eastern spinner dolphins, 2,367 for northeastern offshore spotted dolphins and 1,073 for coastal spotted dolphins (but note that this would apply to a single coastal spotted dolphin stock, which is no longer considered likely) . The stock mortality limits (SML)[7] for these stocks, if computed using this updated information (i.e., the mean abundances from the 1998, 1999, and 2000 surveys), would be 371 eastern spinner, 557 offshore spotted dolphins and 107 coastal spotted dolphins (same caveat applies for coastal spotted dolphins as noted for PBR above).

Changes in the fishery during the last few decades have greatly reduced the reported mortality of dolphins; nevertheless, there continues to be concern that the fishing methods currently used are causing stress to the dolphins involved and that such stress may be affecting population recovery. Emerging from this concern were the IDCPA's explicit research mandates for reviews of stress literature, a program of necropsy observations of dolphins killed in the fishery, evaluation of historical data and samples, and the chase-encirclement field experiment.

The literature review indicated that tuna purse seine operations involve well-recognized stressors in other wild mammals, and it is plausible that stress resulting from chase and capture in the ETP tuna purse seine fishery could compromise the health or reproduction of at least some of the dolphins involved. The specifically mandated necropsy program was conducted over a 3-year period (1998-2000). It was possible to obtain samples from only 56 dolphins killed in the fishery, which is insufficient to make population-level inferences. The other specifically mandated field program, the chase-encirclement stress studies (CHESS) cruise, was conducted during August-October 2001. Because of the experiment's complexity and considerable logistical challenges, it was recognized from the outset that sample sizes for these studies would be limited (Donahue *et al.* 2000) and that population-level inferences from these studies were unlikely

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[7] The nations fishing in the ETP have established a system for calculating annual limits on the allowable fishery mortality level for each stock.

The completed research included a combination of field experiments, retrospective analyses, direct observation, and mathematical modeling, to address a broad range of stress-related effects and other factors that potentially could lead to unobserved dolphin mortality associated with tuna purse seine operations. As expected, the data are insufficient to quantify potential population-level impacts or to determine whether population recovery might be delayed because sample sizes were small and baseline or control data were not available for the affected dolphin species. However, in the aggregate, the findings from the available data support the possibility that tuna purse-seining activities involving dolphins may have a negative impact on some individuals. Some evidence was found for potential stress-related injury or unobserved mortality of dolphins involved in purse seine fishing operations, based on the combined documentation of: (a) moderately elevated stress hormones and enzymes indicative of muscle damage observed in live dolphins examined in the nets; (b) evidence of past (healed) muscle and heart damage in dolphins killed during fishing operations; and (c) fatal heart damage in virtually all fishery-killed dolphins, which most likely was related to elevated catecholomines. The responses observed in the sampled live animals were well within those ranges from which dolphins are expected to recover fully; however, it is possible that some dolphins may experience stronger responses, such as during occasional 'catastrophic' aspects of fishery operations when dolphins may become trapped under a canopy in the net. In theory, this could result in a surge in catecholomines intense enough to cause injury or death within hours or days of being released (a condition known as *capture myopathy*). To date, no live ETP dolphin exhibiting such a response has been identified or sampled.

Analyses of purse-seine sets during which all killed dolphins were examined led to the conclusion that there is some separation of calves from their mothers (Archer *et al.* 2001). For sets in which a lactating female was killed, her calf was usually missing (the frequency of calves was only about 20% of the frequency of lactating females). This implied that there was some unobserved mortality of orphaned calves not previously accounted for. Based on reasonable assumptions about length of nursing dependency, it was estimated that reported fishery mortality was underestimated by 10-15% for spotted dolphins and 6-10% for spinner dolphins in this sample, if separations occur during the later part of the chase and capture process, such that all mother-calf separations are represented by dead lactating females. However, unobserved calf mortality potentially could be large if mother-calf separation occurs during the chase portion of the fishing operation. Whether, and if so how often, such separations occur during the chase is unknown. Direct observations are not feasible. Preliminary modeling of the energetics of swimming suggested that it would be difficult for smaller nursing calves to keep up with an extended chase. Given these uncertainties, only a minimum estimate of unobserved calf mortality is possible, with the caveat that the actual mortality is likely to be larger by an unknown amount.

In addition to reported mortality and any inferred additional mortality, it is important to consider how many times the fishery interacts with dolphins individually and with the populations as a whole each year. The number of interactions is large relative to the population sizes. For northeastern offshore spotted dolphins, there are over 5,000 dolphin sets per year, resulting in 6.8 million dolphins chased per year and 2.0 million dolphins captured (encircled in the purse-seine) per year (numbers are means for 1998-2000). For eastern spinner dolphins, there are about 2,500 sets per year, 2.5 million dolphins chased per year, and 300,000 dolphins captured per year. For coastal spotted dolphins, there are about 150 sets per year, 280,000 dolphins chased per year, and 40,000 dolphins captured per year. When divided by the estimated mean abundances during the same years, a northeastern offshore spotted dolphin is chased 10.6 times per year and captured 3.2 times per year on average. An eastern spinner dolphin is chased 5.6 times per year and captured 0.7 times per year. A coastal spotted dolphin is chased 2.0 times per year and captured 0.3 times per year.

In conclusion, the investigations described above span a broad range of concerns relating to stress and other potential fishery effects. It was recognized at the outset that sample sizes would be small and population-level inferences would not likely be possible. Nonetheless, some plausible mechanisms of additional mortality were identified, and the data support the idea that tuna purse-seining activities might cause the unobserved injury or death of individual dolphins. Without larger sample sizes, the results cannot be evaluated in terms of impacts on population recovery. However, at current dolphin abundances and levels of fishing effort, a lack of recovery could be caused by the loss of only a few additional dolphins per set. The differences between the observed growth rates and the generally expected rate of about 4%/year are 2.3% and 2.6% per year for northeastern offshore spotted and eastern spinner dolphins, respectively, for the models with the shortest (most optimistic) recovery times, as discussed below under Stock Assessments. Given recent population estimates, these percentages correspond to about 14,400 and 11,300 dolphins per year, respectively. Given the number of interactions with the fishery, these numbers correspond to 2.8 dolphins per set, 2 dolphins per thousand chased and 7 dolphins per thousand captured for northeastern offshore spotted dolphins. For eastern spinners, the corresponding numbers are 4.5 dolphins per set, 5 dolphins per thousand chased and 39 dolphins per thousand captured. In other words, because of the intensity of the fishery, a relatively small number of animals affected per interaction (2-5 per set or 2-5 per thousand chased) would be sufficient to explain the low growth rates and long recovery times.

Please see Appendix 7 for more detail on Stress Studies and Other Possible Fishery Effects.

Stock Assessments

The most striking result from the trend and assessment analyses for both eastern spinner dolphins and northeastern offshore spotted dolphins is that their population growth rates are very low. Depending on the model used, estimates of population growth rates ranged from -2% to 2% per year. For eastern spinner dolphins, analyses indicating a decline during the past decade were slightly more probable. Taking all the assessment analyses together, the results are not consistent with recovery from depletion for either stock. This conclusion is not dependent upon a specific model or subset of analyses. (Whether we should expect to observe signs of recovery is addressed below). These rates appear too low overall and suggest some process is acting to suppress population growth. The extent to which this suppression of population growth could be related to the fishery, the environment, or other factors is discussed elsewhere in this report. Regardless of the source of suppression, these low rates are a conservation concern.

There are relatively few direct observations of population growth rates for small cetaceans from which to establish a standard or expectation. Reilly and Barlow (1986) established likely ranges of growth rates, given what is known about dolphin birth and death rates. Information specific to spotted and spinner dolphins indicates they are capable of maximum growth rates in the range of 4% to 7% per year. Because very few pelagic dolphin populations have been studied, and none have actually been observed to increase at these maximum rates, the lower value of 4% is used as a general expectation. This value (4%) was adopted as the default maximum intrinsic growth rate for dolphins in the PBR system for managing marine mammals under the MMPA (Wade and Angliss 1996, Wade 1998). The assessment model results presented in this report are not quantitatively compared to a maximum growth rate of 4%; rather, this value is used somewhat less formally as a context in which to consider the estimates of maximum growth rates presented in this report.

When used in a population model, the low growth rates resulting from the stock assessments presented here lead to long estimated times to recovery (i.e., to OSP range) for these stocks. The best supported models predict recovery in 78 years for northeastern offshore spotted dolphins and a decline (no recovery) for eastern spinner dolphins. A second set of models, slightly less well supported by the data, predicts recovery times greater than 200 years for northeastern offshore spotted dolphins and 64 years for eastern spinner dolphins. If the populations were recovering at 4%/year, the recovery times would be 29 and 18 years, respectively. These estimates of time to recovery assume no change in carrying capacity has occurred since the late 1950s. However, if carrying capacity has changed, the OSP range based on historical data would no longer be the relevant target. Available information would not be sufficient to determine an OSP range for a new carrying capacity.

There has been controversy regarding use of TVOD-based abundance indices in assessments for ETP dolphins. In the context of this research program, TVOD indices were included in the preliminary analyses reported in 1999 (SWFSC 1999), but this was done with strong caveats. Subsequently, published analyses (Lennert-Cody et al. 2001) pointed to substantial problems with TVOD abundance indices, and the authors cautioned against using TVOD in population dynamics modeling. Thus, we did not include TVOD in our initial assessment modeling for this report. This was rejected by the CIE reviewers of the assessment modeling (Haddon 2002, McAllister 2002a), who put forth a method to correct bias in the TVOD series. In keeping with the review process we applied this method for a subset of the assessment analyses (exponential growth models, but not generalized logistic or age-structured models). In the final external review (August 16, 2002) the matter was again raised, with one reviewer asserting that TVOD should be included in all assessment analyses (McAllister 2002b). This reviewer presented analyses demonstrating robustness of the bias correction method to some likely types of problems. However, we remain unconvinced that the many known and potential issues related to these indices have been addressed, and therefore decided to proceed with caution and continued to use them only in some assessment analyses.

Analyses that allow for a change in population growth rates during recent decades suggest the stocks were increasing at reasonable rates until about 1990, then decreasing throughout the past decade. Inclusion of the TVOD abundance estimates makes this scenario appear moderately more likely than the case of a flat trend through recent decades.

The assessments indicated about equal weight for models with and without changes in carrying capacity or maximum potential population growth rates since the onset of the fishery, but the ability to resolve these issues with the available data is limited, and such changes should not be dismissed from consideration. Had the TVOD estimates been included in those analyses, there likely would have been a moderate increase in our ability to select between alternate hypotheses.

The assessment modeling provided contradictory evidence regarding the possibility that there is substantial additional mortality as a simple function of the frequency of sets per year. It might be expected, for example, that if there were frequent cow-calf separations occurring during the chase and capture processes, this would have been reflected in these analyses. Similarly, if lethal stresses resulted from more frequent chase and capture, one would expect this to be reflected in these model runs. One result from including additional mortality in the models was an increase in estimates of maximum potential growth rates. However, when the model increased total mortality for years with more sets per dolphin, the fit of the model was improved, but this improvement was not enough to do a better job overall than the model that did not include the frequency of sets. This suggests several possibilities: 1) that there are no substantial unobserved fishery-related mortality effects, 2) that the data are inadequate to capture the potential effects, or 3) the effects cannot be represented by the simple relationship included in the assessment models (e.g., if an effect has changed through time, if it was only present for a portion of the time series, or if the effect is nonlinear).

The test that included set frequency data did not allow for lagged effects, or effects that might be a function of the actual frequency of capture of individuals. The index used was essentially the average number of times an individual might have been set upon, and assumed equal probability of this occurrence for all individuals. In fact, the mean value may not be so important as the extreme values. That is, three times per year (on average) may not cause lethal effects, but this average may be comprised of a small percentage of the population that is set upon many more times per year. If there are threshold effects that occur only after, say, 10 or more occurrences within a relatively brief period, these model analyses would not detect such effects.

Similar results were obtained from increasing the reported mortality by a constant 50% and 100%. That is, there was a moderate decrease in performance of the models when the scaled up mortality series were included, but estimates of maximum population growth rates increased, and were closer to the expected range.

So, in conclusion, the assessment modeling results were equivocal on the existence of substantial mortality in addition to reported levels. Although such mortality should be regarded as slightly less likely as a result of this assessment modeling, it should not be dismissed from consideration.

Is it reasonable to expect that our methods would have detected evidence of a recovery for these depleted stocks? This question is of central importance. Estimates of rates of change are dependent upon the variability of annual abundance estimates, and this variability must be taken into account when evaluating overall results. This has been done consistently throughout all analyses reported here. Confidence and probability intervals for all estimated rates of increase were broad, reflecting the variability of annual abundance estimates. However, taken as a whole they indicate that any substantial recovery should have been detectable with high probability. Even a modest recovery of around 2% per year likely would have been detected, and only very low rates, around 1% or less, could reasonably have occurred without being detected.

Also potentially relevant is whether populations depleted to such low levels will respond quickly to removal of most human-caused mortality, or if they are held at these levels for additional periods by processes yet to be identified. An analysis of depleted marine fish populations addresses this possibility. Hutchings (2000) examined evidence for recovery of 90 stocks of depleted marine fishes, after more than 15 years since large reductions in biomass. He found little evidence of recovery. (Interestingly, yellowfin tuna in the ETP were cited as an exception, having shown some recovery). Hutchings concluded that actual time to recovery is longer than expected given simple population models. One contributing factor noted was continuing mortality from bycatch or illegal fishing. Best (1993) reviewed evidence for recovery among 12 populations of depleted baleen whales. He reported evidence of recovery in 10 of 12 populations, but for most stocks more than 50 years had elapsed before recovery was evident. This lag was ascribed to a combination of range contractions and underestimation of the original levels of depletion. Whether such a lag from unidentified processes might be operating for depleted ETP dolphins is difficult to evaluate, but might be considered as an additional hypothesis to explain the observations of apparent lack of recovery by eastern spinner and northeastern offshore spotted dolphins.

It is also worth noting that these assessment analyses were based on single-species models, rather than multi-species or ecosystem-based models. This was considered a prudent and reasonable course, given limitations of data availability, and questionable reliability of more complex models. One characteristic of the single-species structure was limited ability to test for possible changes in carrying capacity. Although the analyses of available oceanographic and other environmental data do not lead to the conclusion that a major change in the system's productivity has occurred, it is possible that effective carrying capacity for these stocks could have been modified, either positively or negatively, by changes in abundance of competitors or predators. The existing data on other large animals of the region do not allow reliable evaluation of these possibilities. An increase in productivity of yellowfin tuna has been observed in the ETP since the 1983 El Nino, (Maunder 2001). However, the relevance of this observation can not be determined because it is not yet clear whether these depleted dolphin populations have net positive or negative ecological relationships with yellowfin tunas.

The current status or possible effects of chase and encirclement by the purse seine fishery on the third depleted stock, coastal spotted dolphins, cannot be assessed to the same degree as the two depleted stocks discussed above. Current abundance for coastal spotted dolphins was estimated from data collected on the 1998-2000 research vessel surveys as if only one stock of this subspecies exists. However, results from recent genetic studies indicate that the existence of just one stock of this subspecies throughout the coastal ETP is unlikely. Preliminary genetic analyses identified at least six populations (see Escorza-Trevino *et al.* 2002). Such small, relatively isolated populations risk being substantially reduced if exploitation has concentrated within their limited ranges. Existing information is not sufficient to judge the extent of this possible conservation risk. Recent reports of fishery mortality are relatively low for coastal spotted dolphins (18, 17, 6, and 2 dolphins per year for 1998, 1999, 2000 and 2001, respectively) (C. Lennert-Cody, IATTC, pers.comm.). Whether past, more extensive exploitation has substantially reduced one or more of these stocks is unclear.

Summary

Research conducted under the IDCPA has produced many important, substantial new results: current estimates of abundance for depleted dolphin stocks as well as for other cetaceans in the ETP, with advances in analytic methods for abundance estimation; extensive contributions to understanding the oceanography and ecology of the region; sharpening the focus on likely mechanisms of stress effects on individual dolphins; and an improved understanding of the likely effects of chase and encirclement on the cow-calf bond.

For the two depleted dolphin stocks for which we have sufficient information, the primary results are: (1) northeastern offshore spotted dolphins are at 20% and eastern spinner dolphins at

35% of their pre-fishery levels; and (2) neither population is recovering at a rate consistent with these levels of depletion and the reported kills.

There are three general explanations (hypotheses) for the lack of recovery. The hypotheses are not mutually exclusive; more than one may be operating. While other hypotheses could be proposed (pollution, for example), the leading hypotheses are:

(1) The environment has changed, and the current sizes of the northeastern offshore spotted and eastern spinner dolphin populations are already at, or near, their carrying capacities.

> The expectation of recovery is based on the assumption that the current sizes of both dolphin populations are considerably below their carrying capacities. It is well established that both populations were much larger in the late 1950s. However, the environment may have changed since then in such a way that it would no longer support the same numbers of these dolphins as it did before. Physical and biological data do not support the supposition that such a large-scale environmental change has occurred in the ETP. Although environmental change such that the carrying capacity has come down to match the fishery-induced depletion levels appears unlikely, the hypothesis of some degree of reduction cannot be rejected because relevant data are sparse, and the complicated relationships among species and their environment are so poorly understood.

(2) After bycatch due to the purse-seine fishery has been reduced or eliminated, there is a lag period before recovery begins.

> The expectation of recovery is based on the idea that populations will respond immediately once the factor that has caused their depletion is removed. This might not be the case. The reasons why a lag might or even could occur in recovery of these dolphin populations are not well understood. They could be due to lingering effects of past mortality, for example, such as disruptions to the age or social structure, or to inverse density-dependent effects that occur at low population levels (Allee effects). We do not have data to support or reject this hypothesis.

(3) The purse-seine fishery has effects on the dolphin populations beyond the reported bycatch.

The expectation of recovery is based on the idea that the reported kill represents the main effect of the fishery on the dolphin populations. This may not be the case, either because there are other important fishery-based effects or because the reported kill is not accurate. Research conducted under the IDCPA has evaluated some of the possible fishery effects, including separation of mothers from calves and physiological effects of chase and encirclement ("stress") that affect subsequent survival and reproduction. However, there are other fishery effects that were not investigated because it was not feasible. For example, it is likely that there is increased predation on dolphins that have experienced chase and encirclement, due to injuries, weakness or separation from the school, but we do not have any data to estimate the size of this effect and it was not feasible to collect such data. There are several reasons to think that the actual bycatch is larger than the reported kill, but an investigation of these effects could not be conducted given currently available information. Reasons why the actual bycatch is likely to be larger than the reported bycatch include: (a) some mortality is not observed, simply because the fishery observer cannot see all of the net at all times on all sets; (b) dolphin sets made by boats smaller than Class 6 are not observed; and (c) some observed mortality may not be reported by the fishery observer.

Thus, there are numerous plausible effects of the fishery on the dolphin populations beyond the reported kill. Is the sum of all of these fishery effects sufficient to account for the lack of recovery? Unfortunately, the answer to this central question is not clear. For some effects, such as cow-calf separation, we have estimates of the minimum size of the effect. For others, such as stress effects and unreported mortality, we have indications that effects may exist but do not have any quantitative estimates of their size. It is probable that all of these effects are operating to some degree, and it is plausible that in sum they could account for the observed lack of growth of the dolphin populations. If the sum of the fishery effects were a few dolphins per set or a few dolphins per 1000 dolphins chased, it would be sufficient to account for the lack of recovery. However, without comprehensive quantitative estimates for any of these effects, it is not possible to reach more definitive conclusions.

The final determination of whether or not the purse seine fishery is having a significant adverse impact on these dolphin stocks should be made in consideration of the evidence for adverse fishery effects beyond reported mortality and the lack of evidence for substantial ecosystem change.

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APPENDICES

Appendix 1	Scientific reports and papers produced under the IDCPA research program
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APPENDIX 1
SCIENTIFIC REPORTS RECENTLY PRODUCED UNDER THE IDCPA RESEARCH PROGRAM

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APPENDIX 2
LIST OF ACRONYMS

AIDCP - Agreement on the International Dolphin Conservation Program

CHESS – Chase Encirclement Stress Studies

CIE – Center for Independent Experts

CV – Coefficient of variation

EASTROPAC – Eastern Tropical Pacific - Acronym referring to a series of research cruises conducted during the late 1960s

ENSO – El Niño Southern Oscillation

ETP – Eastern Tropical Pacific

IATTC – Inter-American Tropical Tuna Commission

IDCPA – International Dolphin Conservation Program Act

MMC – Marine Mammal Commission

MMPA – Marine Mammal Protection Act

MNPL – Maximum Net Productivity Level

MOPS – Monitoring of Porpoise Stocks

NMFS – National Marine Fisheries Service (now called NOAA Fisheries)

NOAA – National Oceanic and Atmospheric Administration

OSP – Optimum Sustainable Population

PBR – Potential Biological Removal

PODS – Populations of *Delphinus* Stocks

SML – Stock Mortality Limit

SRP – Stress Response Protein

SST – Sea Surface Temperature

STAR – *Stenella* Abundance Research

SWFSC – Southwest Fisheries Science Center

TVOD – Tuna Vessel Observer Data

APPENDIX 3
CONSULTATIONS HELD WITH THE MMC AND IATTC REGARDING THE IDCPA RESEARCH PROGRAM

2-11 July 1997	NOAA Fisheries workshop to discuss potential methods of measuring fishery-induced stress on dolphins in the ETP with IATTC, SWFSC, and various other scientists. (Curry, B. & E. F. Edwards. 1998. Investigation of the potential influence of fishery-induced stress on dolphins in the eastern tropical Pacific Ocean: Research Planning. NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-254. 59p.)
17-18 December 1997	Technical meeting to discuss methods of estimating dolphin abundance with IATTC, MMC, Mexican and Ecuadorian governments, Alaska Fisheries Science Center, and SWFSC scientists. Southwest Fisheries Science Center, La Jolla, California. (Gerrodette, T., P. Olson, D. Kinzey, A. Anganuzzi, P. Fiedler, and R. Holland. 1998. Report of the Survey design meeting for estimating abundance of eastern Tropical Pacific dolphins, 1998-2000, 17-18 December 1997. SWFSC Admin. Rept. LJ-98-03. 25p.)
10 December 1998	Planning meeting for necropsy sampling of ETP dolphins with IATTC, Mexican government, and NOAA Fisheries scientists. Southwest Fisheries Science Center, La Jolla, California. (SWFSC. 1999. Planning meeting for necropsy sampling of ETP dolphins December 10, 1998. Draft Report. 5p.)
16-17 December 1998	IDCPA Science consultation with IATTC and MMC

21 January 1999	Technical meeting with the IATTC, Mexican government, Peruvian government, and NOAA Fisheries scientists to review the line-transect analysis of the 1998 dolphin abundance estimates. Southwest Fisheries Science Center, La Jolla, California. (Olson, P. & T. Gerrodette. 1999. Report of the meeting to review the preliminary estimates of eastern Tropical Pacific dolphin abundance in 1998- January 21, 1999. SWFSC Admin. Rept. LJ-99-03. 28p.)
9 September 1999	Consultation between NOAA Fisheries and NGOs regarding a potential chase/recapture experiment. Radisson Hotel, La Jolla, California. (Sisson, J. & E. Edwards. 2000. Consultation between NOAA Fisheries and non-government environmental organizations regarding a potential chase/recapture experiment: meeting report. SWFSC Admin. Rept. LJ-00-04. 13p.)
25-26 April 2000	IDCPA research program chase-recapture experiment consultation with IATTC, MMC, NOAA Fisheries scientists and other visiting scientists. Southwest Fisheries Science Center, La Jolla, California. (Donahue, M.A., B.L. Taylor, and S.B. Reilly. 2000. IDCPA research program chase-recapture experiment consultation, Southwest Fisheries Science Center, La Jolla, CA, 25-26 April 2000. SWFSC Admin. Rept. LJ-00-15. 14p.)
27-28 April 2000	IDCPA research program analysis decision framework consultation with IATTC, MMC, Daniel Goodman and NOAA Fisheries scientists. Southwest Fisheries Science Center, La Jolla, California. (Donahue, M.A. & S.B. Reilly. 2001. IDCPA Research Program analysis decision framework consultation, Southwest Fisheries Science Center,

La Jolla, CA, 27-28 April 2000. SWFSC Admin. Rept. LJ-00-16. 32p.)

APPENDIX 4
PEER REVIEWS OF THE IDCPA RESEARCH PROGRAM CONDUCTED BY THE CENTER FOR INDEPENDENT EXPERTS (CIE)

This report and all of its supporting documents (see Appendix 1) were peer reviewed by the CIE. This report and the supporting documents were revised to address reviewers' recommendations; each document contains an appendix summarizing the recommendations and how they were addressed.

Dolphin abundance estimates: 15-17 October 2001
Stress and other research on potential fishery effects: 4-6 February 2002
ETP ecosystem research: 6-8 March 2002
Stock assessment modeling: 3-5 April 2002
Review of comprehensive report of the IDCPA research program (this report): 15-16 August 2002

APPENDIX 5
ABUNDANCE ESTIMATES FOR DEPLETED STOCKS

To estimate the abundance of dolphins in the ETP, a statistical method called line-transect sampling is used. This method is the most widely used method for estimating the abundance of biological populations and belongs to a suite of techniques collectively referred to as "distance sampling," which has been used on various organisms, including trees, plants, insects, amphibians, reptiles, birds, fish, marine and land animals. In line-transect sampling, observers perform standardized visual surveys along a series of lines, searching for objects of interest (i.e. groups of dolphins) and recording each animal or group detected and its perpendicular distance from the transect line. From this information, the abundance of the animals in the survey area can be estimated, including the proportion of animals missed by the observers.

The SWFSC has conducted line-transect sampling surveys on research vessels in the ETP for nearly three decades. Marine mammal surveys in the ETP have been conducted by the SWFSC in the following years: 1974, 1976-77, 1979-80, 1982-83, 1986-1990, 1992, and 1998-2000). Surveys in 1974 and 1976 were primarily feasibility studies and data collected on those surveys are inappropriate to use when estimating abundance using line-transect sampling procedures. Since 1977, data collection on surveys has followed line-transect sampling protocols and allowed abundance estimation of dolphin stocks in the ETP (Wade 1994). However, surveys in 1977 and 1992 did not have sufficient survey effort in the areas of the ETP occupied by northeastern spotted and eastern spinner dolphins, so abundance estimates for these survey years are not available.

To fulfill the research requirements under the IDCPA, research cruises to estimate the abundance of dolphin stocks affected by the tuna purse seine fishery were carried out in 1998, 1999, and 2000. Prior to the surveys, a technical meeting to review the survey design for estimating abundance of ETP dolphins was held at the SWFSC; attendees included experts in line-transect sampling and abundance estimation and scientists representing the IATTC, MMC and governments of Mexico and Ecuador (see Gerrodette *et al.* 1998). After the completion of the 1998 survey, another technical meeting was convened to review the methods for analysis of the data collected during the first survey. Many of the same experts participated in this second meeting, as well as scientists from the IATTC and the governments of Mexico and Peru (see Olson and Gerrodette, 1999).

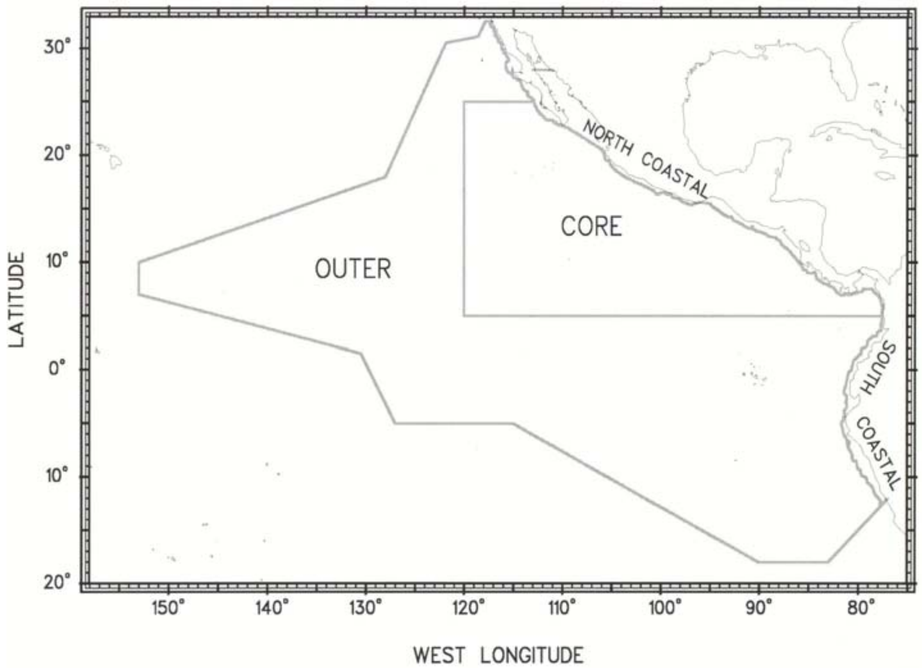

Figure 1 Research vessel survey area in the ETP in 1998-2000.

The field methods used for the 1998-2000 surveys were nearly identical to earlier cruises conducted by the SWFSC in the ETP. Two ships, supplemented by a third vessel in 1998, spent 120 days each year conducting transects in the area of the fishery, producing a total of approximately 100,000 km of search effort in an exceedingly large study area of more than 21,000,000 km^2 . The survey region was divided into four areas (Fig. 1). The north and south coastal areas, extending from the coastline to approximately the 1000-m contour, correspond to the range of coastal spotted dolphins. The core area corresponds to the highest densities of the dolphins most frequently involved in the fishery, in particular, the northeastern offshore spotted and eastern spinner dolphins. The outer area extends further offshore and to the south to ensure that the entire ranges of the depleted stocks were surveyed. The outer area mainly covered the ranges of two other stocks, the western-southern offshore spotted dolphin and the whitebelly spinner dolphin. These two stocks are involved in the fishery but are not depleted, and therefore not the focus this report.

As part of its IDCPA research program scientists at the SWFSC developed improved analytical methods of estimating abundance to account for factors such as dolphin group size, sea state, swell height, sun glare, and other conditions that affect the probability that a dolphin school will be detected (Forcada 2002). These covariate methods are a significant improvement over traditional univariate methods, which model the probability of detection as a function only of distance from the transect line. These methods also deal implicitly with the bias that arises because large schools of dolphins are more likely to be seen than small schools and with the problem that the dolphins occur in mixed-species schools. In addition, the analyses were improved technically in several ways, including improved estimation of dolphin school size by on aerial photography and improved measurements of distances from ship to dolphin sighting.

Abundance estimates resulting from these analyses for the most recent series of research vessel surveys (1998-2000) are shown in Table 1. The coefficient of variation (CV) associated with each estimate is also shown. A "coefficient of variation" is a measurement of the precision of an estimate. For estimates of cetacean abundance coefficients of variation of 20% are considered very good (i.e. a very precise estimate) and those of 30%-50% are considered typical (Barlow 2002).

Table 1 Recent abundance estimates for depleted ETP dolphin stocks from research vessel surveys (from Gerrodette and Forcada 2002).

Stock	1998 abundance estimate	1998 CV (%)	1999 abundance estimate	1999 CV (%)	2000 abundance estimate	2000 CV (%)
Northeastern offshore spotted	675,940	13.5	600,299	16.5	647,218	20.6
Eastern spinner	557,028	22.1	361,209	24.8	427,587	21.8
Coastal spotted	106,399	34.3	96,738	38.6	228,038	34.3

Stock	Mean abundance estimate (1998-2000)	Mean CV (%)
Northeastern offshore spotted	641,153	16.9
Eastern spinner	448,608	22.9
Coastal spotted	143,725	35.7

These new analytical methods were applied to data collected on nine earlier cruises dating back to 1979 as well as to data collected in 1998-2000. Thus, northeastern offshore spotted and eastern spinner dolphin abundance was estimated in each of 12 years over a 21-year period (Figure 2) (Gerrodette and Forcada 2002). Over this 21-year period, estimated abundance of northeastern offshore spotted dolphins ranged from a low of 494,268 in 1986 to a high of 953,547 in 1989, with coefficients of variation ranging from 13.5% to 33.5%. Estimated abundance of eastern spinner dolphins ranged from 271,322 in 1980 to 741,867 in 1989, with coefficients of variation ranging from 21.8% to 40.3%. Estimates of abundance for the coastal spotted dolphin by year were only possible for the most recent surveys (see Table 1) because earlier surveys collected insufficient data in the coastal area to make abundance estimates for those years.

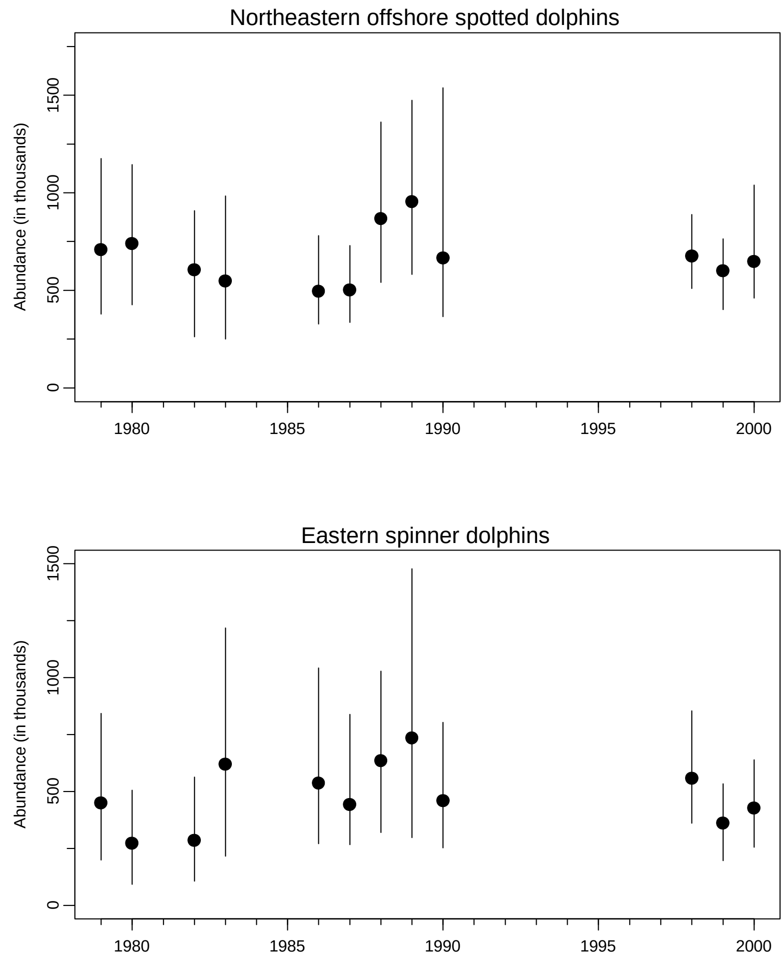

Figure 2 Estimates of abundance for northeastern offshore spotted and eastern spinner dolphins, 1979-2000, with 95% confidence intervals.

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APPENDIX 6
ECOSYSTEM STUDIES AND CONSIDERATIONS

Overview

The role of ecosystem studies within the IDCPA framework is to establish a context which can be used to better interpret results of the dolphin abundance assessments. Should the assessments indicate less-than-expected population growth, ecosystem studies can be used to investigate attribution. Specifically, a lack of recovery for spotted and spinner dolphin stocks that is not congruent with some other change in the ecosystem would render it less likely that environmental change was inhibiting recovery as compared with other possible factors.

The power of ecosystem studies to resolve this issue will increase with the number of habitat variables, taxa and trophic levels studied, and with the length of time for which data are available. Thus these investigations include physical and biological oceanography, and a suite of biological indicators which represent multiple trophic levels, and, within each of these, multiple taxa and ecological guilds.

The most pertinent time scales to examine this issue range across several decades. To the extent possible we have examined long time series for the ETP, and summarized the findings below. These longer time series are comprised almost exclusively of physical data ; almost no biological data are available on decadal and longer scales. We have found it relevant to examine existing biological data (most of which resulted from SWFSC field programs) for patterns of change, even though these data cover less than two decades, from about 1986 through 2000. Clearly any insights arising from these shorter time series will have limited relevance to resolution of long-term environmental effects on dolphin recovery. At the same time, these data could reveal changes since about 1986, and in this context, these investigations are important .

Most of the ecosystem data available for these investigations were collected during two focused research projects: the Monitoring of Porpoise Stocks (MOPS), and the *Stenella* Abundance Research (STAR) expeditions. Both were multi-year dedicated research vessel surveys with two primary goals: 1) to assess the distribution and abundance of dolphins affected by the purse seine fishery; and 2) to conduct related ecosystem studies. Definition of the study area, and details of general survey design, research activities, and trackline coverage for these projects may be obtained in Ballance *et al.* (2002a) and references therein. With respect to ecosystem studies, shipboard operations included a variety of components focused on different taxa and disciplines. Further details can be found at http://swfsc.ucsd.edu/mmd/star/default.htm and in data reports published following each year's survey (e.g. Moser *et al.* 2000, Kinzey *et al.* 2001, Olson *et al.* 2001, Philbrick *et al.* 2001).

The general question to be addressed by the ecosystem studies is the following: *Has any component of the ecosystem changed, and if so, could the change be of sufficient duration and magnitude to affect dolphin stocks?* Ecosystem components vary at seasonal, interannual, interdecadal, or longer time scales. Variations at any time scale may be regular oscillations, irregular perturbations, or phase-shifts (persistent changes in one direction). The comparison between MOPS and STAR periods is particularly important because reported dolphin mortality from the purse seine fishery dropped to very low levels in 1993 (Gosliner 1999) and thus, theoretically, it is at that time when dolphin populations may have begun to recover.

ENSO and Decadal Variability

Environmental variability in the ETP, and persistent environmental change that might affect dolphin stocks, have been assessed in two papers (Fiedler and Philbrick 2002, Fiedler 2002). Here we discuss results of the review of persistent long-term changes. More recent patterns detected in our 1986-2000 data are covered below.

The ocean environment in the ETP varies seasonally, interannually, and on decadal and longer time scales. Sorting out variability at these scales is necessary when attempting to detect environmental change and to interpret or predict effects on dolphin stocks. Seasonal variability exceeds interannual variability in the surface waters of the ETP , except near the equator (Figure 1, Fiedler 2002), where interannual variability is stronger due to the natural cycle of the ocean-atmosphere system called the El Niño/Southern Oscillation (ENSO) occurring with periods of 2 to 7 years.

Changes in fish stocks and ecosystems have been linked to decadal-scale environmental variability in several parts of the North Pacific (Francis *et al.* 1998). Oceanographic variability occurs in the ETP and North Pacific at both ENSO (2-7 years) and decadal (10-30 years) time scales, but with important differences between the two regions. ENSO-scale variability predominates in the

ETP, although some decadal-scale variability is evident. Decadal-scale variability predominates in the North Pacific, while some ENSO events appear in the North Pacific with a delay and reduced amplitude. For example, a time series of sea surface temperature (SST) since 1901 shows ENSO-scale variability in the ETP (Fig. 1). Persistent changes of a decade or longer, called climate shifts, are easily seen as changes in slope (when the series are viewed as cumulative sums). The 1976-1977 climate shift, which has been thoroughly documented in the North Pacific, is also apparent in the ETP, although the magnitude of changes are less than in the North Pacific. At this time, long-term warming began in the ETP and California Current, while cooling began in the central North Pacific. Sea surface temperature warmed by 0.3° C in the eastern equatorial Pacific and by 0.15° C in the ETP core area at this time, compared to warming by 0.6-1° C in the California Current, Gulf of Alaska and Bering Sea and cooling by 0.8-1° C in the central North Pacific (Fiedler 2002, Hare and Mantua 2000). A 1989 climate shift is apparent only in the North Pacific. In general, the SST time series show a prevalence of warm and cool periods of 2-3 years associated with ENSO events in the ETP, and longer warming and cooling trends in the North Pacific corresponding to decadal-scale variability.

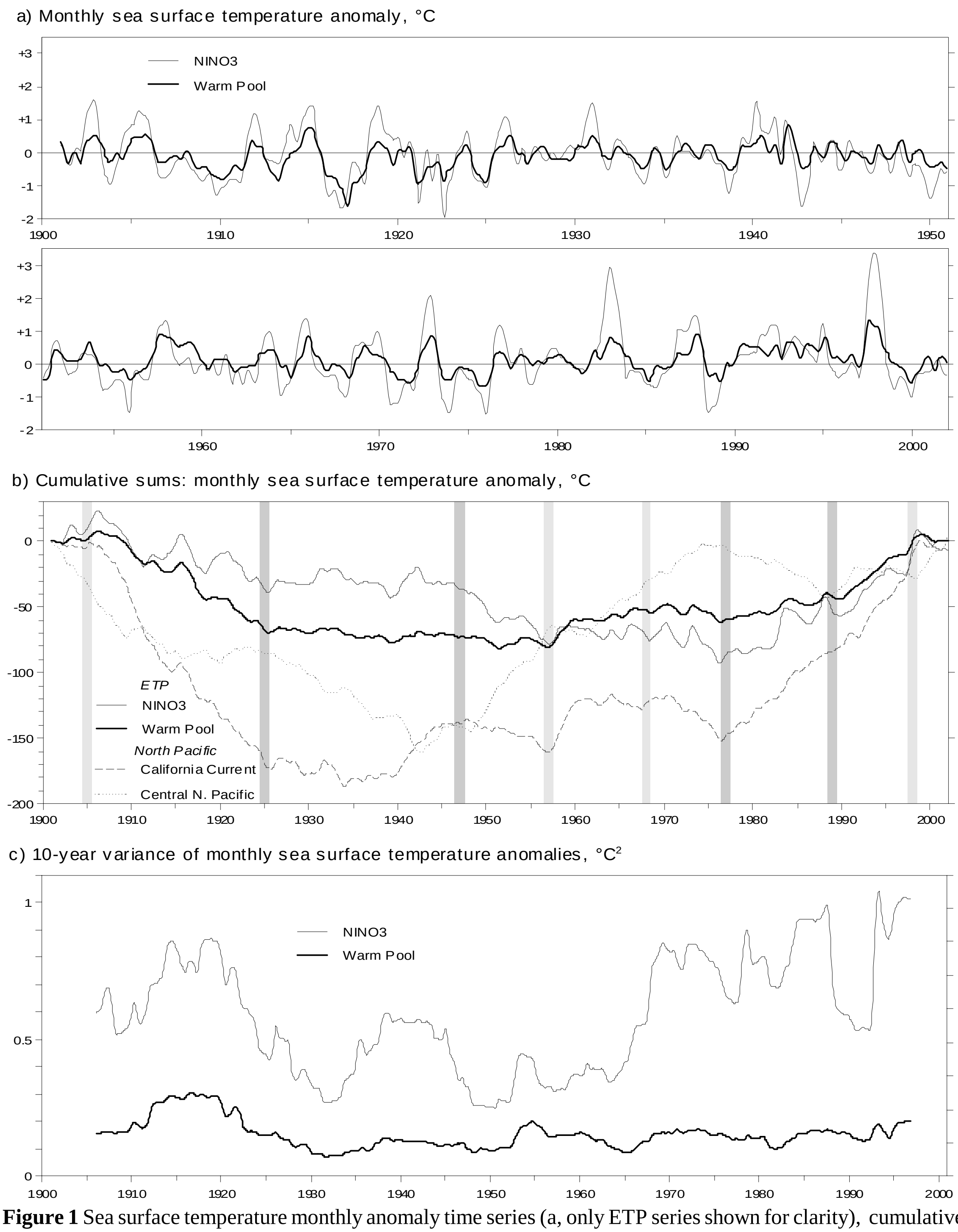

Figure 1 Sea surface temperature monthly anomaly time series (a, only ETP series shown for clarity), cumulative sums (b), and 10-year variance (c), for 1901-2001 in ETP and North Pacific regions. Shaded bars mark climate shifts from published analyses of ocean and air temperature and atmospheric pressure data (light shading = limited evidence). From Fiedler (2002, Fig. 6).

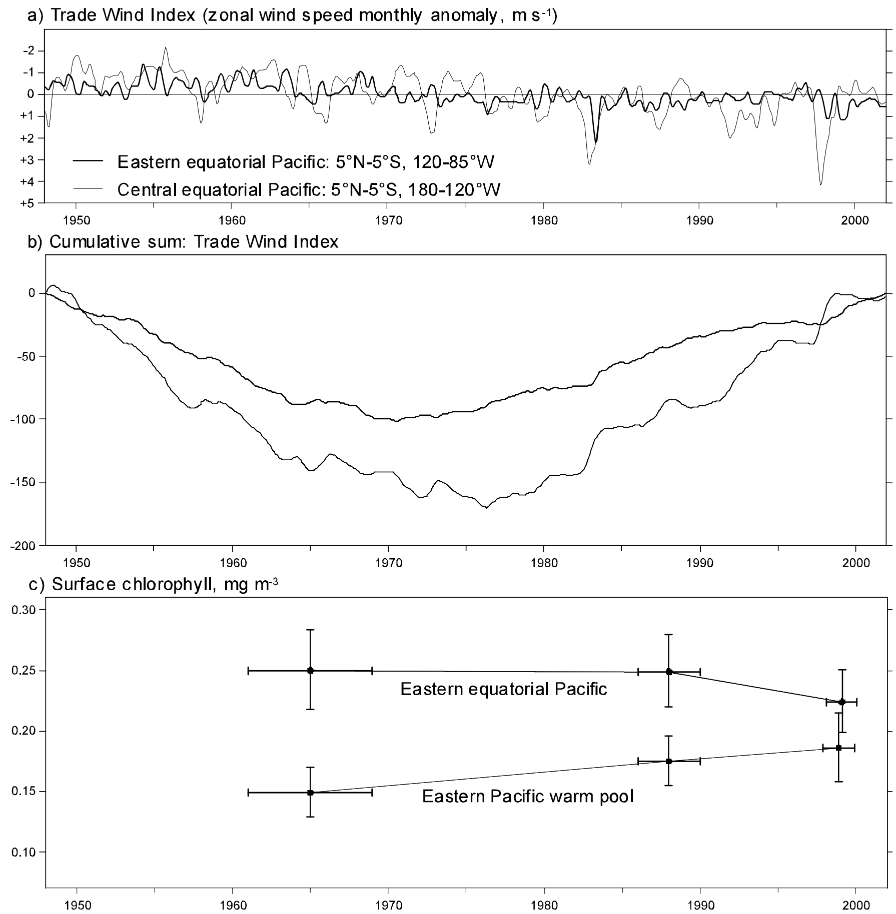

Figure 2

. (A) Equatorial Pacific trade wind indices and (B) cumulative sums, 1948-2001. Monthly areal means calculated from NCEP Reanalysis data from NOAA-CIRES Climate Diagnostics Center web site at http://www.cdc.noaa.gov/. (C) Mean surface chlorophyll concentrations east of 120/W during August-November from gridded values of log-transformed observations for 1960-1969 (NODC World Ocean Database 2001, Conkright et al. 2002) and for 1986-1990 and 1998-2000 (Fiedler and Philbrick 2002). Vertical error bars represent 95% confidence limits estimated from the standard deviation of gridded values, assuming that autocorrelation and smoothing reduces the effective degrees of freedom by a factor of 10.

The late 1970s change in eastern equatorial Pacific SST is the only climate shift since the 1950s that occurs in the 1901-2001 time series of ETP surface temperatures. Along with this persistent warming of a few tenths of a degree C, trade winds weakened (Fig. 2) and trends to a more shallow thermocline[8] are apparent in an analysis of 1980-2001 time series (Fig. 5, Fiedler 2002). Although both surface warming and a shoaling thermocline are consistent with weakened trade winds, and thus reduced wind mixing, the significance of long-term change in thermocline depth is equivocal because the magnitude and direction of linear trends fit to the observations are very sensitive to variations associated with ENSO events (Table 1, Fiedler 2002). This is yet another illustration of how ENSO events dominate environmental variability in the ETP.

ENSO variability has been shown to affect fish, birds, pinnipeds, and cetaceans in both the ETP and North Pacific. Almost all observations of such environmental effects have been on coastal or island populations. El Niño events often cause changes in distribution of species as the distribution of preferred water masses and prey changes. Population effects are observed on local breeding grounds, but recovery usually occurs rapidly when the El Niño event is over. Biological effects of decadal-scale climate variability have been observed and explained in the North Pacific, where time series from commercial fisheries or exceptionally long research programs are available. These effects are generally labeled as “regime shifts” because they involve changes in distribution and/or abundance of several fish stocks, predators and prey. Ecosystem changes in the central North Pacific, Gulf of Alaska, and California Current in the late 1970s have been shown to be caused by changes in productivity and food availability resulting from basin-wide changes in winds (Francis *et al.* 1998, and other references in Fiedler 2002).

A recently published paper (McPhaden and Zhang 2002) presents evidence that equatorial sea surface warming since the 1970s may have been caused by a decrease in upwelling that is part of the meridional (north-south) circulation forced by trade winds blowing from east to west along the equator in the Pacific. Time series of trade wind strength since 1948 show weakening during the 1970s, with a greater weakening in the eastern equatorial Pacific than in the central equatorial Pacific (Fig. 2). Long time series of phytoplankton biomass or productivity in the equatorial Pacific are not currently available. Satellite and shipboard data from the past two decades indicate that phytoplankton biomass has not changed in the central equatorial Pacific, has decreased slightly in

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[8] The thermocline is a layer of sharp temperature change with depth, separating the well-mixed warm surface layer from colder deep waters.

the eastern equatorial Pacific since the 1980s, and has actually increased in the warm pool area of the ETP (Gregg and Conkright 2002, Fiedler 2002).

In summary, review of longer time series of environmental data show that ENSO-scale variability predominates in the ETP. A climate shift in the mid-1970s, resulting in weaker trade winds and warmer sea surface temperatures along the equator, has not reduced primary production in the ETP, except perhaps in the eastern equatorial Pacific since the 1980s. Surface temperature and wind direction and strength have changed little in the area of highest density of depleted dolphin stocks in the ETP (the "core area" of the surveys) since the 1960s (Fig. 9, Fiedler 2002). While there is evidence that the frequency and amplitude of ENSO events increased in the mid-1970s, variability of SST in the ETP core area did not change (Fig. 1). Finally, evidence of a 1998-1999 climate shift in the North Pacific is accumulating, but only continued monitoring will reveal whether a long-term shift occurred in the ETP at this time, rather than a simple transition from El Niño to La Niña.

Ecosystem Change 1986-2000

Oceanography from SWFSC Observations, 1986-2000

Physical and biological oceanographic data have been collected on NOAA dolphin surveys in the eastern tropical Pacific since the late 1970s. We had available yearly means and fields of surface temperature, thermocline depth, and surface chlorophyll for surveys in 1986, 1987, 1988, 1989, 1990, 1998, 1999, and 2000 to examine variability between years and between survey periods (1986-1990 and 1998-2000). Yearly spatial patterns consistently show cooler surface temperature, shallower thermocline and higher productivity in equatorial and coastal regions, compared to the eastern Pacific warm pool region in the central core of the survey area. Effects of El Niño and La Niña are clearly visible in parts of the ETP, but there are no significant differences between 1986-1990 and 1998-2000 for either the core area or the entire survey. Primary productivity and zooplankton distribution and abundance in 1998-2000 were compared to historical data, but no firm conclusions can be made about change over time because of inconsistencies in the data from different programs.

Dolphin Habitats, 1986-2000

We examined patterns of habitat use among schools of dolphins during the three-year period 1998, 1999, 2000, and compared those patterns to previously reported results from approximately a decade earlier (1986-1990). We used multivariate statistical methods to help define relationships between dolphin distributions and oceanographic conditions, then compared results and the geographic distributions of preferred habitats between the two periods. No substantial differences were found. The habitat preferences were essentially identical for the MOPS and STAR periods, and geographic distributions of patterns during 1998-2000 were within the range of variability observed during 1986-1990. After removing variation associated with the six basic oceanographic variables, remaining variance associated with interdecadal differences was trivial.

<u>Other Organisms: whales and dolphins, seabirds, prey fishes and squids, larval fishes</u>

Whales and Dolphins - Between 25 and 30 species of cetaceans are typically recorded in the ETP on a regular basis (Wade and Gerrodette 1993). Five of these were chosen as indicators with the goal being to maximize phylogenetic and ecological diversity. These include two species of dolphins and three species of "whales" (two Odontocetes and one Mysticete). Two of the five are typically found in large schools and are believed to prey primarily on mesopelagic fishes (typical also of spotted and spinner dolphins). The remaining three occur in smaller schools or as solitary individuals; two of these are deep-divers and feed mainly on squid, the third is a relatively shallow diver feeding on schooling fishes.

Data collection and analysis methods were the same as for the target species (ie., the depleted stocks). Striped dolphins (*Stenella coeruleoalba*) were among the most abundant of the species considered with estimates ranging from about 0.8 - 1.5 million. The southern stock of common dolphins was also abundant, with estimates highly variable. Short-finned pilot whales (*Globicephala macrorhynchus*) were the most abundant of the larger cetaceans considered whereas Bryde's whales (*Balaenoptera edeni*) were the least abundant. Abundance estimates over time are represented in Figure 3 in Gerrodette and Forcada (2002). For the three most abundant species/stocks, year-to-year variation in abundance estimates was considerable and the magnitude of this variation was as great within a survey as between MOPS and STAR . Significant changes in abundance between MOPS and STAR were found for two species, Bryde's whales and pilot whales; the trend was an increase over time for both.

Seabirds - Of the approximately 100 seabird species recorded in the ETP, nine were selected as indicators, including the most abundant and widespread species in the ETP, and a diverse array of taxa and residence patterns, trophic levels, and foraging guilds. Four of the nine species depend upon the same tuna-dolphin assemblage as that targeted by the purse seine fishery for successful foraging opportunities. These four species are referred to as “tuna-dependent;” the other five seabird species feed in other ways and thus are “tuna-independent.” Annual distribution patterns indicate that at a large spatial scale (the entire study area), there are distinct species-specific distributions which are consistent over time. At a finer spatial scale (within a particular current system), there is notable variation between years. Both features are evident for tuna-dependent and tuna-independent species.

There were no significant temporal trends in population size for any species but the Tahiti Petrel (*Pseudobulweria rostrata*), for which a significant decline was detected. Abundance estimates for all other species (both tuna-dependent and tuna-independent) fluctuated over time and the degree of variation was greater within a particular survey period (MOPS and STAR) than between them. These differences in population size almost certainly do not represent absolute changes; rather they represent movement of birds into and out of the ETP from elsewhere.

Habitat association patterns were explored using multivariate statistical methods. Species-specific habitat preferences were identified and these appeared to be relatively stable over time, for both tuna-dependent and tuna-independent species.

Prey Fishes and Squids - The distribution and abundance of prey species provide an important link between physical oceanography and higher trophic level predators. Three types of organisms were used as indicators, lanternfishes (family Myctophidae), flyingfishes (family Exocoetidae), and squids of the family Ommastrephidae. All are prey items for dolphins (including the species set on by the purse seine fishery), seabirds, and predatory fishes (tunas and billfishes). The latter two taxa were further classified into three categories each, based on ecological and size characteristics. Data were collected during all years of MOPS and STAR.

Distribution patterns illustrate three general features. First, at a large-scale with respect to both space and time, taxa showed clear affinities for specific current systems . Second, there were clear interannual differences both with respect to overall distribution and location of areas of highest abundance, for each taxon. On a relatively fine scale (100s of km) it was not possible to predict the areas of highest density from year-to-year for any of the groups. Third, some groups exhibited greater interannual variation than others.

Annual mean abundance estimates indicated an apparent multi-year increase in numbers of several taxa from 1986 through 1990; estimates are again low in 1998 and increase through 2000. This pattern is evident for all fish taxa and, to a lesser extent, for squids. Because El Niño events occurred in 1986/1987 and again in1997/1998, we interpret this as evidence that these populations may be negatively affected by such events, gradually increasing subsequent to them.

Habitat association patterns were explored using multivariate statistical methods. A series of analyses were performed using all taxa and various subsets of habitat variables, the latter included oceanographic, geographic, and temporal variables. Taxon-specific habitat preferences were identified and these appeared to be relatively stable over time.

Larval Fishes - Larval fish (and other plankton) were collected using Manta (surface) net tows. A total of 721,257 fish eggs and 31,508 fish larvae distributed among 314 taxonomic categories were represented in this data set. The fish larvae included 178 species, 78 genera, 5 subfamilies, 48 families, and 3 orders. Recurrent group analysis and ranked lists of occurrence and abundance of fish larvae identified two primary recurrent groups and 17 taxa that were most likely to show the effects of environmental change. Examination of variation in occurrence, abundance, and distribution of these key taxa revealed no consistent temporal trends. Highest densities of coastal taxa were generally concentrated in upwelling regions along the Mexican and northern Central American coast, whereas highest densities of oceanic taxa were generally concentrated offshore of this region, usually to the northwest of the highly productive Costa Rica Dome. Abundance of key shorefish taxa was generally higher in STAR survey years as compared with MOPS, however this pattern may have resulted from the increased nearshore sampling effort during the latter surveys. Offshore taxa exhibited no such temporal trends.

Synthesis of Available Data for Investigation of Ecosystem Shifts

In order to look for common patterns of change across the range of physical and biological variables measured within the ETP, we assembled the time series of all data collected by SWFSC field programs (reviewed in the sections above), and added series of tuna recruitment estimates produced by the IATTC, for the period 1975-2000. We searched for, but did not find, any other continuous or even approximately continuous biological time series representing the entire ETP during this time period. (The equatorial region is relatively better sampled, but comprises only a small section of the ETP, and is a very different habitat from that preferred by the spotted and spinner dolphin stocks targeted by the fishery). Each index was normalized and re-presented in terms of standard deviation units to allow appraisal of patterns of change from the long-term mean. Most indices were too sparse to allow interpretation of temporal patterns, and very few began before the physical shift of the late 1970s, so that in general the available information does not allow meaningful analysis of whether or not there have been ecosystem shifts within the ETP. Exceptions to this occur for the tuna recruitment series. Yellowfin tuna appear to have shifted from a low to a high recruitment period following the El Niño of 1983. Skipjack appear to have undergone a similar shift much later, around 1994. We looked for patterns of coherence in extreme values among indices within each year, and found a modest suggestion of larger anomalies coincident with the El Niño events of 1983, 1987-1988, and 1997.

Synopsis and Conclusions Regarding Ecosystem Considerations

A climate shift in the late 1970s affected the physical environment throughout the Pacific and had major effects on North Pacific ecosystems (Ebbesmeyer *et al.* 1991, Francis *et al.* 1998, Anderson and Piatt 1999, Hare and Mantua 2000, Fiedler 2002). An important question relative to the goals of IDCPA is to what extent did this event affect the ecosystem of the ETP in general, and the carrying capacity of spotted and spinner dolphins in particular. At this time, it is not possible to evaluate the biological effects of this regime shift for any higher trophic level due to the fact that biological data collected prior to the mid-1980s are extremely limited and most have not been recovered (although efforts to rescue data from the "Eastern Tropical Pacific Research Cruises" conducted during the late 1960s, "EASTROPAC," have begun). Available oceanographic data indicate that shifts in surface temperature and trade wind strength have occurred periodically throughout the 1900s, specifically in the 1920s and 1950s, but that these shifts were not as great in magnitude as those recorded during the late 1970s. It is important to note that, in the ETP, the magnitude of all of these longer-time scale changes is swamped by that of ENSO-scale perturbations (whereas the reverse is true for the north Pacific).

There is clearly strong year-to-year variation in the physical environment as well as in the distribution and abundance patterns of organisms at all trophic levels investigated. The magnitude of this variation is as strong within a particular decade as between decades. Most of the data sets considered here spanned two strong ENSO events; these events were clearly documented in a number of oceanographic parameters, both physical and biological, in predictable ways. Physical changes due to ENSO in the ETP warm pool (the core area of MOPS and STAR surveys) were about half the magnitude and several months delayed from those along the equator. There was some indication that prey fishes and squid populations also responded to ENSO events, with populations at lowest levels immediately following an El Niño and increasing over time subsequently. At higher trophic levels, the effects of ENSO events were not clear, although variation in distribution and relative abundance of organisms at many trophic levels corresponded to the scale of ENSO events (2-7 years).

When making comparisons from the 1980s through 2000, few trends were evident. Physical oceanography in the ETP warm pool indicated an unusually persistent warming in the early 1990s (but not a significant trend since 1980; Fiedler 2002). Throughout the ETP, there was no evidence of any trend in distribution or habitat association patterns for any biological indicators investigated. Two cetaceans significantly increased in abundance and one seabird significantly decreased during this period; the latter was likely due to factors other than those within the ETP. No other trends in abundance were detected.

It also must be kept in mind that our sampling of recent decades is relatively sparse over time (even though extensive spatially and intensive within given years). This provides little power to detect ecosystem changes that might affect recovery of depleted dolphin stocks.

In conclusion, it is unclear whether there has been an ecosystem shift that would affect recovery of dolphin stocks that had been depleted by the early 1970s. There is evidence of small physical changes in the ETP around 1977 as part of a persistent, Pacific Ocean-wide shift: SST increased and trade winds weakened. Coincident and perhaps associated with these shifts have been changes in surface phytoplankton biomass. Whether these environmental changes have had negative, positive, or no effects on the recovery of depleted dolphin stocks cannot be determined given the present lack of information on the ecology of these dolphin populations and their environment. In order to explain the low population growth rates estimated for the depleted dolphin stocks, the carrying capacity of the ecosystem must have been effectively reduced by about 80% for northeastern offshore spotted dolphins and by about 65% for eastern spinner dolphins (as they are estimated to be depleted by those amounts from their pre-exploitation population levels). Such dramatic decreases in carrying capacity seem unlikely, but given our present limited knowledge cannot be categorically ruled out.

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APPENDIX 7
STRESS AND OTHER POSSIBLE FISHERY EFFECTS

Overview

During the past decade, changes in the eastern tropical Pacific purse seine fishery have reduced the observed dolphin mortality to levels that are unlikely to affect population dynamics significantly. Nonetheless, the number of sets per year remains high (about 8,000-10,000), and there are concerns that current fishing methods may cause stress to the dolphins involved, or that there may be other undocumented fishery-related mortality. The International Dolphin Conservation Program Act (IDCPA) therefore mandated four related research projects to assess the occurrence and magnitude of potential fishery-induced stress in dolphins targeted by this fishery: (1) a literature review of relevant stress-related research; (2) a study of necropsy samples from dolphins obtained by commercial vessels; (3) a review of historical demographic and biological data for the affected dolphin stocks; and (4) an experiment involving the repeated chasing and capturing of dolphins by means of intentional encirclement. Additional investigations into other undocumented fishery-related mortality were conducted as part of the overall stock assessment modeling in Appendix 8. Results from these studies are presented below.

Other fishery-related mortality

A major objective of this research program has been to evaluate the possibility of fishery-related mortality in addition to that reported by the tuna vessel observers. Such undocumented mortality logically could come from the following sources: (1) mortality occurring before capture or after release and therefore unobserved and unreported; (2) mortality occurring in the net but unobserved and therefore not reported; (3) mortality observed and unreported. Mortality resulting from category (3) includes all stress-related deaths, death of dependent calves separated from their mothers, and any other deaths that might result from the fishing process when the animals die outside the net. Failures of reproduction are in fact indistinguishable from additional mortality in terms of numbers of animals removed from the population, and so spontaneous abortions, interrupted mating, and related effects are indirectly subsumed within these same coarse categories. Category (3) is covered in depth below in the discussion of the completed studies.

Although some amount of mortality from categories (1) and (2) is no doubt occurring, it is not possible to measure such mortality directly given information presently available to NOAA Fisheries. For these depleted stocks the effect of most interest would be delay or complete hindrance of the stocks' abilities to recover from depletion. We have approached this evaluation indirectly by structuring a subset of the assessment models (Appendix 8) to include information on the amount of fishery activity, then comparing results with equivalent runs not including the fishery indices to see which performs better. The relative performance of different models is used as a form of hypothesis testing, with statistics computed that report which of two models was more probable, given the patterns of change in abundance estimate time series.

The first test in the assessment models included data on the number of sets made per year (by stock), divided by the estimated number of animals in the population each year to give a crude, average index of each animal's chances of being set upon each year. This index was used as a covariate, or multiplier, of the survival parameter. The second test was simply to multiply the reported mortality by large factors (50% and 100%). These large factors were selected so as to encompass any possible smaller levels of unobserved or unreported mortality, following the logic that if, for example, a doubling of reported mortality did not appear to improve model performance, then increases of say 10% would not do so either.

In summary, the models including these simple mortality terms did not perform as well as the models without the additional mortality (see Appendix 8). On the one hand, this would suggest that undocumented mortality is unlikely to have occurred; on the other hand, as discussed below, there is biological evidence that, in fact, some level of undocumented mortality is occurring (cow/calf separation) or potentially occurring (capture myopathy). This apparent discrepancy could arise either if the additional mortality was of a small magnitude, or if the assessment model including additional mortality was too simplistic. Regardless, further study will be required to resolve these questions related to potential undocumented fishery mortality.

Stress Literature Review

A review of relevant stress-related research was completed by Curry (1999) and updated by St. Aubin (2002). This information provides a context for stress studies conducted by NOAA Fisheries, describing what is known about physiological and behavioral stress in mammals and relating this knowledge to the chase and encirclement of dolphins in the ETP tuna purse seine fishery. Observed stress responses in mammals vary greatly between species and individuals, making it difficult to quantify stress or recognize at what point an adaptive, beneficial stress response becomes maladaptive and causes harm or death. Repeated exposure to stressors can produce a variety of outcomes: the effects may become cumulative and compromise the survival or reproduction of an individual; the response may become blunted as the individual adapts to the stressor; or repeated stimulation can exhaust an individual's ability to respond adaptively to future stressors. Different individuals may respond very differently to the same stressor.

The operations involved in catching tuna associated with dolphins are well-recognized stressors in other mammals, particularly wild animals. Chases that approach or exceed the physical limits of an individual may result in muscle damage, an effect that can be exacerbated by release of hormones associated with fear. The resulting syndrome, commonly referred to as *capture myopathy*, can be manifested within hours or days, and can cause symptoms ranging from minor temporary effects (e.g., muscle stiffness) to massive muscle damage and death of the individual. Intense muscle activity also generates heat, which must be dissipated to prevent damage to sensitive structures such as the brain, reproductive organs, and fetuses. Psychosocial stressors that may be encountered during fishing operations, such as disruption of foraging and social activity, fragmentation of social bonds, aggression, and novelty, can influence metabolism, growth, reproduction, and immune status, and therefore can significantly alter the survival and reproductive success of an individual. Given the broad range of responses exhibited by mammals, it is plausible that the stress resulting from chase and capture in the ETP tuna purse seine fishery could compromise the health of at least some of the dolphins involved. It is not known, however, what proportion of the population may be susceptible to the effects of specific stressors, and whether this level of susceptibility is sufficient to have a population-level impact.

Necropsy Program

To investigate the health status of ETP dolphins associated with the tuna purse seine fishery, a systematic sampling program was established to collect specimens from dolphins accidentally killed during fishing operations. A target sample size of 300 dolphins per stock was previously determined to be the minimum number required to detect potential rare effects and to allow scientifically valid extrapolation to the sampled population of ETP dolphins; however, logistic difficulties allowed only 56 dolphins to be sampled during the 3 year effort. The small sample size limits the ability to draw population-level conclusions, and, therefore, the necropsy results are restricted to descriptions of findings and expert evaluation of potential implications for individual dolphins.

Diseases unrelated to the fishery were found in the majority of the dolphins, as expected in a random sample of an essentially healthy population of wild mammals (Cowan and Curry 2002). Lymph nodes examined to assess the animals' immune status revealed an essentially normal, active, functioning lymphoid system (Romano *et al.* 2002a). Lesions that could be linked directly to the immediate cause of death by drowning (actually, asphyxiation) in fishing gear were noted in heart, lungs, and kidney. These lesions most likely resulted from an overwhelming alarm reaction ('sympathetic storm,' Cowan and Curry 2002), which presumably led to death by cardiac arrest. There was also evidence of previous tissue damage that had healed to form patchy fibrous scars in heart muscle and associated blood vessels. These abnormalities are consistent with those produced by excess secretion of stress hormones (catecholamines); however, it was not possible to determine whether they developed as a result of prior involvement in fishing activities or from some other stressor, nor whether the lesions were extensive enough to compromise heart function. Blood results for live dolphins sampled during the Chase Encirclement Stress Studies (see below) indicate that at least mild forms of muscle damage can occur during fishing operations, but it is not known whether some released dolphins may experience more severe effects. Although skeletal muscle was not examined systematically, opportunistic samples showed cell damage similar to that in heart muscle. The findings are indicative of a degree of capture myopathy that could lead to unobserved mortality in some cases.

Historical Demographic and Biological Data

The intent of the historical and demographic data projects was to assess whether archived samples collected from dolphins incidentally killed in the fishery during the 1970s and 1980s could be used to evaluate aspects of fishery-related stress and mortality in ETP dolphins. Two projects were initially planned for these historical data analyses when the Act passed. One was to compare the life history parameters (e.g. reproduction, maturation rate, sex ratio, etc.) from historical samples (1975-1990) to estimates of the same parameters using samples collected from the current fishery (1991-2001). The other project was to compare the genetic identifications of individuals killed in a set to determine relatedness within a herd, and more specifically, to determine whether a killed, apparently dependent, nursing calf's mother was among the lactating females killed and sampled. In the end, several lines of investigation were pursued that were slightly different than those envisioned at the outset. After evaluating the available biological samples, it became clear that the planned direct comparison of historic and current life history parameters for dolphins killed in the fishery would not be possible, because too few samples were collected after 1990. Results from the trend analyses of historical life history data (i.e., samples collected from 1974 to 1990) indicated that more than 100 samples/year would be needed to do a meaningful analysis (Chivers and DeMaster 1994). However, less than 40 samples were available for 1991-1992, none were collected between 1993 and 1998, and only 56 samples were collected during 1999-2001 as part of the IDCPA Necropsy Program (see above). Thus, the available data were insufficient to examine biological indices for samples collected after 1990, as originally envisioned when the Act was passed. Similarly, the available samples were inadequate to directly evaluate genetic relatedness of cows and calves killed within a single set. Instead, Archer *et al.* (2001) examined the cow-calf bond by determining how likely a cow and her calf would die together in the same set, based on the numbers of lactating females and dependent calves in sets where all dolphins killed were sampled by technicians. Several additional lines of investigation were identified and conducted as part of the historical and demographic data project, because they seemed to be the most promising avenues of research to utilize the archived biological samples and address potential unobserved mortality and stress impacts of the fishery on ETP dolphins. Individual detailed summaries of the completed studies are provided below.

The potential for separation of cows and calves during fishing operations was examined through historical data analysis, a review of behavioral and physical data, and an energetics model of swimming constraints. Archer *et al.* (2001) analyzed the number of lactating females and dependent calves in sets where all killed dolphins were sampled by technicians, and found fewer nursing calves than expected from the number of lactating females, implying that at least some calves become permanently separated from their mothers, and possibly die, as a result of the chase. If the separation occurs only within the net, such that some calves escape during dolphin release procedures but their mothers do not, the data indicate that dolphin mortality in the fishery is underestimated by about 10%. If, however, the separation occurs earlier in the fishing operations, the magnitude of this underestimation will be greater. Of particular concern are potential separation events during chase and prior to capture. Edwards (2002a) reviewed physical and behavioral characteristics of dolphin mothers and calves, and determined that the disparity between calves and mothers with respect to physical size and stamina may contribute significantly to likelihood of separation, especially for smaller calves, faster chase speeds, and longer chase durations. Calves not soon reunited with their mothers are vulnerable to predation or starvation, and may represent an important source of unobserved mortality. Edwards (2002b) examined details of dolphin physical and physiological constraints during chase, using an energetics models for adult dolphins and calves of varying sizes. At the estimated frequencies with which dolphins are encircled (see Archer *et al.* 2002, an update of earlier calculations presented in Perkins and Edwards 1999), the results imply that fishing activities probably do not significantly increase daily energy costs for spotted dolphins in the ETP.

A second study examined dolphin skin for evidence of physiological stress (Southern *et al.* 2002) and related the response to recent fishing effort in the area of sample collection (Dizon *et al*. 2002). Dolphin skin was examined for expression of a suite of 40 stress responsive proteins (SRPs). Samples from nearly 900 dolphins accidentally killed in fishing sets or biopsied while bow-riding research vessels were scored as having either 'normal' or 'altered' SRP expression profiles, and then analyzed in relation to the number of sets within specific spatial and temporal windows (up to 70 days and within 300 nautical miles) around the place and time where the tissues were collected. Although the results appeared to suggest a higher proportion of altered profiles in fishery-killed dolphins and in areas of higher fishing activity, the samples also yielded some contradictory findings that cannot presently be resolved. Application of this novel method, therefore, will require further validation before it can be used to diagnose potential fishery-caused chronic stress in dolphins.

Historical data on the behavior of spotted, spinner, common, and striped dolphin around research vessels was examined relative to the level of fishing effort within the previous 10 – 70 days and 30 – 300 nautical miles (Mesnick *et al.* 2002). Reaction indices were established statistically based on five discrete behaviors indicating a reaction to the research vessel. The findings from over 1,200 sightings during 1998 and 1999 suggest a causal link between fishing effort and the behavior of pelagic dolphins: the primary target species (spotted and spinner dolphins) have a greater tendency to exhibit behaviors associated with ship avoidance and evasion than species not primarily targeted (common and striped dolphins).

Data from aerial photographs collected during research cruises between 1980 and 2000 were used to estimate reproductive and demographic parameters for eastern spinner dolphins (Cramer and Perryman 2002). The proportion of calves in schools photographed in 1998 and 2000 was significantly lower than that for 1988, 1992, and 1993, although no trend could be detected across the entire time series. The proportion of calves in a school was not significantly related to the species composition (pure eastern spinner schools versus schools composed of spotted and spinner dolphins) or the number of spinner dolphins in a school. No trend in the proportion of juvenile animals was detected between 1987 and 2000.

Chase Encirclement Stress Studies

The Chase Encirclement Stress Studies (CHESS) included complementary research projects designed to assess whether the health, reproduction, and survival of dolphins may be negatively impacted in animals experiencing repeated chase and encirclement during tuna fishing operations. During the course of this 2-month project, schools of spotted and mixed spotted/spinner dolphins were located, chased, and encircled by a chartered tuna purse seine vessel, sampled and tagged by experienced biologists and veterinarians, and subsequently released as a group using the "backdown" procedure routinely employed during fishing operations (see Coe and Sousa 1972, for a description of the purse-seining process). Radio-tagged focal dolphins were tracked from a NOAA research vessel, and attempts were made to recapture and sample the same individual and any associated dolphins over the course of several days. The sampling effort targeted spotted dolphins, the primary species involved in tuna purse-seining activities, in an effort to maximize the statistical value of what was expected to be a small sample size. The stress studies included investigations of blood samples, immune function, thermal condition, stress-response proteins in skin, behavior, and reproductive parameters. The studies were based on the expectation that serial samples collected from individuals captured on multiple occasions might reveal whether stress responses to successive capture events were fundamentally the same or if there appeared to be cumulative adverse effects. Two important concerns regarding the study design were recognized at the outset: the lack of baseline data for spotted dolphins, and the necessity to obtain serial data from individuals to assess chronic effects. Key results are summarized below.

The analysis of blood samples is a well-established approach for assessing health and the status of a variety of physiological systems in humans and other animals. Blood components investigated during CHESS included standard veterinary blood panels, with particular focus on exertion-related enzymes and stress hormones (St. Aubin, 2002) and indicators of immune status (Romano *et al.*, 2002b). Blood was obtained from 61 different dolphins, 53 of which were assumed to have been captured for the first time; the remaining samples were from dolphins recaptured 1-3 times. The results of hormone and enzyme analyses provide strong evidence for activation of an acute stress response and for muscle injury resulting from exertion (St. Aubin 2002). The observed changes fell well short of those noted in life-threatening capture myopathy; however, some individuals (<10% of the sample) showed more dramatic elevations in hormones, enzymes, and other metabolic indicators, suggesting that a subset of the population may be more susceptible to developing serious forms of capture myopathy. The analysis of blood samples for studies of immune function did not reveal any notable abnormalities in the captured and recaptured dolphins (Romano et al 2002b).

The concern that dolphins may overheat during chases in the warm waters of the ETP, potentially causing damage to the brain, reproductive tissues, and developing fetuses, was investigated by measuring skin surface and deep body temperatures, and by determining the rate of heat transfer across the skin of the dorsal fin using a thermal tag (Pabst *et al.*, 2002). Skin surface temperatures, analyzed from thermal photographs, were elevated after chases of more than 75 minutes. Heat flux increased during the chase for one of the two tagged and tracked individuals. Core body temperatures for all but one of the 48 sampled dolphins did not become elevated, indicating that dolphins appear to be able to regulate body temperatures during chases. The uncharacteristically high temperature in one female dolphin could not be explained by any other evident disease (i.e. from blood analyses), and may represent either an anomaly or an indication that this individual may have been more prone to overheating following a prolonged chase.

Skin samples from 283 dolphins were analyzed for the presence of stress responsive proteins (SRPs, see above). Overall, the occurrence of 'altered' expression profiles was comparable to that observed in archived samples taken from fishery-impacted dolphins. However, individual dolphins sampled on multiple occasions did not maintain a consistent pattern of expression, and in a number of cases the presumed stress signal was paradoxically less apparent on recapture. Methodological issues, such as variability observed in different sampling sites on the same individual, have not completely been resolved to allow the use of this technique as a validated diagnostic test for stress.

Movement patterns observed during CHESS were consistent with those observed during previous tracking studies of spotted dolphins in the ETP, revealing highly fluid school dynamics within the study area (Chivers and Scott, 2002). Group cohesion of marked animals following release was very low, apparently because individuals or small groups split up at night to forage and regrouped opportunistically with other dolphins the following morning. Systematic behavioral data were collected for a subset of the dolphin groups chased and encircled. Behaviors were categorized as active or passive, and compared to various characteristics of the set operations, including duration of chase, encirclement, capture, backdown, and total duration of the set (Santurtún and Galindo

2002). Passive behaviors were correlated with increasing total set duration, and dolphin activity was higher in sets with longer backdown durations and fewer dolphins captured. Dolphins were observed circling outside the purse seine net in 77% of the sets, suggesting that some (at least temporary) splitting of social groups may occur. Overall, it was evident that dolphins are familiar with purse seine operations and can anticipate backdown for release from the net.

The potential for chase and encirclement to interfere with reproduction was investigated by noting cow/calf pairs during captures and subsequent recaptures, by evaluating pregnancy status, and by analyzing reproductive hormone levels in all sampled dolphins. No evidence was found to suggest the loss of a fetus during the interval between captures or to indicate a change in hormone levels that would affect pregnancy or sperm production; however, there were modest declines in levels of progesterone and testosterone in the two animals sampled after successive captures. The small number of samples precludes any generalization regarding the impact of fishery operations on reproductive physiology. Nine captured females were observed to be with a calf during the initial capture; three of these females were recaptured during subsequent sets, and in all cases the calf was still present. This included one pair chased seven times and captured four times and two pairs chased and captured twice. All of the spotted dolphin calves identified during CHESS were larger calves, not the young calves that are most likely to be separated during chase based on behavioral and energetics considerations (Edwards 2002a, b).

In summary, during the Chase Encirclement Stress Studies, a stress response was expected and confirmed in blood samples collected from dolphins prior to their release from the net. Chases of even short durations (10-20 minutes) produced mild muscle damage, consistent with lesions described in fishery-killed dolphins as part of the separate Necropsy Program. Changes in blood hormones provided a possible explanation for lesions found in heart muscle that suggest some form of capture myopathy in the fishery-killed animals. Thus, the blood analyses on live dolphins identified minor muscle damage, the necropsy program identified lethal muscle damage, and it is presently unknown whether some dolphins may experience intermediate levels of muscle damage, potentially leading to unobserved death within hours or days. Blood and tissue samples from a much larger sample size of live and fishery-killed dolphins would be required to address this. Chases longer than 75 minutes resulted in elevated skin temperature, while core body temperatures did not increase in all but one dolphin. Stress-responsive proteins were demonstrated in the skin of the dolphins, but the interpretation of these patterns is confounded by unresolved sampling issues. Behavioral data suggest that dolphins are familiar with fishing operations, and that some splitting of social groups may occur. Findings of seemingly anomalous values for body temperature, stress hormones, and muscle-specific enzymes in some dolphins indicate that selected individuals may be particularly sensitive to the stresses associated with chase and encirclement. However, these rare events will require considerably larger sample sizes before they can be evaluated in the context of potential population-level effects.

Conclusions Regarding Stress and other Possible Related Fishery Effects

Though collectively reported here as stress studies, the investigations described above span a broad range of concerns, only some of which relate to a stricter physiological definition of stress. It was recognized at the outset that sample sizes for these studies would be limited (Donahue *et al.* 2002), and that population-level inferences would not likely be possible. Nonetheless, the studies provided substantial new information on a variety of factors that could potentially lead to unobserved dolphin mortality associated with tuna purse seine operations. Techniques included a combination of direct observation, mathematical modeling, field experiments, and retrospective analysis. Studies focused largely on the primary species and stock involved, the northeastern offshore stock of pantropical spotted dolphin. As expected, the data are insufficient to quantify potential population-level impacts or to determine whether population recovery may be delayed because sample sizes were small and baseline or control data were not available for the affected dolphin species. However, in the aggregate, the findings from the available data support the possibility that tuna purse-seining activities involving dolphins may have a negative impact on some individuals. In particular, the evidence of cow/calf separation leading to unobserved mortality warrants further study. Furthermore, there is some evidence for potential stress-related injury or unobserved mortality of dolphins involved in purse seine fishing operations, based on the combined documentation of: (a) moderately elevated stress hormones (catecholomines) and enzymes indicative of muscle damage observed in live fishery-involved dolphins; (b) evidence of past (healed) muscle and heart damage in dolphins killed during fishing operations; and (c) fatal heart damage in virtually all fishery-killed dolphins, which most probably was related to elevated catecholomines. The responses observed in the sampled live animals were well within those from which dolphins are expected to recover fully; however, it is possible that some dolphins may experience stronger responses, such as during occasional 'catastrophic' aspects of fishery operations when dolphins may become trapped under a canopy in the net. In theory, this could result in a surge in catecholomines intense enough to cause injury or death within hours or days of being released (a condition known as capture myopathy). To date, no live ETP dolphin exhibiting such a response has been identified or sampled, and future research should be designed to address this plausible, but untested, harmful stress effect. Continuation of necropsy sampling to achieve at least the required sample size of 300 animals per stock, and establishment of sound baseline data on blood constituents and other stress responses for the target dolphin species are likely to provide the most conclusive data in the future.

When considering the possible impacts of the ETP tuna fishery on the depleted dolphin populations, it is important to consider how many times the fishery interacts with each dolphin population each year. The number of interactions is large (Table 1). For northeastern offshore spotted dolphins, there are over 5,000 dolphin sets per year, resulting in 6.8 million dolphins chased per year and 2.1 million dolphins captured (encircled in the purse-seine) per year (numbers are means for 1998-2000) (Archer et al. 2002). For eastern spinner dolphins, there are about 2,500 sets per year, 2.5 million dolphins chased per year, and 300,000 dolphins captured per year. For costal spotted dolphins, there are about 150 sets per year, 280,000 dolphins chased per year, and 40,000 dolphins captured per year.

How strong would these interactions have to be to account for the low observed growth rates of the depleted populations? An indication of the strength required may be obtained by calculating the difference between the expected growth (recovery) rate and the observed growth rate in terms of the frequency of these interactions. Table 1 shows the number of dolphins per set, per 100 dolphins captured and per 100 dolphins chased that are "missing" in order to account for the difference between the observed growth rates (generalized logistic model in Appendix 8) and expected recovery rates of 3% and 4% per year. . For northeastern offshore spotted dolphins, for example, the difference between the observed growth rate (1.7%/year) and the generally expected value (4%/year) is 2.3%. Given a population size of about 640,000, a growth rate of 2.3% represents a net production (births minus natural deaths) of about 14,700 dolphins each year. The number of dolphins reported killed by the fishery is about 300, so the expected annual growth increment would be 14,400 dolphins per year. Table 1 shows that to account for this many dolphins would require 2.8 dolphins per set, 0.7 dolphins per 100 dolphins captured, or 0.2 dolphins per 100 dolphins chased. In other words, fishery effects of these sizes would be required to explain the low population growth rates. These numbers represent the sum of all potential fishery effects on the dolphin population, including separation of mothers from calves, physiological effects of chase and encirclement ("stress") that affect subsequent survival and reproduction, increased predation, effects due to social disruption, unobserved mortality, and observed but unreported mortality.

Table 1 Number of interactions of the ETP tuna fishery with depleted dolphin stocks per year, and differences between observed and expected growth rates in terms of the frequency of these interactions. Observed growth rates are based on the generalized logistic model. For coastal spotted dolphins, data are insufficient to estimate a population growth rate.

Northeastern offshore spotted dolphins	Average of 1998-2000 estimates	
Population size	641,152	
Number of dolphin sets	5,159	
Number of dolphins captured	2,060,666	
Number of dolphins chased	6,778,849	
Number of dolphins killed (bycatch)	317	
	Expected recovery rate	
	3%	4%
Difference between expected and observed rates	1.3%	2.3%
Difference as number of dolphins (production - bycatch)	8,018	14,430
Difference as dolphins per dolphin set	1.55	2.80
Difference as dolphins per 100 dolphins captured	0.39	0.70
Difference as dolphins per 100 dolphins chased	0.12	0.21

Eastern spinner dolphins	Average of 1998-2000 estimates	
Population size	448,608	
Number of dolphin sets	2,513	
Number of dolphins captured	291,933	
Number of dolphins chased	2,492,899	
Number of dolphins killed (bycatch)	353	
	Expected recovery rate	
	3%	4%
Difference between expected and observed rates	1.6%	2.6%
Difference as number of dolphins (production - bycatch)	6,825	11,311
Difference as dolphins per dolphin set	2.72	4.50
Difference as dolphins per 100 dolphins captured	2.34	3.87
Difference as dolphins per 100 dolphins chased	0.27	0.45

Coastal spotted dolphins	Average of 1998-2000 estimates
Population size	143,725
Number of dolphin sets	154
Number of dolphins captured	39,705
Number of dolphins chased	284,339
Number of dolphins killed (bycatch)	14

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APPENDIX 8
QUANTITATIVE ASSESSMENT OF THE DEPLETED DOLPHIN STOCKS

Overview

As part of our research on ETP dolphins, we quantitatively evaluated the overall significance of key research results by conducting stock assessments for the depleted dolphin stocks. Stock assessments are regularly done for many different species to provide a basis for resource management. Methods for conducting quantitative assessments of stocks can vary widely depending on the quality and quantity of data available and may involve relatively simple calculations or may consist of more complex population modeling approaches. In the case of the northeastern offshore spotted dolphin and the eastern spinner dolphin stocks, the available data allowed the construction of a variety of quantitative population models. Data for coastal spotted dolphins are considerably more sparse, and in fact it has not been possible to assess their status. This is discussed further near the end of this appendix.

Population models attempt to approximate the real dynamics of biological populations, and are a powerful tool for evaluating observed patterns, such as changes in the population size over time. Most importantly, population models allow incorporation of uncertainty in our ability to measure ETP dolphin abundance, and they enable us to estimate various parameters, or measurable characteristics of the population, such as growth rates or survival rates. We can also predict both historical and future trends in abundance using population models.

In addition to the simple regression analysis of trends (see results below), three different population models were used to assess the condition of the northeastern offshore spotted dolphin and eastern spinner dolphin stocks. Both stocks experienced heavy, unsustainable mortality during earlier periods of the purse seine fishery, which led to their depletion. Examining results from multiple models can indicate how robust the results are or whether a particular model is producing anomalous estimates. The objective of the three models is essentially the same, that is, to determine if the depleted stocks are growing or declining, and at what rates. The models differ in how many different types of data can be used in them. The more complex the structure of the model, the more different types of information it can accommodate.

The Models

A detailed, technical description of the population models can be found in Wade (2002), and only a general overview is provided below. The models include one of two related measures of population growth: *productivity*, defined as the number of animals, expressed as a proportion of the total, added to the population each year before removal of fishery mortality, or the *growth rate* of the stock, which is the realized rate of population increase after taking fishery mortality into account. The two concepts are related in that the growth rate is equal to productivity minus mortality. It is important to bear this distinction in mind when reviewing the models below. In both cases, a positive value (e.g., 0.02) indicates a net gain of individuals (positive growth), a negative value (e.g. -0.02) indicates a net loss of individuals from the population (negative growth), and zero indicates no change in the number of individuals in the stock. Two types of growth rates were estimated, by different types of models: the observed or achieved rate, and, the maximum potential or intrinsic rate.

Model 1 is a simple exponential growth model, which assumes a population grows proportional to its size. We applied this model to our data to estimate the stock's *productivity*. The simplest form of this model (*1-slope model*) assumed that productivity was constant during the examined period. In addition, the structure of this model also allowed us to include two different productivity levels (*2-slope model*) to examine whether the productivity itself may have changed during the monitored period. This could occur, for example, if there was a change in the environment, or if there were other factors influencing dolphin survival or reproduction whose magnitude changed during the examined period. In response to the CIE reviewers of this research, we also included the TVOD abundance index (see Data section below) in a set of runs using both the 1-slope and 2-slope version of this model.

Model 2 is a generalized logistic model containing a nonlinear term that is density-dependent: it allows population *growth rates* (as determined by births and deaths) to change as the population increases, and food resources become more limited. This relationship between birth and death rates and population size is not necessarily linear; therefore, the model allowed either linear or nonlinear effects, as determined by the data. This is a standard approach for investigating the population dynamics of large mammals, especially cetaceans. In this study, the model provided an estimate of the maximum rate at which the dolphin stocks could have grown during the examined time period, taking into account the fishery mortality, the observed rates of change (from the abundance estimates), and the estimated depletion levels of the stock (current stock size relative to its historical abundance or carrying capacity). This approach allowed us to examine not only potential changes in the actual growth rate of the stock, but also whether the carrying capacity of the environment has changed since the onset of purse seine fishing in the ETP. Furthermore, the possibility that reported fishery mortality is an underestimate of true mortality was examined by performing model runs in which the reported number of dolphins killed per year was increased by 50% and 100%. Finally, the base model was projected forward 200 years to estimate when the stocks would reach Optimum Sustainable Population (OSP) levels, both with and without a continued annual mortality equal to the level reported for the year 2000. This level was selected because it is the lowest on record, and given the recent performance of the fishing fleet it seems reasonable to assume they could maintain this level, on average, in the long term.

Model 3 is a more realistic age-structured model; it is the most complex and incorporates age-specific data related to survivorship (the probability of an individual surviving from a given age to the next), and fecundity (a measure of the potential reproductive capacity of an individual). For example, the model can explicitly include the age of dolphins killed in the fishery ("age-specific fishery mortality") or the number of years it takes a dolphin to reach sexual maturity ("age at sexual maturity"). This age-structured model provided an estimate of the population *growth rate*, and allowed investigation into the possibility of unobserved fishery-related mortality. Such unobserved mortality would be indicated if the observed dynamics of the dolphin stock could be better explained by a model wherein individual dolphin survivorship is correlated with the average number of times it is likely to be set on each year, than by a simple model without fishing effort. In these models, the average number of times set on was estimated as the annual number of sets on a stock divided by the estimated stock size for that year (see Archer *et al.* 2002).

Once the results from all the models' runs were obtained, we compared the extent to which one model performed better than another, by examining how well the models accounted for the observations made (i.e., the data) on depleted ETP dolphin stocks. The statistical measure for model comparison is called a *Bayes factor*; which represents a numerical summary of the evidence in favor of one model as opposed to another. For interpretation purposes, it is standard practice to give verbal descriptions to different ranges of values of the Bayes factor. A Bayes factor between 1 and 3 is considered weak evidence that one model should be favored over another, 3-12 represents moderate evidence, 12-150 is strong evidence, and >150 is considered decisive evidence in favor of a particular model (Kass and Raftery 1994). As is the case with other statistical measures for comparing models (e.g. Akaike's Information Criteria), it is not possible to compare analyses from model runs that used different data sets. For example, the Bayes factor cannot be used to compare results from model runs using the TVOD estimates to those not using them.

The Data

In general, stock assessments can include current and historical abundance, trends in abundance, human-caused mortality, and estimates of biological parameters for the stock (e.g. age at sexual maturity, natural mortality rate, sex ratio, and pregnancy rate) (Breiwick and York 2002, Wade 1994). For the northeastern offshore spotted and the eastern spinner dolphin stocks, the available data for our population models included: (1) estimates of reported mortality in the fishery, 1959-2000 (see Wade 2002 for more details); (2) estimates of "absolute" abundance[9] from 12 NMFS research vessel abundance surveys between 1979-2000; (3) an index of "relative" abundance from Tuna Vessel Observer Data (TVOD) from 1979-2000; and (4) life history data (e.g., indicators of maturity, sex, length, reproductive state) from dolphins killed in the fishery during periods when biological samples were being collected by observers.

The third category of data, the TVOD indices of relative abundance, requires some further elaboration. Since the late 1970s, observers on board tuna purse seine vessels in the ETP have recorded data on marine mammal sightings while the vessel's crew was searching for dolphin schools to determine if tuna were associated with them. These data have been used to estimate indices of relative abundance for northeastern offshore spotted dolphin and eastern spinner dolphin stocks since the late 1970s (Lennert-Cody *et al.* 2001). However, these indices have been considered problematic because of the opportunistic, or non-random way in which these data are collected during fishing operations introduces various biases (Buckland and Anganuzzi 1998, see also Anonymous 1999). The TVOD indices were included in the SWFSC's report of preliminary results from the IDCPA research program (Anonymous 1999), along with the concerns about their use.

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[9] Estimating "absolute" abundance of a species is an attempt to quantify the actual number of individuals in an area. Estimates of "relative" abundance can indicate the direction of changes in the size of a population but cannot quantify its actual size. Relative abundance estimates are often presented as an index of population size over time that is presumed to be correlated with true population size. More intensive field work is required to collect the data necessary to make absolute abundance estimates.

Subsequently, a scientific paper was published documenting serious issues regarding estimation and interpretation of these abundance indices and advising against their use in population models (Lennert-Cody *et al.* 2001). Based on these assessments, the TVOD indices were excluded from the preliminary analyses submitted for peer review by the CIE in April 2002 (see Appendix 4 for more information on the CIE reviews). However, the reviewer panel did not agree that the concerns expressed by Lennert-Cody *et al.* (2001) and Perkins (2000) were sufficiently strong to exclude the data entirely. Rather, they advised that the TVOD indices should be included in a modified form to minimize potential biases, and one reviewer presented a specific approach, based on similar applications used in fisheries assessments (McAllister 2002).

In accordance with the protocol of the peer-review process, we applied the recommended procedure, which attempts to correct biases in the TVOD indices, and we have included these indices in a subset of our population models. In these models, we used the most recently published series in Lennert-Cody *et al.* (2001), which uses a modeling approach that is less sensitive to the non-random manner in which TVOD are collected and appears to minimize some of the important problems identified by the authors. In the final CIE review conducted during August, 2002, there again was disagreement with one reviewer on whether the TVOD indices should be included in all assessment analyses. This reviewer presented new analyses in his report to address one of our concerns, that the bias correction method would not deal well with an abrupt change in bias. These new analyses indicated this likely would not be a problem for biases up to about 20% in magnitude. However, we remain unconvinced that the many known and potential issues related to these indices have been addressed, and therefore decided to proceed with caution and continued to use them only in some assessment analyses. From the subset for which the TVOD were included we have a general idea of the likely contribution to results for other analyses, and have included comments on this where possible and approprite. In general we present the results including TVOD below with reservations, but acknowledge that the bias correction method proposed by the CIE reviewer has addressed many of the major issues with these estimates. Further development of bias correction for TVOD should be a high priority for work to follow this report.

Modeling Results

<u>Simple Trend Analysis</u>

Before discussing the results of the three population models discussed above, we present here the results of a simpler analysis technique (linear regression), which is commonly used to determine trends in the abundance of a stock based on a limited number of data sources (e.g., only abundance estimates). Using only the research vessel abundance data collected over 21 years, neither the northeastern offshore spotted dolphins nor the eastern spinner dolphins exhibited any statistically significant change – either upwards or downwards – in their abundance during this time period (Gerrodette and Forcada 2002). This result must be interpreted in the context of "statistical power," which examines the likelihood that a given trend would be detected using a particular analysis technique. Statistical power and the strength of the analysis conclusions increase as the number of abundance estimates and their precision increases. Between the years of 1979 and 2000, the power analysis estimated the probability of detecting annual growth rates of 1%, 2%, 3%, 4%, and 5% would be 26%, 67%, 95%, 100%, and 100%, respectively. In other words, if the dolphin stocks had been growing at a rate of 3% or more per year between 1979 and 2000, there is a 95% or greater probability that the regression analysis would have detected it. Thus, it is highly unlikely that either the northeastern offshore spotted dolphin or the eastern spinner dolphin stock was growing at a rate of 3% per year or more during this period. The power analysis also indicated about a 67% probability of detecting a 2% per year growth rate, suggesting less strongly that the growth rate did not reach this level. The probability of detecting a 1% per year growth rate was only 26%, indicating that the data were not very informative about whether a 1% per year growth rate was taking place.

If the TVOD indices were included in these analyses, as modified for bias trends, the power of detecting trends would increase moderately to substantially. The trend estimates would not be affected, because the method for bias correction forces the TVOD indices to follow the trend in the RV abundance estimates.

<u>Population models</u>

The results obtained using the three population models are presented below by stock. A more technical presentation of these results can be found in Wade (2002).

Northeastern Offshore Spotted Dolphins

<u>Model 1 (Exponential):</u> This model was run using the twelve NMFS research vessel abundance estimates, allowing either one or two rates of *productivity* during the study period, and both with and

without the TVOD indices of relative abundance. If only one rate is allowed (*1-slope model*), productivity is estimated as **0.017** (95% probability interval:-0.001, 0.036) without TVOD, and **0.013** (95% probability interval -0.005 to 0.030) with TVOD. The precision of this estimate improved slightly when the TVOD were included, but the results are essentially the same. The model runs allowing two rates of productivity (*2-slope models*) suggested that there was a decline in productivity around 1990. Prior to 1990, productivity is estimated as **0.026** (95% probability interval:-0.066, 0.071) without TVOD, or **0.046** (95% probability interval:0.011, 0.077) with TVOD. After 1990, estimates are less precise, but productivity is estimated to be nearly zero (**0.002**, 95% probability interval: -0.090, 0.074) without TVOD, or negative (**-0.042**, 95% probability interval: -0.138, 0.014) with TVOD.

The confidence that a change in productivity actually occurred was evaluated based on the Bayes factor. Without TVOD, the Bayes factor comparing models is low (1.0), and therefore we cannot conclude whether the productivity of this stock actually changed. In contrast, the models including TVOD resulted in a Bayes factor of 5.9 in favor of the 2-slope model, indicating that it is almost six times more probable that the productivity changed than that it was constant. Therefore, if one accepts the use of TVOD estimates as appropriate, these results provide moderate evidence that the growth rate of the northeastern offshore spotted dolphin stock changed from a positive to a negative rate in the late 1980s or early 1990s.

Model 2 (Logistic): This model was run using the twelve NMFS research vessel abundance estimates and the estimates of reported fishery mortality. It allowed estimation of the maximum rate at which the population could have grown over time, whether this growth rate had changed through time, the depletion levels of the stock, whether there was any evidence for a change in the ecosystem's carrying capacity, and how long it would take for the stock to recover to its OSP level. Because this model incorporates fishery mortality estimates as well as abundance estimates, the time period relevant to this model is 1959-2001, the years during which dolphin mortality has occurred in the fishery, and for which mortality estimates are available. The simplest model with one growth rate and one carrying capacity estimated a low maximum growth rate (**0.017**, 95% probability interval: 0.002, 0.036). When the growth rate was allowed to change during the study period, a decline in growth rate around 1990 (as with the 2-slope Model 1) was weakly suggested. The model run allowing for two carrying capacities does not lead to substantially different results from the model with a single carrying capacity. All three generalized logistic models are approximately equally probable (the Bayes factors are all close to 1), and thus there is insufficient evidence from the research vessel abundance estimates alone to help determine whether the maximum population growth rate or the carrying capacity have changed for the northeastern offshore spotted dolphin stock.

Because the generalized logistic growth model allows fishery mortality estimates as one of its inputs, we can explore the response of the stock's growth rates to hypothetical increases fishery mortality. If reported fishery mortality is increased by 50%, the maximum growth rate estimate actually increases by a substantial amount to **0.025** (up from 0.017). If mortality is increased by 100%, the estimated maximum growth rate increases to **0.035**. The Bayes factor for these models indicated that the base run using actual reported fishery mortality, was favored over the models with higher mortality, but only weakly to moderately so (Bayes factor is 2.43 for the 50% increase in fishery mortality scenario and 7.43 for the 100% increase scenario). If mortality is increased only after 1991 (to investigate whether mortality reporting might have changed with the inception of the IDCP[1]), the maximum population growth rate is estimated as **0.018**, nearly the same as the result obtained from the base run. However, the Bayes factor of 1.05 indicated that this model was no more likely than the base model including only the reported fishery mortality. In summary, none of the model runs in which fishery mortality was hypothetically increased as a simple multiple of reported mortality performed better than the base model which included actual reported fishery mortality.

The final run performed with Model 2 projected forward 200 years in time to estimate when the northeastern offshore spotted dolphin stock size would be within its OSP range, both with and without mortality continuing at the level reported in 2000 (295 dolphins; IATTC 2002). Using the base model with a single maximum growth rate and assuming the dolphin by-catch remains constant at year 2000 levels, the projection indicated that the stock would reach OSP in about 78 years (95% probability interval: 28 to >200 years). In contrast, the model allowing two different maximum growth rates projected that the stock would not reach OSP within 200 years (95% probability interval: 19 to >>200 years). For both models reducing the annual mortality to zero had no detectable effect on the time it would take this stock to reach OSP.

Model 3 (Age-structured): This model contains a density-dependent component similar to the logistic Model 2, but also includes data specific to age-related subgroups of dolphins (survival, fecundity, rate of fishery interaction). The estimated maximum growth rate and carrying capacity were essentially identical to those obtained from Model 2. The northeastern offshore spotted dolphin stock was estimated to have a maximum growth rate of **0.017** (95% probability interval: 0.002, 0.035) and be at about 21.4% (95% probability interval: 0.124, 0.378) of its carrying capacity before the onset of the fishery. Again, it is worth noting that a maximum growth rate of only 0.017 is considered very low, though the probability interval for this estimate is rather wide. We also ran the age-structured model including information on the per capita number of sets per year, estimated as the number of sets on a stock each year divided by the stock size. The per capita number of sets on dolphins per year gradually increased over time, with a sharp increase in the mid 1980s and then a small decline after 1990. Taking this pattern into account, the model indicates that dolphin survival from one year to the next year declined between 1958 and 1970, was constant until the mid 1980s, sharply declined to a low in the late 1980s, and then rose slightly during the 1990s. The overall decline in survival since 1958 resulted in a maximum growth rate of **0.027** (95% probability interval: 0.006, 0.053), which is greater than for the simpler age-structured model assuming constant survival. However, the model including the per capita number of sets resulted in finer scale dynamics that provided a poor fit to the abundance data for the early 1980s, and was estimated to be 4.6 times less probable than the model excluding the set data. The Bayes factor of 4.6 is regarded as only moderate evidence in favor of the model without the per capita frequency of sets. Contradictory evidence arose from finding a positive relationship between mortality and set frequency (the 95% probability interval did not include zero). That is, while the models with the mortality covariate did not fit the data as closely as models without the covariate, there still was estimated to be a pattern of lower mortality rates in years with fewer sets per individual. It is unclear whether this contradictory set of results would have been resolved by inclusion of the TVOD abundance indices in these analyses.

<u>Spotted dolphin summary:</u> The rates of maximum population growth identified in the models for the northeastern offshore spotted dolphin stock consistently were very low, and the stock is estimated to be well below Maximum Net Productivity Level (MNPL). The results were largely consistent for models of varying complexity. Models using actual reported fishery mortality performed slightly better than those with higher mortality, and models without an effect of the number of sets per dolphin per year performed moderately better than those with such an effect. The models did not provide clear evidence for or against the occurrence of a change in the ecosystem’s carrying capacity for this stock. Inclusion of the TVOD indices in the exponential model slightly increased precision, and it moderately strengthened the otherwise weak indication of a decrease in stock productivity since around 1990. There was no clear indication in any of the models that the northeastern offshore spotted dolphin stock is recovering.

Eastern spinner dolphin stock

Model 1 (Exponential): This model was run using the twelve NMFS research vessel abundance estimates, allowing both one and two rates of *productivity* during the study period, and both with and without the TVOD indices of relative abundance. The results for eastern spinner dolphins were remarkably similar to those identified for the northeastern offshore spotted dolphin stock. If only one rate is allowed (*1-slope model*), productivity is estimated as **0.010** (95% probability interval: -0.013, 0.035) without TVOD, or **0.010** (95% probability interval -0.011 to 0.032) with TVOD. The precision of this estimate improved trivially when the TVOD were included, and the results are virtually identical. The model runs allowing two rates of productivity (*2-slope models*) suggested that there was a decline in productivity around 1990. Prior to 1990, productivity is estimated as **0.040** (95% probability interval:-0.015, 0.078) without TVOD, or **0.047** (95% probability interval: -0.007, 0.078) with TVOD. After 1990, estimates are less precise, but productivity is estimated to be negative in both cases: **-0.021 (**95% probability interval: -0.077, 0.041) without TVOD, or **-0.033** (95% probability interval: -0.142, 0.020) with TVOD.

The confidence that a change in productivity actually occurred around 1990 was evaluated based on the Bayes factor. Without TVOD, the Bayes factor comparing models is low (2.1), and there is only weak evidence for a change in the productivity of this stock. In contrast, the models including TVOD resulted in a Bayes factor of 5.1 in favor of the 2-slope model, indicating that it is over five times more probable that the productivity changed over this period than remained constant. Therefore, if one accepts the use of TVOD estimates as appropriate, these results provide moderate support for a conclusion that the growth rate of the eastern spinner dolphin stock changed from a positive to a negative rate in the late 1980s or early 1990s.

Model 2 (Logistic): As before, this model was run using the twelve NMFS research vessel abundance estimates and the estimates of reported fishery mortality. It allowed estimation of the maximum rate at which the population could have grown over time, whether this growth rate had changed through time, the depletion levels of the stock, whether there was any evidence for a change in the ecosystem's carrying capacity, and how long it would take for the stock to recover to its OSP range. Again, the time period relevant to this model is 1959-2001, the years for which mortality estimates are available. The simplest model with one growth rate and one carrying capacity estimated a very low maximum growth rate (**0.014**, 95% probability interval: 0.001, 0.052) for the stock at its estimated depletion level and with the continued fishery mortality. However, the model fits the data only moderately well, suggesting that it does not capture all the dynamics of the population. When the growth rate was allowed to change during the study period, a decline in growth rate around 1990 (as with the 2-slope Model 1) was weakly suggested. However, the two estimates of growth rate were less precise than the single estimate of the 1-slope model because there were fewer years available for each estimate. The model run allowing for two carrying capacities does not lead to substantially different results from the model with a single carrying capacity. Although the model with two growth rates has the highest probability relative to the other runs of Model 2, the probabilities for all three generalized logistic models are similar (the Bayes factors are all close to 1), and thus there is insufficient evidence from the abundance data to determine whether the maximum growth rate or the carrying capacity have changed for the eastern spinner dolphin stock.

By varying the fishery mortality estimates in the logistic model, we explored the response of the stock's growth rates to hypothetical increases fishery mortality. If reported fishery mortality is increased by 50%, the maximum growth rate estimate actually increases by a small amount to **0.016** (95% probability interval: 0.001, 0.043) up from 0.014. If mortality is increased by 100%, the estimated maximum growth rate increases to **0.020**. The Bayes factor for these models indicated that the base run using actual reported fishery mortality was weakly favored over the models with higher mortality. If mortality is increased only after 1991 (i.e., if mortality changed with the inception of the IDCP), the maximum population growth rate is estimated as **0.014**, the same as result obtained from the base run. However, the Bayes factor of 1.1 indicated that this model was no more likely than the base model including only the reported fishery mortality. In summary, none of the model runs in which fishery mortality was hypothetically increased as a simple multiple of reported mortality performed better than the base model which included actual reported fishery mortality.

The final run performed with Model 2 projected forward 200 years in time to estimate when the eastern spinner dolphin stock size would be within its OSP range, both with and without mortality continuing at the level reported in 2000 (275 dolphins; IATTC 2002). Using the base model with a single maximum growth rate and assuming that the year 2000 mortality levels remained constant each subsequent year, the projection indicated that the stock would reach OSP in about 65 years (95% probability interval: 10 to >200 years). In contrast, the model allowing two different maximum growth rates projected that the stock would not reach OSP within 200 years (95% probability interval: 10 to >>200 years). For both models, reducing the annual mortality to zero had no detectable effect on the time it would take this stock to reach OSP.

Model 3 (Age-structured): This model contains a density-dependent component similar to the logistic Model 2, but also includes and age-specific data for individual dolphins (survival, fecundity, rate of fishery interaction). The estimated maximum growth rate and carrying capacity were essentially identical to those obtained from Model 2. The eastern spinner dolphin stock was estimated to have a maximum growth rate of **0.014** (95% probability interval: 0.001, 0.051), and be at about 35% (95% probability interval: 18%, 76%) of its carrying capacity before the onset of the fishery. Again, it is worth noting that a maximum growth rate of only 0.014 is considered very low, though the probability interval for this estimate is rather wide. We also ran the age-structured model with information added on the per capita number of sets per year, estimated as the number of sets on a stock each year divided by the stock size. The per capita number of sets on dolphins per year gradually increased over time, with a sharp increase in the mid 1980s and then a small decline after 1990. Taking this pattern into account, the model indicates that dolphin survival from one year to the next year declined between 1958 and 1970, was constant until the mid 1980s, sharply declined to a low in the late 1980s, and then rose slightly during the 1990s. The overall decline in survival since 1958 resulted in a maximum growth rate of **0.033** (95% probability interval: 0.004, 0.069) which is greater than for the simpler age-structured model assuming constant survival. This is, in effect, an estimate of the maximum growth rate in 1958 when there were no sets on dolphins. However, the model including the per capita number of sets resulted in finer scale dynamics that provided a poor fit to the abundance data for the early 1980s, and was estimated to be three times less probable than the model excluding the set data. The Bayes factor of 3.1 is regarded as only moderate evidence in favor of the model without the per capita frequency of sets. Contradictory evidence arose from finding a positive relationship between mortality and set frequency (the 95% probability interval did not include zero). That is, while the models with the mortality covariate did not fit the data as closely as models without the covariate, there still was estimated to be a pattern of lower mortality rates in years with fewer sets per individual. It is unclear whether this contradictory set of results would have been resolved by inclusion of the TVOD abundance indices in these analyses.

Eastern spinner dolphin summary: The rates of maximum population growth identified in the models for the eastern spinner dolphin stock consistently were very low, and the stock is estimated to be well below Maximum Net Productivity Level (MNPL). The results were largely consistent for models of varying complexity, although actual rates of reported fishery mortality were better than higher mortality, and models without an effect of the number of sets per dolphin per year were better than those with such an effect. The models did not help resolve the question of whether there has been a change in the ecosystem's carrying capacity for this stock. Inclusion of the TVOD indices in the exponential model slightly increased precision, and it moderately strengthened the otherwise weak indication of a decrease in stock productivity around 1990. There was no indication in any of the models that the eastern spinner dolphin stock is recovering.

Coastal spotted dolphin stock

The paucity of available data for coastal spotted dolphins, particularly during the early years of the fishery, did not allow a quantitative stock assessment to be performed. However, some new information was obtained as part of the IDCPA research program, which is relevant for future status assessments for this stock. These new developments are described below.

To investigate stock structure in spotted dolphins in both the offshore and coastal forms (*Stenella attenuata attenuata* and *S. a. graffmani*) in the eastern tropical Pacific, DNA was examined from 209 animals from six different coastal areas, and 90 animals from offshore. As expected given that coastal spotted dolphins are considered a distinct subspecies, there were statistically significant genetic differences between the offshore and the coastal animals. These genetic differences mean there is demographically insignificant genetic interchange between the two forms. Unexpectedly, there were also significant differences among the six different coastal regions, although in this case the differentiation was probably due to the females, i.e., due to female isolation and male dispersal among the coastal types. While preliminary, these results point toward the existence of at least six female-based coastal populations; current U.S. marine mammal management practice treats such units as separate. However, the ability to resolve stock structure among coastal spotted dolphins was limited by small sample sizes for some areas, and in general by the patchy nature of the spatial distribution of the 209 existing samples.

Our abundance estimation has been conducted with the existing definition of a single stock for all coastal spotted dolphins. Those abundance estimates are relatively imprecise, and ranged from as low as 96,738 (95% limits 32,849, 177,302) to as high as 228,038 (73,332, 392,756). As noted above, this single-stock definition appears unlikely to be accurate given the recently-completed genetic analyses. The existing sightings data are insufficient to post-stratify into the six putative separate areas (assuming they are correct, and more data are required to resolve the pattern), so currently it is not possible to report abundance by sub-area. Recent reported mortality in the purse seine fishery is quite low: 18, 17, 6, and 2 for 1998 through 2001. However, it is not clear whether past, more extensive exploitation has depleted one or more stocks, and therefore whether it is appropriate to protect one or more of these stocks from exploitation.

Clearly, additional, focused work on the coastal stocks is required. As discussed later under Recommended Research, this should consist of dedicated biopsy sample collection along the entire nearshore coastal area of the ETP, coupled with a concentrated sightings survey of the same area that applies sufficient sighting effort to produce reliable abundance estimates for these stocks. Given the absence of historical data on the abundance of these stocks in addition to the currently unresolved stock structure, it is not possible to assess the status of the coastal stock(s) of spotted dolphins.

Stock Assessment Synopsis and Interpretation

Trend analysis

The abundance estimates for northeastern offshore spotted and eastern spinner dolphin stocks did not show any statistically significant change, either upwards or downwards, during 1979 - 2001, the period covered by NMFS research vessel abundance surveys. The overall patterns for both stocks were generally similar to the relative index of abundance calculated from TVOD (Lennert-Cody et al 2001). There was no indication, for either stock, of movement toward recovery from their depleted levels. However, the calculations of statistical power for this analysis showed that if the stocks were in fact growing but at low levels below about 2%, our ability to detect that recovery with this type of analysis would not be high. Thus, the results of this simple trend analysis alone were not sufficiently informative about whether or not recovery was occurring. This suggested that other more sophisticated analyses, such as those with the exponential, generalized logistic, and age-structured models were needed. The results from such population modeling are discussed below.

Stock Assessment Modeling

Overall, the most striking result from the population modeling, for both eastern spinner and northeastern offshore spotted dolphin stocks, is that the population growth rates are very low. The results consistently show that both stocks are either staying essentially stable at their current depleted levels, or, have possibly even decreased over the past decade. That is, no recovery from depletion is apparent for either stock. This conclusion is not dependent upon a specific model's structure, or upon inclusion of any fishery-dependent data (reported mortality estimates or TVOD-based abundance indices).

The model runs that estimated current depletion levels indicate both stocks are still depleted with respect to the standards set by the MMPA. The eastern spinner dolphin stock is estimated to be at approximately 35% of its abundance level prior to the onset of the fishery. The northeastern offshore spotted dolphin stock is estimated to be at just over 20% of its pre-exploitation level. However, these estimates have relatively low precision. For example, the 95% probability interval for eastern spinners span the range from as low as 18% of its pre-exploitation level to as high as 75%. This range for the northeastern offshore spotted dolphin stock has a low of 11% of its pre-exploitation size to a high of 35%.

In the analyses of whether there had been a change in growth rates during the period 1979-2001, we found weak evidence in support of such a change. However, including the TVOD abundance indices increased the probability, from weak to moderate evidence, that there was a change in growth rates for the stocks during this time, and that the change was from an increase through about the early 1990s, followed by a decrease through 2000, the last year of the series (Table 1).

As discussed above, we included the TVOD abundance indices in only the exponential set of models, and not in the generalized logistic and age structured models. Given the bias correction method applied to the TVOD series, including them probably would not change substantially any point or median estimates of population trends, but because of the added number of abundance estimates and their precision, there would be gains realized in the precision of trends and other parameters estimated. Additionally, there would be some level of improvement in our ability to distinguish between different models. As applied here, different models fit to the same data can be viewed as alternate hypotheses, such as whether there has or has not been a change in carrying capacity, or, a change in maximum intrinsic growth rate. Similarly, for models with and without additional fishery-related mortality, there likely would be some improvement in ability to select which model provided a better fit to the data. However, as noted above, we still have reservations about possible problems inherent in the TVOD abundance series, and chose the more cautious route of not including them in all analyses, to avoid the possibility of making apparent gains in precision but being wrong throughout.

The analyses conducted based on the research vessel abundances provided no clear discrimination regarding possibilities that either carrying capacity or the maximum growth rate for these stocks have changed during the period since the onset of the fishery. The model runs that estimated a maximum intrinsic growth rate all indicated that this rate is very low for both stocks. Because intrinsic growth rates of less than 0.02 are questionable for small cetaceans, it is somewhat likely that these estimates are biased downward but for unidentified reasons. When including a fishery effect factor related to survival, represented in the model as the number of sets made per individual in each year, the maximum growth rate estimates increase to around 0.03. This is still lower than the rate generally expected for small cetaceans (0.04) but not by a considerable amount given the imprecision of the growth rate estimates, and the modest amount of information that formed the basis for the 0.04 expectation. However, the inclusion of this survival factor decreased the fit of these models to the data, which were then considered moderately less probable according to their Bayes factors. Similarly, models with reported mortality scaled up by 50% and 100% were less probable, but only weakly so, than models with just reported mortality levels. Contradictory evidence arose from finding a positive relationship between mortality and set frequency (the 95% probability intervals for both stocks did not include zero). That is, while the models with the mortality covariate did not fit the data as closely as models without the covariate, there still was estimated to be a pattern of lower mortality rates in years with fewer sets per individual. It is unclear whether this contradictory set of results would have been resolved by inclusion of the TVOD abundance indices in these analyses.

In our projections of stock size, the results indicated that neither stock would reach OSP range for many decades. The most optimistic models estimated recovery times of 65 years for eastern spinner dolphins and 78 years for northeastern offshore spotted dolphins. Less optimistic models indicated no recovery in 200 yrs for either stock, and with eastern spinner dolphins actually declining. These results remained unchanged whether the future fishery mortality was set to zero or was set at the levels reported in the year 2000. Such slow projected growth rates are reflective of the low observed rates during the period observed since the late 1970s. The data do not provide a clear choice between the more and less optimistic recovery times, but the data do indicate that a recovery at the expected rate of 4% per yr is unlikely (Table 2).

Table 1. Summary of Bayes factors for 2-slope vs. 1-slope models. The numbers in the table give the odds that the 2-slope model is true relative to the 1-slope model for the exponential model, the exponential model including the TVOD index, and the generalized logistic model.

Model	**NE offshore spotted**	**Eastern spinner**
Exponential	0.98	2.12
Exponential with TVOD index	5.92	5.11
Generalized logistic	0.75	1.38
Geometric mean	1.63	2.46

Table 2. Summary of modeling results for time to recovery to OSP range. Scenarios in this table assume that carrying capacity has not changed for either stock, that no lags occur before recovery begins, and that bycatch remains at 2001 levels. Approximate probability for "normal" recovery at a 4% growth rate is based on the probability that $R_{max} \geq 0.04$ for each species (Figs. 5 and 15 in Wade 2002), and the time to "normal" recovery is based on a deterministic projection at an annual growth rate of 4%. Times to recovery for the other scenarios are based on growth rates estimated from the data (generalized logistic model, Tables 12, 14, 29 and 31 in Wade 2002), with approximate probabilities between the 1-slope and 2-slope models based on the Bayes factors for the generalized logistic model.

Stock	Scenario	Growth rate	Time to recovery	Approximate probability of scenario
NE offshore spotted	Change in growth rate around 1993 (2-slope model)	0.001	>> 200 yr	0.42
	No change in growth rate (1-slope model)	0.017	78 yr	0.57
	"Normal" recovery	0.040	29 yr	0.01
Eastern spinner	Change in growth rate around 1991 (2-slope model)	-0.016	Does not recover	0.56
	No change in growth rate (1-slope model)	0.014	64 yr	0.41
	"Normal" recovery	0.040	18 yr	0.03

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