Evaluating trends and biases in shipboard tuna vessel data used in the estimation of Dolphin abundance
by Eric John Ward

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University

Abstract:
Since the 1950s, several million dolphins have been reported killed by tuna vessels in the eastern tropical Pacific Ocean. In response to the Marine Mammal Protection Act, data has been collected on all stock of dolphins in the eastern tropical Pacific, including the stock most affected by the yellowfin fishery, the northeastern stock of offshore spotted dolphins (Stenella attenuatd). Data collected aboard tuna vessels does not conform to the assumptions necessary to analyze standard line transect data, but because of the volume of data available, tuna vessel data may be statistically corrected to examine relative trends in dolphin abundance. A third bias is that dolphin schools reported by tuna vessels are significantly larger than those reported by research vessels.

In this analysis, I attempted to quantify the impact each of the mentioned biases has on estimates of relative dolphin school size estimates from tuna vessel data. Search effort appeared to become more concentrated in areas of the eastern tropical Pacific with larger school sizes. Search technology also focused more effort on schools that were larger than average. Assuming both of these biases exhibited linear trends, I rescaled school sizes and abundance trajectories relative to the 1980 estimates. After removing the temporal and spatial variability that may affect estimates of dolphin schools reported by tuna vessels, I was able to conclude that schools reported by tuna vessels tend to be larger than those reported by research vessels (and this difference appears to have decreased over time). My final correction of tuna vessel data relied on research vessel data, which was only collected for half of the time series. While it does appear to reduce a small amount of bias in estimates calculated from tuna vessel data, I was not able to correct for all of the bias, due to the limitations of the research vessel data.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content., English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Since the 1950s, several million dolphins have been reported killed by tuna vessels in the eastern tropical Pacific Ocean. In response to the Marine Mammal Protection Act, data has been collected on all stock of dolphins in the eastern tropical Pacific, including the stock most affected by the yellowfin fishery, the northeastern stock of offshore spotted dolphins (*Stenella attenuata*). Data collected aboard tuna vessels does not conform to the assumptions necessary to analyze standard line transect data, but because of the volume of data available, tuna vessel data may be statistically corrected to examine relative trends in dolphin abundance. A third bias is that dolphin schools reported by tuna vessels are significantly larger than those reported by research vessels.

In this analysis, I attempted to quantify the impact each of the mentioned biases has on estimates of relative dolphin school size estimates from tuna vessel data. Search effort appeared to become more concentrated in areas of the eastern tropical Pacific with larger school sizes. Search technology also focused more effort on schools that were larger than average. Assuming both of these biases exhibited linear trends, I rescaled school sizes and abundance trajectories relative to the 1980 estimates. After removing the temporal and spatial variability that may affect estimates of dolphin schools reported by tuna vessels, I was able to conclude that schools reported by tuna vessels tend to be larger than those reported by research vessels (and this difference appears to have decreased over time). My final correction of tuna vessel data relied on research vessel data, which was only collected for half of the time series. While it does appear to reduce a small amount of bias in estimates calculated from tuna vessel data, I was not able to correct for all of the bias, due to the limitations of the research vessel data.

INTRODUCTION

The tuna-dolphin issue in the eastern tropical Pacific Ocean (ETP) represents one of the best examples of the trade-off between conservation biology and commerce. Since the 1950s, the yellowfin tuna (*Thunnus albacares*) fishery in the ETP has been using purse-seine technology, and has become one of the most financially successful fisheries in the world. Schools of *T. albacares* are not usually visible from the surface, but since dolphins that associate with tuna are visible, fishermen can exploit the tuna-dolphin relationship to capture tuna. Ideally, dolphins are allowed to escape over the top of the purse-seine net after being encircled, but injuries and death do occur. The two species of dolphin with the closest ecological relationship to tuna, the spotted dolphin (*Stenella attenuata*) and the spinner dolphin (*S. longirostris*), have suffered large reported incidental mortality by the fishery. The northeastern stock of *S. attenuata* and the eastern stock of *S. longirostris* have been listed as depleted under the Marine Mammal Protection Act (MMPA) since 1993. Historically, the dolphin mortality incurred by the fishery has represented significant fractions of the northeastern stock of *S. attenuata* (Smith, 1983) and the stock is not showing clear signs of recovery (Wade et al., 2002). This analysis will focus on the northeastern stock of *S. attenuata*, which historically has been the stock with the highest reported mortality and has been involved in the largest proportion of sets on dolphins in the ETP (Archer et al., 2002; Gosliner, 1999).

Beginning in the late 1970s, the Inter-American Tropical Tuna Commission (IATTC) and National Marine Fisheries Service (NMFS) have collected independent data on the northeastern stock of *S. attenuata*. Research surveys have been conducted by NMFS (Gerrodette et al., 1991; Gerrodette et al., 2002; Holt et al., 1987; Holt et al., 1989; Wade et al., 1992) in twelve years between 1979-2000. The research vessel surveys utilize standard line transect methods (Buckland et al., 1992; Buckland et al., 1993, Buckland et al., 2001). The IATTC has maintained a second data set, which is opportunistic data collected from tuna vessel observers, and is known to violate standard line transect methods and assumptions (Buckland et al. 1988). The tuna vessel observer data set has been collected in all years since 1974 and has been used to compute an index of relative abundance (Anganuzzi et al., 1991; Anganuzzi et al., 1993; Anganuzzi et al., 1994). Because of possible changes in data quality and variables relating to tuna vessel fishing technology (Lennert-Cody et al., 2001) the appropriate use of tuna vessel data as a complement to research vessel data has become uncertain.

History

During the 1960s and early 1970s, annual incidental dolphin mortality in the ETP was estimated to be several hundred thousand animals (Gosliner, 1999; Wade, 1995). In 1972, Congress passed the MMPA, prohibiting the future kills of marine mammals in U.S. waters, kills of marine mammals by U.S. citizens, and imported marine mammal products. The first important piece of the original MMPA legislation was the definition of the term "take," as the act or attempted act of harassing, hunting, capturing or killing marine mammals. Congress recognized the necessity of not destroying the ETP tuna fishery, and granted the fishery an exception to the MMPA. The taking of *S. attenuata* was still allowed, with the ultimate goal of eventually approaching zero mortality. A second important piece of legislation in the MMPA was that the term "depleted" could be applied to any stock estimated to be at a level less than its calculated optimum sustainable population size (OSP, 60% of carrying capacity).

In an effort to monitor the annual number of dolphins killed by the fishery, NMFS started placing trained observers on some U.S. tuna vessels, starting in 1974. The IATTC began placing observers on non-U.S. vessels, starting in 1979. Some observers were placed on tuna vessels prior to 1974, but participation in those programs was voluntary (Gosliner, 1999). The initial responsibility of tuna vessel observers was to monitor the number of dolphins killed or injured during sets, but observers also collected information on dolphin school size, species composition of schools, and additional variables not relating to fishing behavior (e.g. Beaufort conditions, water temperature). By 1986, 100% of the countries fishing in the ETP were participating in the observer program (Gosliner, 1999); however, full observer coverage on all tuna vessels was not in place until 1995.

Over the course of the 1980s, several amendments were passed to the original MMPA. As fishing regulations in the ETP became stricter about setting on dolphins, many vessels that were registered in the U.S. became registered in foreign countries. Between 1980 and 2000, the number of U.S. vessels in the fleet dropped from approximately 100 vessels to less than 10, and U.S. vessels became outnumbered by non-U.S. vessels approximately 20:1 in 1995 (Gosliner, 1999). As a result of the change in fleet demographics, U.S. dolphin mortality dropped significantly, and incidental mortality by international vessels increased. In an effort to pressure non-U.S. vessels to achieve mortality levels similar to U.S. vessels, the U.S. adopted an embargo against countries that did not practice dolphin-safe sets. This embargo was ultimately overturned with the International Dolphin Conservation Act (1992). The La Jolla Agreement was also signed in 1992 and was important for several reasons. First, an international quota on dolphin kills was passed for the first time, and was recognized by all countries fishing in the ETP. Second, the overall dolphin quota was shifted from a quota for the entire fleet to a by-vessel quota, or "dolphin mortality limit" (Gosliner, 1999). The goal of the new quota system was to reward captains and crews that achieved low mortality levels, rather than punish them when the fleet-wide quota was reached.

Line Transects

Ecological surveys for estimating wildlife abundance typically fall into one of two categories. The first method, capture-recapture, involves conducting multiple surveys on the same population, and estimating abundance by repeatedly capturing or marking individuals during each survey (Seber, 1982). The second method involves estimating abundance by conducting point transect or line transect surveys (Buckland et al., 1993). Line transect surveys have been conducted on dolphin stocks in the ETP for several reasons. First, the size of the northeastern stock area of *S. attenuata* is approximately 60% the size of the U.S. ($5.69 \cdot 10^6$ km^2 versus $9.63 \cdot 10^6$ km^2), requiring large-scale shipboard or aerial surveys. Second, because there are hundreds of thousands of dolphins in the region, the probability of an individual being sighted and re-sighted in a capture-recapture study is extremely small. Capture-recapture studies for marine mammals often rely on large photographic databases for identification, and the number of *S. attenuata* individuals photographed in the ETP has been relatively small.

Several parameters need to be estimated for each object detected during line transect surveys. It is possible to estimate the perpendicular distance of an object from the survey trackline, but generally more accurate to estimate the radial distance from the point of detection to the object, and the sighting angle between the trackline and the detected object. After a transect or set of transects is complete, perpendicular distances are calculated from sighting angles and radial distances. The histogram of perpendicular distances is normalized and fit with a detection function (Buckland, 1985; Buckland, 1992a; Buckland, 1992b). For individual animals occurring in groups, such as dolphins, group size also needs to be estimated. Using the probability density function (p.d.f.) of detection distances evaluated at zero (f (0)) and the average group size, the standard line transect estimator can be applied (Burnham et al., 1980): $N_d = \frac{A \cdot n_s \cdot f(0) \cdot \bar{s}}{2L}$, where N_d represents the estimated number of animals, A is the size of the survey area, n_s is the number of groups detected over the entire survey, $f(0)$ is the p.d.f. of perpendicular distances evaluated at zero, $\bar{s}$ is the average group size, and L is the total length of trackline searched. The quantity f (0) can also be written as $\frac{1}{w}$, where w is the effective strip half-width of the transect.

To obtain unbiased estimates of abundance from line transect surveys, several assumptions are required. Some of these assumptions are more robust than others, however all are applicable to both research vessel surveys and opportunistic tuna vessel surveys. These assumptions are listed in order of decreasing importance (Buckland et al., 1988):

1) Within each region or stratum, either vessel search effort is randomly distributed or dolphin schools are randomly distributed;
2) Any movement of dolphin schools before detection is slow relative to the speed of the vessel;
3) All schools on the trackline are detected and identified with probability 1.0;
4) Sighting angles and distances are made without measurement error;
5) Sightings of schools are independent events;
6) School size is recorded without measurement error (and for mixed species schools the proportion of a given species is recorded without error);
7) The probability of detection for a given school is independent of its size, at least out to the boundary of the effective strip width.

Some of the above assumptions are violated in both research vessel data and the tuna vessel data. For example, it is impossible to assume that sighting angles and distances are recorded perfectly, as both are prone to human measurement error and rounding (Hammond et al., 1983). However, it is possible to assume that the errors on bearing and distance measurements are normally distributed, and do not exhibit directional trends that would contaminate the data (Kinzey et al., 2002). Because tuna vessel data are known to violate most of the above assumptions, *S. attenuata* abundance estimates derived from tuna vessel data cannot be used as indices of true abundance. The IATTC has relied on tuna vessel data for inference of relative abundance estimates. The time series of relative abundance is dependent on the assumption that any biases in tuna vessel data have remained constant in time and have not exhibited a trend (Buckland et al., 1988). As *S. attenuata* abundance estimates have fluctuated since 1980, biases in the tuna vessel data must have remained proportionally constant over the time series. If biases have exhibited a temporal trend, inference of relative abundance will be impossible unless that trend in bias can be estimated and corrected. There also may be non-lethal biases present in the data that do not exhibit a temporal trend, but are problematic and should be corrected before final abundance estimates are calculated.

Current Status

Since 1992, incidental kills of the northeastern stock of *S. attenuata* have dropped significantly. Based on the advancements in fisheries technology, current estimates of reported incidental mortality for this stock are less than 1000 dolphins annually, having dropped from more than an estimated 300,000 dolphins annually (Gosliner, 1999; Wade, 1994). This represents a relatively insignificant fraction of the total stock size, however the population does not appear to be recovering to its pre-exploitation population size (Wade et al., 2002). The abundance trajectory calculated from the research vessel surveys (Figure 1; Gerrodette et al., 2002) does not show a clear trend since 1980, nor do the individual components of the line transect estimator calculated from research vessel data (Figures 2-4; Gerrodette et al., 2002). Average school size estimates do appear to be sensitive to strong El-Niño events (1983, 1998). In years with smaller average school size, there does appear to be a higher encounter rate of schools per nautical mile.

Figure 1. Abundance of the northeastern stock of *S. attenuata*, calculated from research vessel surveys (Gerrodette et al., 2002). Error bars indicate 1 standard error.

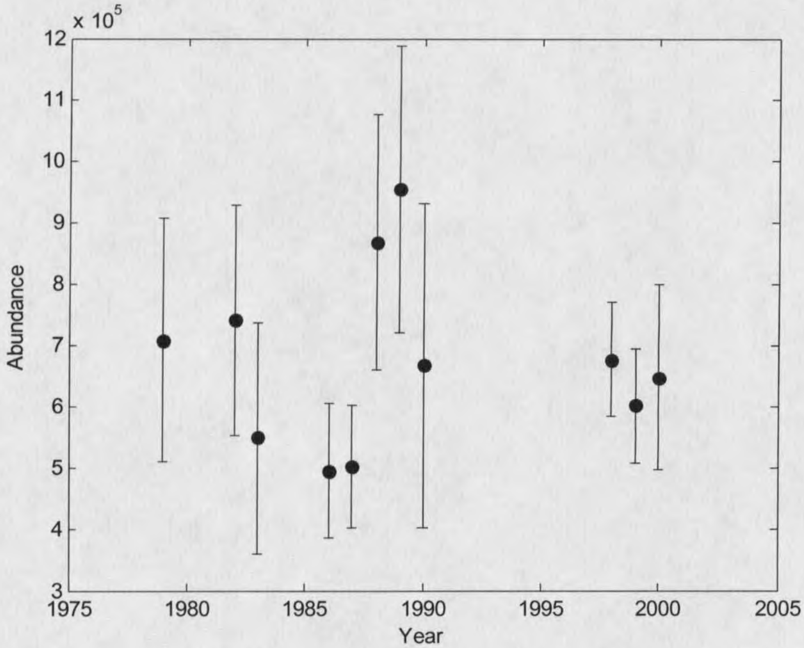


Figure 2. Estimates of f (0) for the northeastern stock of *S. attenuata*, calculated from research vessel surveys (Gerrodette et al., 2002). Error bars indicate 1 standard error.

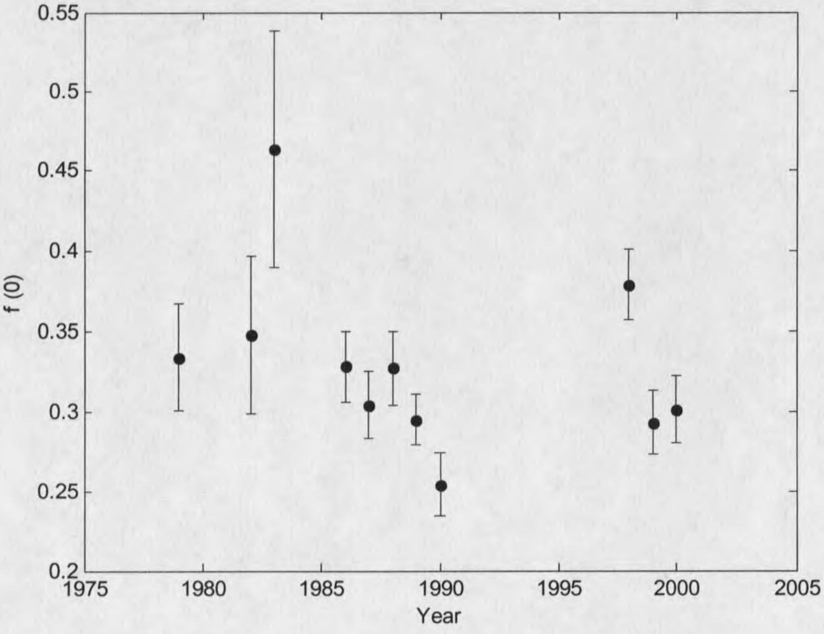


Figure 3. Estimates of average school size for the northeastern stock of *S. attenuata*, calculated from research vessel surveys (Gerrodette et al., 2002). Error bars indicate 1 standard error.

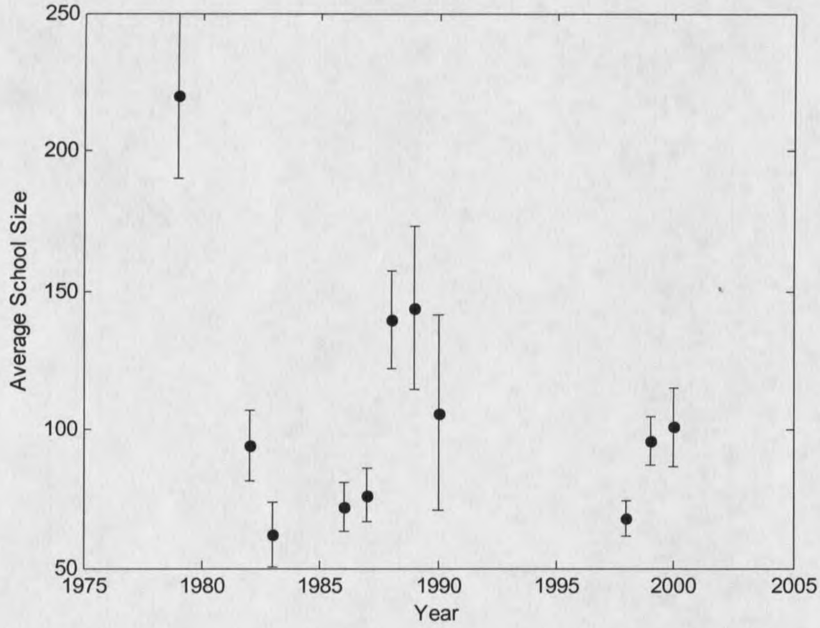
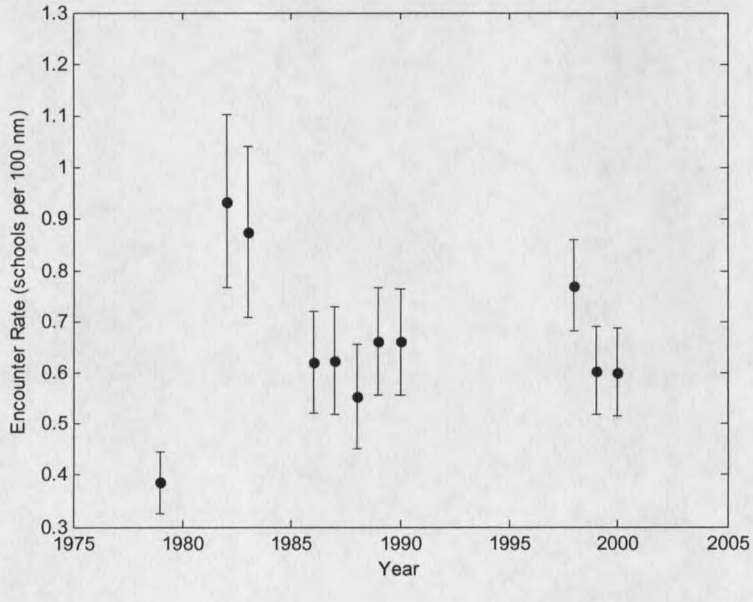


Figure 4. Estimates of encounter rate for the northeastern stock of *S. attenuata*, calculated from research vessel surveys (Gerrodette et al., 2002). Error bars indicate standard error.



There are several hypotheses for why the northeastern *S. attenuata* stock has not recovered. First, the population of *S. attenuata* may have shifted outside of the defined northeastern stock region, either because of environmental variables (Fiedler et al., 1994; Polacheck, 1987; Reilly et al., 1994) or in response to increased fishing in the stock region. Second, there may be indirect mortality involved in the fishing process, where animals are weakened or injured significantly during sets, but are not reported as killed. Third, the increased efficiency by the tuna fishery has caused some dolphin schools to be set on an average of eight times annually (Perkins et al., 1999). This increased efficiency may have detrimental effects on population fecundity, via increased stress levels (Curry, 1999). Since 1980, the estimated number of set on *S. attenuata* has increased (Figure 5; Archer et al., 2002), as has the estimated number of captured and chased *S. attenuata* individuals (Figure 6-7; Archer et al., 2002). The intensity of fishing activity appears to have decreased since the late 1980s, and appears to have been relatively constant since the early 1990s. Several types of fishing procedures not involving sets on dolphins have been explored (i.e. setting nets on logs or other floating debris), however all are less efficient at catching large yellowfin tuna than setting on schools of dolphins (United States, 1997). In 2001, NMFS used a chartered fishing vessel to measure the effects of stress on dolphins as a result of repeated chase and encirclement. In addition to blood and skin samples, information was collected on cow/calf separation and behavior between chases.

Figure 5. Estimated sets on the schools of *S. attenuata* in the northeastern stock region of the ETP (Archer et al., 2002).

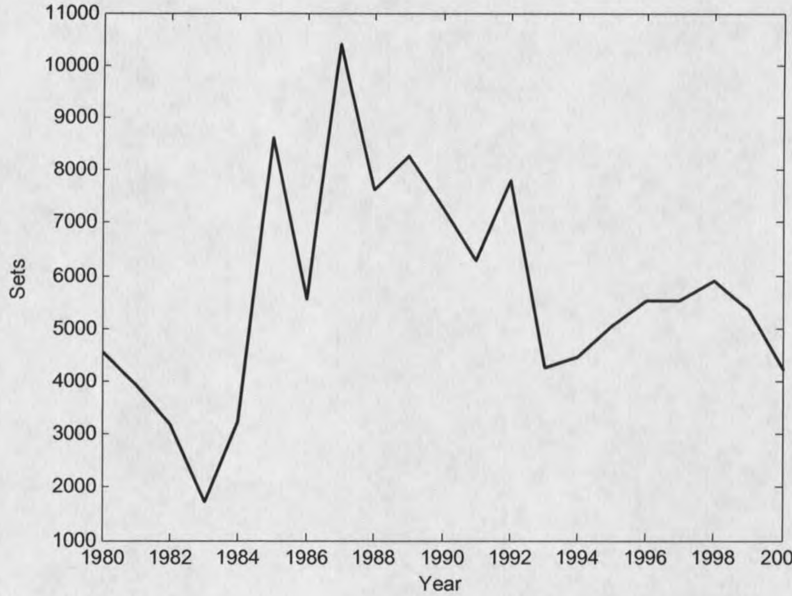


Figure 6. Estimated *S. attenuata* individuals captured in purse-seine nets in the northeastern stock region of the ETP (Archer et al., 2002).

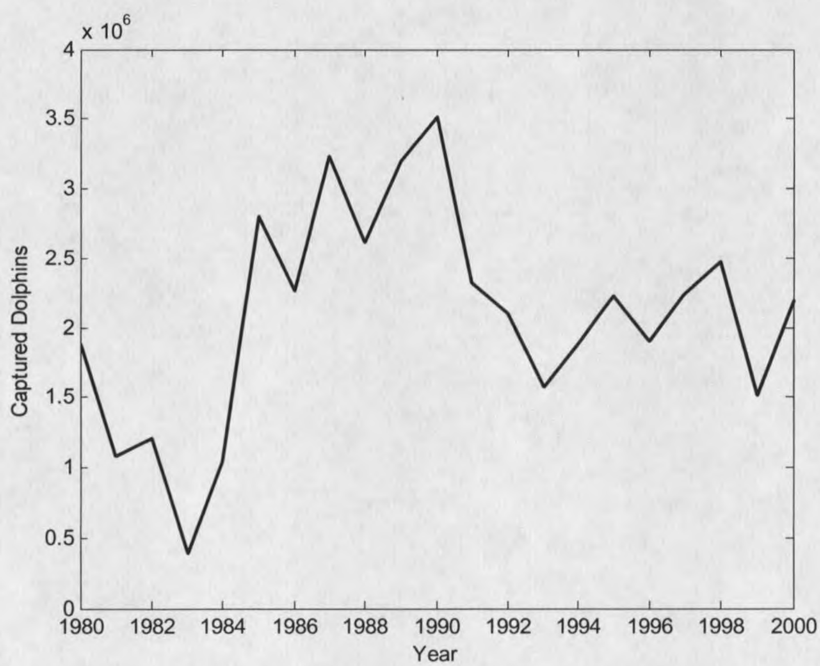
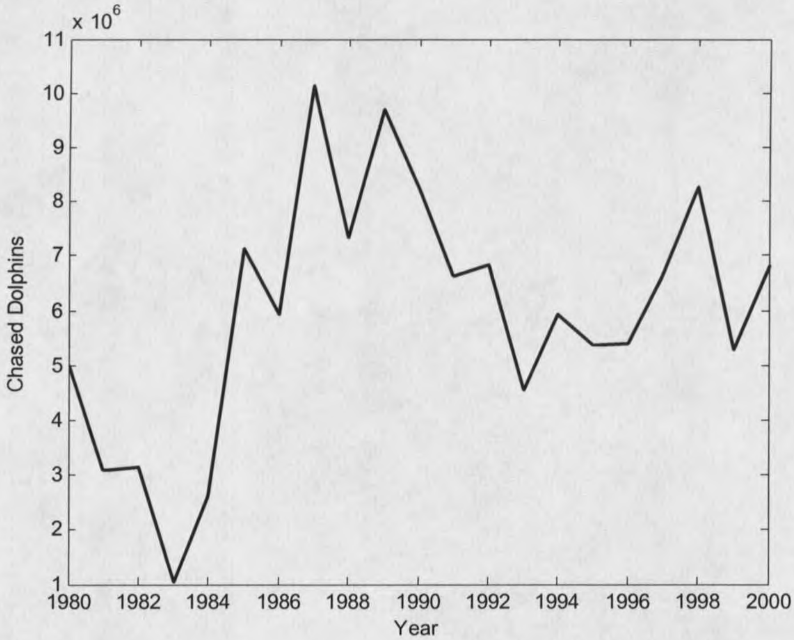


Figure 7. Estimated *S. attenuata* individuals chased during purse-seine fishing operations (captured and not captured) in the northeastern stock region of the ETP (Archer et al., 2002).



After conducting the chase and encirclement study, in addition to a 3 year population survey between 1998-2000, NMFS declared that purse-seine fishing operations were not detrimental to the recovery of the northeastern stock of *S. attenuata*, or any other depleted dolphin stock in the ETP (NMFS, 2002). An independent review panel reviewing NMFS' research suggested that portions of the tuna vessel data be used in addition to data collected from research vessel surveys, as data from research vessel surveys does not represent a continuous time series (Southwest Fisheries Science Center, 2002). If tuna vessel data and research vessel data are to be analyzed together to create a combined time series of abundance, time-varying biases cannot be present in the tuna vessel data.

Objectives

Of the three components associated with estimating dolphin abundance, the estimate of average school size has the largest vulnerability to bias, and will be the focus of this analysis. While all three of the line-transect components are affected by the non-random search process, search effort may be deliberately school size selective, and school size estimates are prone to observer error (encounter rate is only dependent on whether or not a school is observed and reported, and radar is often used to estimate the radial distance and bearing of each school detected by tuna vessels (Lennert-Cody et al., 2001), used to estimate $f(0)$).

There have been certain biases in the tuna vessel data set that represent a temporal trend and remain uncorrected for, such as the change in fishing technology and searching methods (Lennert-Cody et al., 2001). Related to this change is that there may be a trend in the distribution of tuna vessel search effort relative to the distribution of *S. attenuata* school sizes, as tuna vessels have become more skilled at finding large dolphin schools. According to basic line transect assumptions, the distribution of tuna vessel search effort should be random. Any departure from randomness should not exhibit a trend, because inference of the relative abundance estimates would be biased. A second uncorrected bias is that *S. attenuata* school sizes reported by tuna vessel observers have historically been larger than those reported by research vessels. It is unclear whether tuna vessels sample different spatial portions of the stock region, or whether observations made from tuna vessels tend to be overestimated. If there is a systematic over-reporting by tuna vessel observers, any temporal trend in this bias would also prevent inference using the tuna vessel data index.

From a management standpoint, inference of tuna vessel data would not only supplement the existing research vessel data, but may be able to provide more insight on temporal and spatial variability on ETP dolphin populations. An absolute decision of whether or not *S. attenuata* abundance estimates from TVOD are reliable is beyond the scope of this project. The first objective of this analysis is to include a detailed description of the abundance estimation procedure currently used by the IATTC to estimate dolphin abundance from TVOD. A second objective is to attempt to quantify some known biases that exist in the TVOD, and to explore additional biases that may be subject to temporal trends. If biases in the TVOD are found to exhibit time-varying biases, I will attempt to correct for them. Any such correction depends on identifying the true model for the underlying bias (e.g. linear, quadratic, etc.).

Some biases in the TVOD have already been thoroughly examined (Lennert-Cody et al., 2001; Perkins, 2000). Other biases, such as the non-random distribution of search effort, have been evaluated (Anganuzzi, 1992), but the impact of the bias on TVOD estimates have not been quantified. Changes in search technology and tuna vessel fishing behavior have been examined (Lennert-Cody et al., 2001), but the impact of this bias on TVOD estimates has not been previously quantified. My goal is to quantify and correct for these biases, assuming that they have been varying linearly.

One bias that has not been examined in previous analyses is the disparity between dolphin schools reported by research vessel surveys, and dolphin schools reported by tuna vessels. The magnitude of the difference is quite large (tuna vessel observers often