Data Available for Assessing Dolphin Population Status in the Eastern Tropical Pacific Ocean

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Workshop on Methods for Monitoring the Status of Eastern Tropical Pacific Ocean Dolphin Populations
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1) Background

(Michael D. Scott, Cleridy Lennert-Cody)

For almost 50 years, the tuna-dolphin issue in the eastern tropical Pacific Ocean (ETP) has been studied and debated. Tuna vessels have used the co-occurrence of yellowfin tuna (*Thunnus albacares*) with dolphin species to locate the tuna since at least the 1940s (Silva 1941; NRC 1992). Tuna purse seiners began encircling dolphins in the late 1950s to catch the tunas (McNeely 1961; NRC 1992) and this fishing method resulted in substantial bycatch of dolphins (Perrin 1968; Lo and Smith 1986; NRC 1992; Wade 1995). Through fishermen's ingenuity and implementation of national and international management measures, however, mortality has been reduced to very low levels (NRC 1992; Joseph 1994; Hall 1998; IATTC 2016). Population dynamics modeling of dolphins has been used to evaluate stock status (Gerrodette and Forcada 2005; Reilly *et al.* 2005; IATTC 2006; Wade *et al.* 2007, Gerrodette *et al.* 2008), and those models have relied on estimates of abundance from fishery-independent cetacean and ecosystem assessment surveys conducted by the National Marine Fisheries Service (NMFS) periodically between 1979 and 2006.

As a result of a hiatus in the NMFS surveys since 2006, there are currently no reliable indicators with which to monitor the abundance of the ETP dolphin populations. This lack of information is problematic because, in spite of the current low levels of reported mortalities (IATTC 2016), high levels of historical mortality (Wade 1995), and low estimated population rates of increase (Gerrodette *et al.* 2008) have resulted in an ambiguous population status.

The Antigua Convention of the Inter-American Tropical Tuna Commission (IATTC) requires that the status of all species potentially impacted by the tuna fisheries in the eastern Pacific Ocean be monitored. As a step towards addressing this requirement, this workshop has been organized to bring together experts in the fields of line-transect and mark-recapture surveys, abundance estimation and population modelling, and imagery, tagging, genetics and life history data, to discuss options for developing indices with which to monitor dolphin populations. The goal of the workshop is to identify methods, both conventional and novel, for monitoring and assessing dolphin stock status.

Data will form the basis for any assessment of dolphin stock status. This document summarizes available and potential data that could be used to assess dolphin population status and trends. Because of the long history of the tuna-dolphin issue, there are long-term data from ship-board observers on marine mammal sightings, purse-seine fishing operations, dolphin and tuna life history, dolphin mortality, plus long-term data from cetacean and ecosystem assessment surveys. This document focuses on stocks of the three species with greatest historical involvement with the fishery: spotted (*Stenella attenuata*), spinner (*Stenella longirostris*), and common dolphins (*Delphinus delphis*).

2) Cetacean Line-Transect Data from NOAA Research Vessel Surveys (Tim Gerrodette)

Line-transect surveys conducted in the ETP by the Southwest Fisheries Science Center (SWFSC) began in 1974 using a combination of aircraft and ships. Data collection procedures were refined each year and, by 1979, were close to current procedures. Large-scale ship surveys covering substantial parts of the ETP were carried out in 1979, 1980, 1982 and 1983, but the amount, distribution and timing of effort varied each year. Beginning in 1986, the surveys used a stratified random design covering the whole area at the same time of year, so this date is usually taken as the beginning of a consistent time-series for estimates of abundance for the dolphin stocks of interest. Such whole-area surveys were conducted annually from 1986-1990 and then, with a different stratification following a redefinition of stock boundaries, in 1998-2000, 2003 and 2006. Additional data were collected in 1992, 1993, 2007 and 2009, but these surveys were carried out for other purposes and did not cover the entire stock areas of the northeastern spotted and eastern spinner dolphins (see figures in Life History Data: Data for Stock Definition). The number of sightings of spotted, spinner, and common dolphins for each survey since 1986 is presented in Table 2-1. Detailed discussion of the NMFS line-transect survey design can be found in Buckland *et al.* (Background Document 2).

Potential costs: The estimated cost for a cetacean and ecosystem assessment survey, in 2017 dollars, is about $10M. These costs were computed from the latest NMFS budget dated July 15, 2016, based on the costs of two NOAA vessels, for a combined 266 ship days, plus additional costs for collection of ancillary data (*e.g.*, environmental data, biopsy sampling), and logistics and analysis.

Table 2-1. Number of dolphin groups sighted, both on and off effort, of the 3 main target species by year. "Pure" means groups composed of a single species, and "Mixed" means groups containing one or more other species. "Size" is mean group size; in the case of mixed schools, this refers to the estimated size of the subgroup of the species.

Year	Species	Pure	Mixed	Total	Size
1986	Spotted dolphin	65	86	151	33.3
	Spinner dolphin	24	48	72	159.3
	Common dolphin	45	5	50	273.3
1987	Spotted dolphin	75	80	155	49.2
	Spinner dolphin	15	45	60	143.9
	Common dolphin	31	2	33	200.2
1988	Spotted dolphin	41	66	107	58.7
	Spinner dolphin	6	33	39	285.5
	Common dolphin	56	2	58	520.6
1989	Spotted dolphin	64	86	150	50.8
	Spinner dolphin	18	54	72	199.6
	Common dolphin	45	3	48	364.3
1990	Spotted dolphin	67	62	129	75.2
	Spinner dolphin	13	34	47	140.7
	Common dolphin	43	3	46	388.9
1998	Spotted dolphin	134	126	260	83.0
	Spinner dolphin	33	80	113	121.9
	Common dolphin	135	7	142	175.4
1999	Spotted dolphin	64	94	158	93.6
	Spinner dolphin	12	64	76	49.7
	Common dolphin	121	8	129	171.1
2000	Spotted dolphin	68	92	160	116.5
	Spinner dolphin	17	60	77	65.5
	Common dolphin	86	6	92	229.5
2003	Spotted dolphin	72	109	181	113.2
	Spinner dolphin	14	66	80	66.4
	Common dolphin	90	4	94	122.1
2006	Spotted dolphin	85	127	212	128.5
	Spinner dolphin	23	92	115	90.7
	Common dolphin	133	5	138	217.9

3) Abundance Indices – Tuna Vessel Observer Data
(Cleridy Lennert-Cody, Michael Scott)

Marine mammal sighting information collected by fisheries observers aboard tuna purse-seine vessels represents an extensive data set in both space and time. Unlike research vessel data that have been collected only seasonally in some years, tuna vessel observer data have been collected year-round since the 1970s throughout the area of the ETP occupied by the fishery. Beginning in 1971, NMFS observers aboard U.S. vessels began collecting information on dolphin sightings, however, it was not until 1975 that data were also collected on effort. In 1979, observers of the IATTC began recording dolphin sightings and effort data aboard a subset of trips of vessels of the international purse-seine fleet (Bayliff 2001; IATTC 2014). Beginning in 1992, dolphin sightings and effort data have been collected aboard trips of all large purse-seine vessels (>363 t fish-carrying capacity), with very few exceptions due to non-compliance or discrepancies in the estimates of a vessel's fish-carrying capacity. These data, which span roughly 40 years, represent thousands of vessel trips and hundreds of thousands of dolphin school sightings.

The data collected by onboard fisheries observers are a summary of daily fishing activities and related events. While the purse-seine vessel is in search mode and the observer is on duty, the observer records data on all sightings of which he/she is made aware. The following is a brief summary of the sighting information that has been collected by IATTC observers since 1979, and national program observers since 1992 (which is generally compatible with data collected by NMFS observers aboard U.S.-flagged vessels since 1975):

a) Information as to the type of searching gear carried aboard the vessel (*e.g.*, presence of radar, helicopter);
b) Estimates of dolphin school size (number of animals) and species composition for each sighting (observer and vessel crew initial estimates; observer best estimate);
c) Estimates of bearing and distance to each sighting from the purse-seine vessel;
d) The cue that led to the sighting (*e.g.*, birds, splashes);
e) The search "method" to first report the sighting (vessel crew using high-powered binoculars, vessel crew in helicopter, vessel crew using bird-radar, other). Observers report which search method they believe to have first detected the dolphin school, however they are dependent on the vessel crew for the majority of the sightings, and the crew are searching for dolphins associated with yellowfin tuna, and not dolphins *per se*. Therefore, it is impossible to unequivocally determine which search method first saw the dolphin school;
f) Date and time of the sighting;
g) If the dolphin school was seen previously;
h) If the dolphin school is later involved in a purse-seine set, this information is recorded so that the original sighting can be linked to the set.

In addition, over the course of each day the observer records the activities of the vessel (*e.g.*, searching, setting, running, drifting), as well as periodically recording location of the vessel.

In spite of the large amount of data collected by onboard observers, not all details of the searching process are documented. The following is a brief summary of some key information that is not collected by onboard observers:

a) Effort information for the helicopter (when search by the helicopter began and ended; helicopter location during search; all dolphin sightings seen by the helicopter pilot during search);
b) The amount of time bird-radar is in use for search;
c) Whether tuna were associated with the sighting, for those sightings that did not lead to a purse-seine set (and the amount tuna);
d) Best estimates of school size and species composition for all sightings recorded (best estimates are only made by the observer if the dolphin school becomes involved in a purse-seine set).

Because of the large amount of observer data, relative to data from fishery-independent surveys, methods to estimate indices of relative abundance from purse-seine observer data have been proposed (Hammond and Laake 1983; Buckland and Anganuzzi 1988; Anganuzzi and Buckland 1989). At the time these methods were proposed, the primary method of dolphin school detection was by the vessel crew using high-powered binoculars (Buckland and Anganuzzi 1988; Lennert-Cody *et al*. 2001). However, since this time search for dolphins associated with tunas has evolved and sightings associated with helicopter or radar constitute the majority of sightings (Lennert-Cody *et al.* 2001; 2016). There are serious challenges to developing a reliable index from fisheries observer data, several of which are listed below.

Nonrandom distribution of tuna vessel search effort

To decrease bias due to nonrandom search, estimates of the line transect components (encounter rate, f(0), mean school size) were estimated within strata defined by encounter rate as a proxy for dolphin school density (Buckland and Anganuzzi 1988). However, search methods have evolved since the late 1980's, with radar use becoming common, and radar and helicopter being the dominant sources of reported sightings since the late 1990's (Lennert-Cody *et al*. 2001; 2016). In addition, relative abundance indices for the spotted dolphin computed with line-transect methods, as well as generalized additive models, beginning in 1990, were found to show similar trends on both short and long time scales to a yellowfin tuna index (Lennert-Cody *et al*. 2016). Because tunas and dolphins have different life history characteristics, this similarity was hypothesized to indicate that the dolphin indices were tracking the tuna-dolphin association, indexing fishermen's ability to find areas where tuna were associated with dolphins. No method for mitigating this problem was proposed.

Potential differences in availability of sighting information by search method

The greater proportion of helicopter sightings that led to purse-seine sets, relative to binocular sightings (Lennert-Cody *et al*. 2016), may indicate selective reporting of dolphin schools by helicopter crew; *i.e*., helicopter crew are less likely to report dolphin schools that would not be set upon. This, in combination with an increase in the proportion of sightings that were reported by helicopter (Lennert-Cody *et al*. 2001; 2016), which has been hypothesized to correspond to an increase in search by helicopters, may have led to a trend through time in sighting data availability (Lennert-Cody *et al*. 2001; 2016). The attempt made to correct for this potential trend in sighting data availability in the generalized additive model analysis by introducing a trip-specific detection variable was not successful, possibly because the types of search methods in use during any given trip appear to depend in part on the vessel's perception of the local abundance of dolphins associated with tunas, as well as on general searching practices in use by the fleet at any given time (Lennert-Cody *et al*. 2016).

School size estimation

Estimating school size is a difficult problem, but the importance of this issue may depend to some extent on whether a relative or absolute index of abundance is to be computed. The sizes of schools sighted by research vessel observers within a limited spatial-temporal window of schools reported by tuna vessel observers were found to be much smaller than schools reported by the tuna vessel observers (Ward 2005). Consistent overestimation of school size by tuna vessel observers, or selective reporting, were proposed as possible explanations for the differences. School size estimates by observers on research vessels have been extensively calibrated by comparing observers' estimates to counts from aerial photographs (Gerrodette *et al*. 2002). Unlike research vessel observers' estimates, tuna vessel observers' estimates are not calibrated, although methods have been proposed to adjusted observers' initial school size estimates when no best estimate is available using data from sightings where both initial and best estimates were available (Buckland and Anganuzzi 1988).

Bearing data quality

Bearing data quality appears to have changed over the years from an excess of sightings on the trackline, possibly because the vessel had turned towards the sighting before the bearing was recorded (Buckland and Anganuzzi 1988), to a deficit of sightings on the trackline, possibly the result of subsequent emphasis during observer training on avoiding recording bearings near zero unless certain (Lennert-Cody *et al*. 2001). Smearing was used to minimize the effect of the former issue and a hazard rate model for the detection function for the latter. However, neither of these approaches addresses the issue in a satisfactory manner because neither approach directly models the underlying (and unknown) processes that generated the data. Moreover, the approach used to address changes in bearing data quality may affect the estimated trend in the index (Lennert-Cody *et al*. 2001).

4) Mark-Recapture Methods

(Michael Scott, Cleridy Lennert-Cody, Hans Skaug, Carolina Minte-Vera, Jenny Hofmeister)

Visual Tags

A statistical design for a mark-recapture study of spotted dolphins was described in a contract report to NMFS (Southward and Urquart 1979). They calculated that for a population of 1 million dolphins, dedicated seiners would need to mark 9,500 dolphins during the tagging phase of the study and the same number would have to be examined for marks on the recapture phase of the study. They also calculated that with good sightings conditions, 125 days of dedicated seiner time would be needed for the combined two phases; 320 days would be required for moderate sightings conditions.

Large-scale visual tagging of ETP dolphin species was attempted by NMFS (Perrin *et al*. 1979; Hedgepeth 1985; Table 4-1), but early mark-recapture attempts were hindered by small tag numbers that could not be read at a distance, high tag loss, and low return rates. Mark-recapture analyses to estimate abundance have not been attempted in the ETP.

Table 4-1. Tagging studies conducted in the ETP. Includes both visual and radio tags, although resightings do not include radiotracking positions.

Study	**Study Years**	**Spotted Dolphins Tagged (resighted or recovered)**	**Spinner Dolphins Tagged (resighted or recovered)**	**Other Dolphin Species**
Perrin *et al*. (1979)	1969-1976	2,996 (97)	324 (7)	392
Hedgepeth (1985)	1969-1978	701 (102)	25 (1)	16
Scott & Chivers (2009)	1992-2001	247 (2)	1	

Small-scale tagging and tracking have been conducted for studies of the tuna-dolphin association, movements, diving patterns, social associations, and stress (Leatherwood and Ljungblad 1979; Perrin *et al*. 1979; Scott and Chivers 2009; Scott *et al*. 2012; Archer *et al*. 2010; Table 4-1).

The potential for large-scale tagging effort for mark-recapture analysis will be discussed in the Workshop. The sample-size requirements calculated by Southward and Urquart (1979) should probably be re-examined using more-modern quantitative methods. Relevant information to keep in mind is:

a) The tags most currently in use for dolphins are rototags (cattle ear tags attached to the dorsal fin), freezebrands applied to the dorsal fin and dorsal body surface, and a variety of radio tags attached to the dorsal fin with pins or to the dorsal surface with suction cups

(Fig. 4-1). In the past, spaghetti tags and large visual tags have been used to identify ETP dolphins (White *et al.* 1981). Some tags (such as spaghetti tags and rototags) are quick to apply but have small numbers that cannot typically be read from a distance. In general, the tags that are the quickest to apply are also the quickest to be shed.

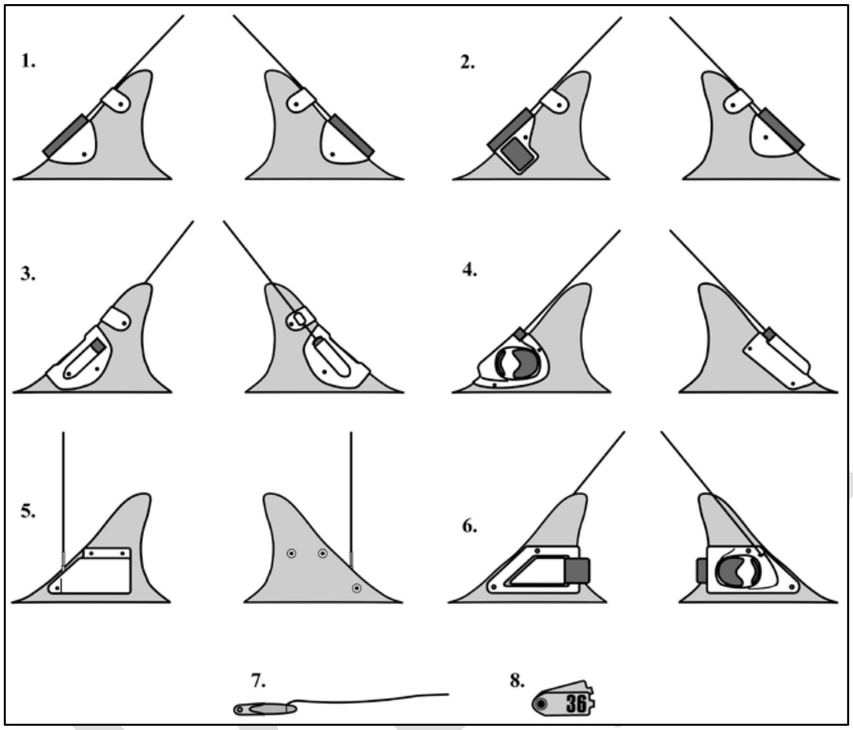

Figure 4-1. Tag types used during 1992-2001 tracking studies. Type 1: high-power transmitter used in 1992–1993, Type 2: high-power transmitter with a Mk-5TDR used in 1992–1993, Type 3: high-power transmitter with a Mk-7 TDR used in 2001, Type 4: high-power transmitter with a Mk-8 TDR used in 2001, Type 5: satellite transmitter used in 2001, Type 6: low- or high-power transmitter with a Mk-8 TDR and a thermal data logger, Type 7: "bullet" tag with a low-power transmitter and flexible antenna, and Type 8: Dufflex visual tag (from Scott and Chivers 2009).

b) Tagging without capture has been attempted using crossbow-propelled spaghetti tags. They can be applied opportunistically to bow-riding dolphins, but spaghetti tags have a high loss rate (Irvine *et al*. 1982).

c) Capturing and tagging dolphins encircled by tuna purse-seine nets have proved successful, but this requires a dedicated purse seiner, and only a limited number of dolphins can be tagged in a single set, as delaying the backdown procedure for much more than about a half-hour makes it more difficult to release the dolphins. During the CHESS (Chase Encirclement Stress Studies) cruise (Chivers and Scott 2002), as many as 28 rototags were attached during one set; as many as 5 dolphins were placed into a raft, blood sampled, measured, sexed, radio-tagged using a pin attachment, and released in one set.

Potential costs: Assuming 320 days of chartered purse-seiner time (based on the Southward and Urquart calculations), at a daily rate of $16-25K (Lennert-Cody *et al*. 2016), the charter costs plus tags and personnel would range between $5.0-8.2M.

PIT tags

In 2005, the IATTC and NMFS proposed development of Passive Integrated Transponder (PIT) tags to study dolphin-purse-seine interactions, as well as dolphin movement and abundance, (IATTC 2005). It was anticipated that purse-seine vessels would be used in the initial tagging phase of such a project, as well as for subsequent tag detections. A dolphin is "marked" with an internally implanted PIT tag (thus reducing tag loss) and "resighted" when a tag reader detects the presence of the PIT tag. It was proposed that research be conducted on the viability and practicality of mounting tag readers inside the floats of the purse-seine corkline at the apex of the backdown channel. This could allow for automatic detection and identification of any tagged dolphins that were encircled and released from tuna purse-seine nets during normal fishing operations. The proposal was not developed further, however. Some issues that would need to be considered if such a project were to be initiated include:

a) Improving the detection range of tag readers so that tagged animals at the surface can be detected when passing over the purse-seine corkline located at 1-2 m below the surface;
b) Development of tag readers that would be rugged enough to pass through the power block when the purse-seine net is rolled;
c) Tag loss rates and detection probabilities are unknown and would need to be estimated;
d) A sampling design would need to be developed;
e) Customized data processing software may need to be developed.

As with other tagging options that might utilize the fishery to obtain resightings (recaptures), it would be necessary to establish that non-random resighting probabilities could be evaluated, and if necessary, taken into consideration during data analysis through modelling (see Buckland *et al*. Background Document 2).

Potential costs: Research and development costs presently unknown

Acoustic telemetry tags

Acoustic telemetry has been used to monitor movement and behavior of a variety of taxa in the marine environment (Cooke *et al*. 2004; Hussey *et al*. 2015; McGowan *et al.* 2016). However, their use for mark-recapture with dolphins, particularly where "resightings" were to be obtained from receivers aboard tuna vessels would be nonconventional, and as a result, a research and development phase would be necessary to ascertain the feasibility of this tagging option. As with PIT tags, dolphins would need to be captured to be tagged with acoustic tags, and thus it is anticipated that purse-seine vessels would be used in the initial tagging phase of such a project, as well as for subsequent tag detections. As an example of current receiver technology, stock receivers made by VEMCO (http://vemco.com/) are available at two frequencies: 69 kHz and 180 kHz. The 69-kHz frequency is not viable as it is in the middle of the dolphins' hearing range, but the 180-kHz frequency is above or at the upper end of the dolphins' hearing range. Detection ranges for low-frequency transmitters are greater than for high-frequency transmitters; if used aboard tuna vessels, high-frequency receivers might be incorporated into the corkline of the backdown channel or positioned in some other manner near the apex of the backdown channel. Depending on the level and frequency range of vessel noise, the water temperature, and any objects blocking the receiver, high-frequency receivers might have detection ranges of 10's of meters.   Some issues that would need to be considered during a research and development phase include:

a) Receiver frequency, taking into consideration hearing range of dolphins, vessel noise, and options for receiver placement;
b) Receiver sensitivity to physical damage (stock receivers cannot withstand much physical abuse, *e.g.*, as might happen when the corkline passes through the power block);
c) Tag delay time to optimize individual tag detection when multiple tagged animals are present in the purse-seine net;
d) Estimates of tag loss rates and tag detection probabilities;
e) A sampling design would need to be developed;
f) Any customized data processing that might be necessary (*e.g.*, to filter vessel noise).

With stock systems, data can be removed from the acoustic receivers via Bluetooth, and this could be done when the vessel was in port so as not to interfere with normal fishing operations. Depending on the receiver sampling rate, battery life might be roughly one year or more. As with other tagging options that might utilize the fishery to obtain resightings or recaptures, it would be necessary to establish that non-random recapture probabilities could be evaluated, and if necessary, taken into consideration during data analysis through modelling (see Buckland *et al.* Background Document 2).

Potential costs: Research and development costs presently unknown

Close-Kin Genetics

Genetic mark-recapture techniques (*e.g.,* Pearse *et al*. 2001) and "close-kin analysis" methods (*e.g.,* Skaug 2001; Bravington *et al*. 2014), use genetic information to estimate abundance. Mark-recapture methods require an initial sample for marking and a subsequent recapture sample; close-kin methods require sampling of both adults and juveniles, with sampling of juveniles independent of that of adults. Both methods require genetic markers for dolphin species to be developed, and also require genetic analyses in the laboratory. Recently, a more general close-kin method has been formulated, which does not necessarily require parent-offspring pairs, but will also work with half-sibling pairs (Bravington *et al*. 2016). This new method is applicable also to data collected for ordinary mark-recapture studies, and the authors argue that the new methods always provide extra information.

Mark-recapture genetics methods could involve a random sampling design to collect the initial samples using either research vessels or dedicated purse seiners, and follow-up (recapture) sampling could be collected on commercial vessels during normal operations. This would require assistance from the purse seiner crew and/or would require the observers to perform additional duties, perhaps at the expense of some of the data currently collected. Based on genetics literature and the 2006 estimates of dolphin abundance, tissue samples from about 10,000 northeastern offshore spotted dolphins would need to be collected during each phase for the mark-recapture study; for close-kin (parent-offspring) analysis, samples from about 6,000 animals would be required in the first year, but perhaps fewer samples in subsequent years.

Potential costs: Using the maximum number of animals biopsied during the NMFS CHESS cruises (28 animals in one dolphin-set), and assuming 1 dolphin-set per day, genetics sampling using the close-kin (parent-offspring) method would require over 220 sea-days ($3.5-5.5M in charter time alone) and more for the mark-recapture method. For close-kin methods, it may be possible to obtain samples from dead animals only, but at the current annual mortality level of less 1,000 animals, it would take several years to obtain an initial sample for marker development and for a methodological assessment of the technique for ETP dolphin populations.

All of these mark-recapture methods would require development of a sampling design, and some of them would require extensive ship time aboard tuna purse seiners, either vessels whose ship time was donated or vessels that are chartered for dedicated research cruises.

5) Abundance Surveys Using Long-Range Unmanned Aerial Vehicles (UAVs)

UAVs have not previously been used in the ETP, although they present a potential method for lower cost-surveys of the area. UAVs are currently being used in Arctic surveys (Megan Ferguson, pers. comm.) Many questions need to be answered to assess the usefulness of this method and design a survey for the ETP. Among them are:

a) Are the ranges of the UAVs great enough to cover such a large area, particularly the offshore areas?
b) What is the optimal speed and altitude for both detecting dolphin herds and covering an effective trackline?
c) Is the camera resolution high enough to detect and count individual dolphins?
d) Upon detection of a herd, will the UAV be instructed to circle the herd to gather size information or continue along the trackline?
e) If a survey is feasible, what would the survey cost?

This topic is further discussed in Buckland *et al.* (Background Document 2).

6) Passive Acoustic Monitoring

(Jay Barlow and Cleridy Lennert-Cody; based on Heinemann *et al*. 2015)

Marine mammal vocalizations can be recorded by passive acoustic data monitoring systems, and have been used to estimate indices of relative and absolute abundance, in addition to studying species occurrence and seasonal distribution (Heinemann *et al*. 2015). Acoustic surveys have potential advantages over visual surveys because visual surveys are limited by environmental conditions, daylight, and visual detection range. Acoustic data can be collected by acoustic sensors on moored platforms (bottom or surface mounted arrays), towed arrays, and autonomous platforms (buoyancy-driven gliders and floats, free-drifting systems, wind/wave-powered vehicles). For ETP dolphin species, buoyancy-driven gliders and floats may offer the greatest potential. The size of the survey area, water depth and vessel traffic would make collection of acoustic data with moored platforms logistically challenging. The principle use of towed arrays has been to supplement data collected during visual line-transect surveys of species with long dive times. Therefore, towed arrays would not be expected to reduce visual line-transect survey effort or costs when the primary objective of such surveys is to estimate abundance of *Stenella* and *Delphinus* stocks. Because data collected by towed arrays can be compromised by flow noise, ship noise, electronic noise and frequent changes in ship course and speed, towed arrays would not be expected to perform well when towed behind commercial vessels. Free drifting systems are hydrophone recorders tethered to surface floatation (surface drifters) or designed to sink to a desired depth and drift with currents at that depth (buoyancy drifters). Wind and wave powered vehicles are still in the development/testing phase.

Species identification from acoustic data requires libraries of species-specific vocalization repertoires that cover different ecological and social contexts so that species can be unequivocally identified. Techniques for categorizing whistles of ETP dolphin species are being developed (Oswald *et al*. 2003; 2007) but more research is needed to reliably distinguish species. Complete whistle libraries are critical to avoid bias in abundance and trend indices due to environmental and social factors, and presently complete libraries do not exist for many delphinid species, including ETP species. Passive acoustics data using sonobuoys and towed or hull-mounted hydrophone arrays have been collected during visual line-transect surveys in 2000, 2003, 2004, and 2006 (Rankin *et al*. 2008). All surveys were conducted between June/July and December, but vary considerably in their spatial coverage (effort) among years.

Instead of vocalization counts, the total accumulated energy within a specific frequency band can be used as a proxy for presence of one or more individuals of the target species. However, this is only realistic when the target species is the dominant species producing energy in a specific frequency band. For delphinids, which emit high-frequency vocalizations that only travel relatively short distances, the energy received at the acoustics detector is not likely dominated by the target species and thus vocalization counts would be expected to be a better index of individuals and groups

Potential costs: For repeated long-duration surveys, such as might be conducted for ETP dolphin species, a passive acoustic system that was integrated into a glider or float would be preferable from a data-collection perspective. Buoyancy-driven floats and gliders can collect data continuously for weeks to a few months. Floats drift with the current at a specified depth; gliders can control both vertical and horizontal position (average speed is ~ 0.5 knots). The unit cost of floats and gliders (without the passive acoustic system) is US$15-20K and US$100-150K, respectively. A disadvantage of floats and gliders, however, as compared to free-drifting systems, is that electronic and mechanical noises (*e.g*., due to the buoyancy pump) can contaminate the acoustic signal and therefore data require additional processing. As with all passive acoustic systems, the large volumes of data generated require processing to remove unwanted noise, identify vocalizations of the target species and locate those vocalizations in space. This data processing must be done by skilled analysts and specialize computer software. More information about feasibility and survey design would be required to estimate the cost of an acoustic survey.

7) Dolphin Incidental Mortality Data

(Cleridy Lennert-Cody)

Dolphin incidental mortality data have been collected since the mid-1960’s, although both sampling design and coverage have changed considerably over the years. Mortality data were collected by the NMFS aboard U.S. vessels from 1964 to early 1995 (Smith and Lo 1983; Nick Vogel, pers. comm.). NMFS sampling of tuna seiners prior to 1971 was opportunistic, with only four trips[1] observed between 1964 and 1968 (Smith and Lo 1983). In 1971, the NMFS established a regular, albeit voluntary, observer program (Lo *et al*. 1982), and in 1976 participation in this program became mandatory for captains fishing on tunas with dolphins (Wahlen 1986). The IATTC began placing observers aboard vessel of the international fleet in late 1979, although it was not until 1986 that sampling adequately covered the vessels of all countries participating in the fishery (Joseph 1994). Observer coverage of the international fleet for large vessels (>363 t fish-carrying capacity) by the IATTC and national observer programs increased from about 11-24% prior to 1986 to nearly 100% in 1992 (Joseph 1994). Since 1992, the observer coverage of the international fleet of large vessels has been at or nearly 100% based on a combination of sampling by IATTC observers, observers of national observer programs of Mexico, Venezuela, Ecuador, European Union, Colombia, Panama and Nicaragua, and the Western and Central Pacific Fisheries Commission (IATTC Annual Reports through 2010, http://www.iattc.org/AnnualReportsENG.htm , and thereafter in IATTC MOP documents,

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[1] Dolphin mortality data from an additional two trips were collected prior to 1971 by the IATTC (R. Allen, pers. comm., cited in Smith and Lo 1983), however, the details of those data currently are not known.

e.g., IATTC 2016). Small purse-seine vessels have only rarely been sampled by observer programs since the early 1980's; it has been assumed that in general small vessels do not have the capability to make sets on tunas associated with dolphins. The mortality data recorded by onboard observers is the number and species of dolphins killed during the set. Additional information is collected on sex and size composition of the kill. Details of incidental mortality data collected by IATTC observers can found in IATTC (2014).

Prior to 100% observer coverage of large purse-seine vessels, estimates of incidental dolphin mortality have been based on ratio estimators, including dolphin mortality-per-set and dolphin mortality-per-ton of tuna. The most recent dolphin incidental mortality estimates use mortality-per-set and estimates of total fleet sets (Lo *et al*. 1982; Lo and Smith 1986; Hall and Boyer 1986; Wade 1995). Estimates of the total fleet sets come from logbook and observer data (Punsly 1983; IATTC unpublished data, and IATTC Fishery Status Reports). Since 1993, estimates of incidental mortality have been based on tallies of mortalities reported by onboard observers (IATTC 2015). The history of mortality for the international fleet from 1979 to present is updated annually by the IATTC (IATTC 2016). Estimates for years prior to 1979 can be found in several sources (Whalen 1986; Wade 1995; Wade *et al*. 2007; Lennert-Cody *et al*. 2013). Despite complete observer coverage of trips by large purse-seine vessels, it has been suggested that unobserved mortality and/or reproductive suppression due to a variety of causes may be occurring (Archer *et al*. 2001; 2004; Reilly *et al.* 2005; Lennert-Cody and Berk 2007; IATTC 2007; Cramer *et al*. 2008; Kellar *et al*. 2013a; Lennert-Cody *et al*. 2013).

8) Life History Data

(Susan Chivers, Kerri Danil, Leanne Duffy, Robert Olson, Michael Scott, Aleta Hohn)

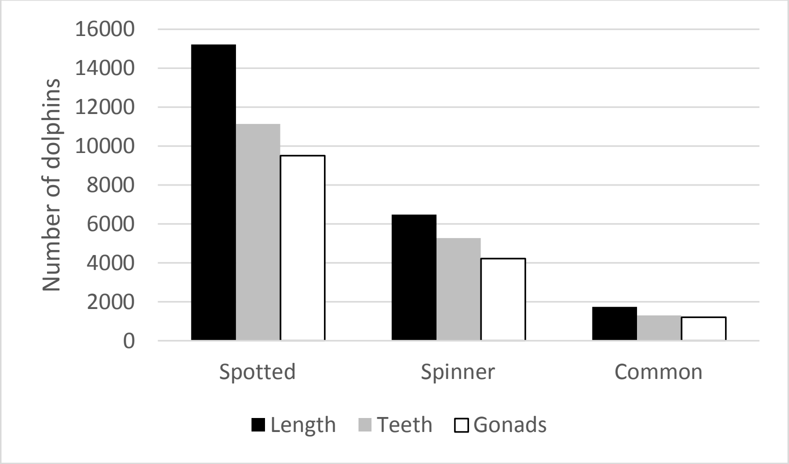
Numerous studies have been published describing the morphology and biology of pantropical spotted, spinner and short-beaked common dolphins impacted by the fishery. The results from life history studies, including age distributions and reproductive rates, can provide basic inputs for integrated population modelling, characterize fishery selectivity, and describe a species' natural history; food habits data have provided insights into trophic relations and environmental changes affecting population condition. Life history data can provide evidence of population condition, although the data often need to be interpreted in light of other data such as current and historical mortality, environmental changes, and previous population estimates. Conversely, life history data can assist in the interpretation of abundance trends, for example, when populations approach the carrying capacity of their environment. This section provides an overview of the life history data collected and select publications where primary life history information about ETP dolphins was published.

Biological sampling program overview

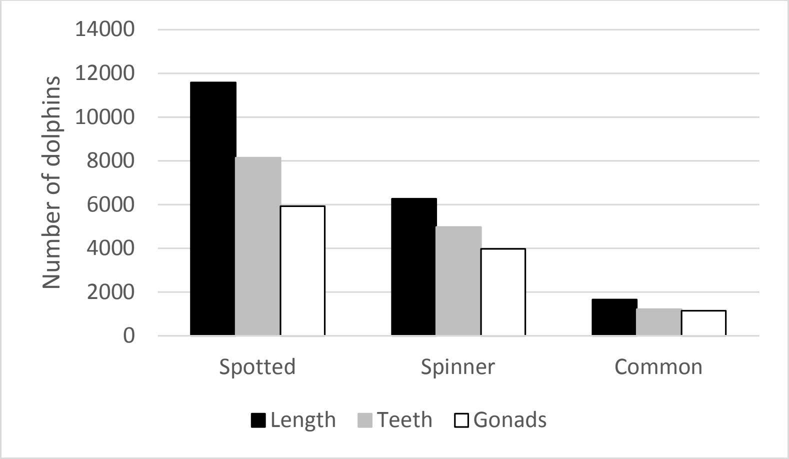
U.S. government scientific observers onboard commercial tuna purse seiners in the eastern tropical Pacific (ETP) began to monitor mortality and to collect biological data from dolphins in the fishing operation in 1966 (Gerrodette 2009). The National Marine Fisheries Service (NMFS) implemented and coordinated the program from its inception. The Inter-American Tropical Tuna Commission (IATTC) joined the NMFS in placing observers aboard U.S. vessels and collecting life history data in 1979. Observers recorded dolphin length, sex, and the color phase of spotted dolphins (an indicator of age class, Perrin 1969) and collected reproductive organs, stomach contents, teeth (for estimating age), and sometimes the entire carcass. The NMFS observer program, along with the dolphin sampling life history program, ended in 1994 as the U.S. fleet moved out of the ETP (see Figure 8-1 for a program overview).

Figure 8-1. An overview of the life history data collected by observers, 1966-1994, for the three most frequently killed species: pantropical spotted, spinner and short-beaked common dolphin.

(A) Females



(B) Males



The IATTC has continued to place observers on fishing vessels of the international fleet to the present and has coordinated the collection of data for monitoring dolphin mortality. Observers still record body length, girth, sex, and spotted dolphin color phase, but sampling has occurred only occasionally for specific projects. While the re-initiation of life history sampling by observers has been encouraged by the Meeting of the Parties to the Agreement for the International Dolphin Conservation Program (IATTC 2003, IATTC 2005a, IATTC 2005b) and a research proposal was approved in 2005 (IATTC 2005c), the necessary funding has yet to be made available.

NMFS, however, developed remote sampling technologies and molecular marker techniques to continue its life history studies. They developed molecular techniques to quantify steroid hormones from the small samples of skin and blubber collected from wild dolphins using projectile biopsy techniques (Kellar *et al*. 2006; 2009; 2014; 2015). They have also expanded the use of aerial photogrammetry from counting and measuring dolphins (Allen *et al*. 1980; Scott *et al.* 1985; Barlow *et al*. 1998; Gerrodette *et al*. 2002; Caretta *et al.* 2011) to life history studies of pelagic dolphins (Perryman and Lynn 1991; 1993; 1994; Scott and Perryman 1991). Photogrammetric data can be enriched by the more traditional, biological sample-based life history metrics, and the integration of the two data types can extend time series to facilitate monitoring biological changes through time, especially reproductive output which reflects the influence of environmental conditions on individual animals (Perryman and Lynn 2002; Cramer *et al.* 2008; Chivers *et al*. 2016). More recently, the development of UAVs to view pelagic cetaceans is contributing to life history studies, especially animal condition and reproductive success (Durban *et al*. 2016). These developments, coupled with the further understanding of the influence of natural and anthropogenic stressors and how to measure them (*e.g.*, Hart *et al.* 2015) can increase our ability to study and monitor pelagic dolphin populations.

Biological data collection

Life history data were collected from dead dolphins brought on board with the tuna, and therefore represent a sub-sample of the total mortality. The pantropical spotted dolphin, spinner dolphin, and short-beaked common dolphin have been the most frequently killed species in this fishery. The observers recorded species and stock when appropriate and sex of these dolphins along with the date and geographic location of the set. Total body length was also measured by the observer for most of the dolphins sampled, and for a subset of those, additional biological samples, such as reproductive organs and teeth, were collected.

Beginning in 1974, life history data collection procedures were standardized, and the original sampling scheme that selectively collected large, female specimens was replaced by a less-selective sampling scheme that sampled the first available dead dolphins brought aboard. Instructions and protocols for collecting life history data were the same for NMFS and IATTC observers. Several modifications to the collection of data and samples were made during the course of the program. Procedures for the collection of life history data are described in Perrin *et al*. (1976), and the data forms used to collect the data are included as appendices in Perrin and Oliver (1982). Information about the changes in protocols are largely captured in Oliver (1991), and additional sampling protocol details with updated data forms are available in Myrick (1986) and Jefferson *et al*. (1994). Studies have evaluated potential biases in sample collection, including the under-sampling of calves, protocol changes and sampling techniques (Chivers and Akin 1991, Archer *et al.* 2001, Kellar *et al.* 2013b). Life-history data and other tissues collected are archived at the SWFSC and a list of biological sample types collected is provided in Table 8-1. Osteological material collected are archived in museums (see Perrin and Chivers 2011).

Table 8-1. Summary of biological samples collected with the primary preservative and use for each.

Sample	**Preservative**	**Study type**
Carcass	Frozen	Morphology
Head	Frozen	Morphology
Teeth	Formalin	Age
Gonads	Formalin	Reproduction
Stomachs	Frozen	Food habits

Data for Stock Definition

An important part of population assessment is defining the population. Stock delineation for dolphin species in the ETP has changed over the years as new information on morphology, distribution, and genetics has been collected. Currently three stocks of spotted dolphins (*Stenella attenuata*) are recognized: coastal (*S. a. graffmani*), northeastern, and western/southern (Figure 8-1), three stocks of spinner dolphins (*Stenella longirostris*) are recognized: Central American (*S. l. centroamericanus*), eastern (*S. l. orientalis*), and whitebelly (Figure 8-2), and three stocks of short-beaked common dolphins (*Delphinus delphis*) are recognized: northern (which includes a separate sub-species, the long-beaked common dolphin, *D. delphis bairdii*), central, and southern (Figure 8-3).

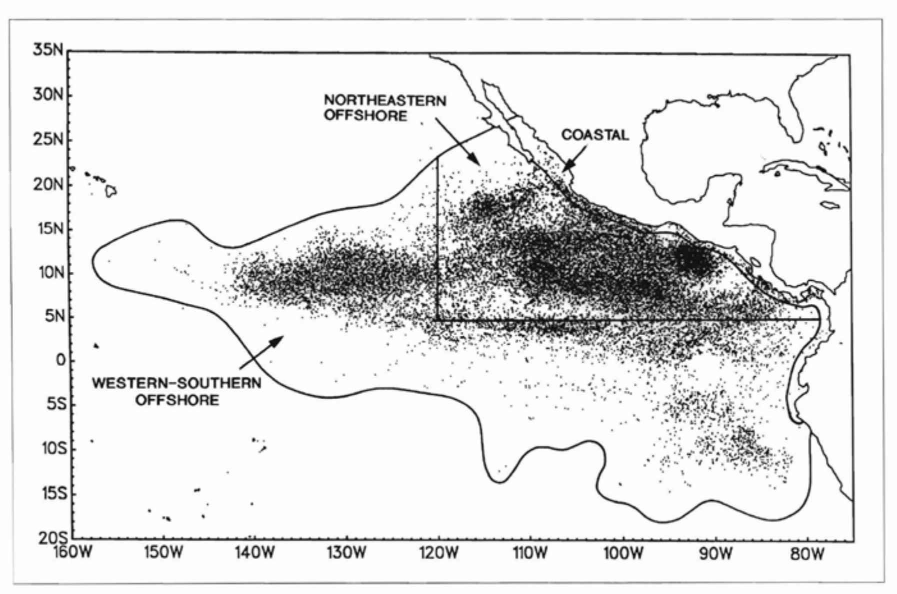


Figure 8-1. Spotted dolphin stocks (Dizon et al. 1994).

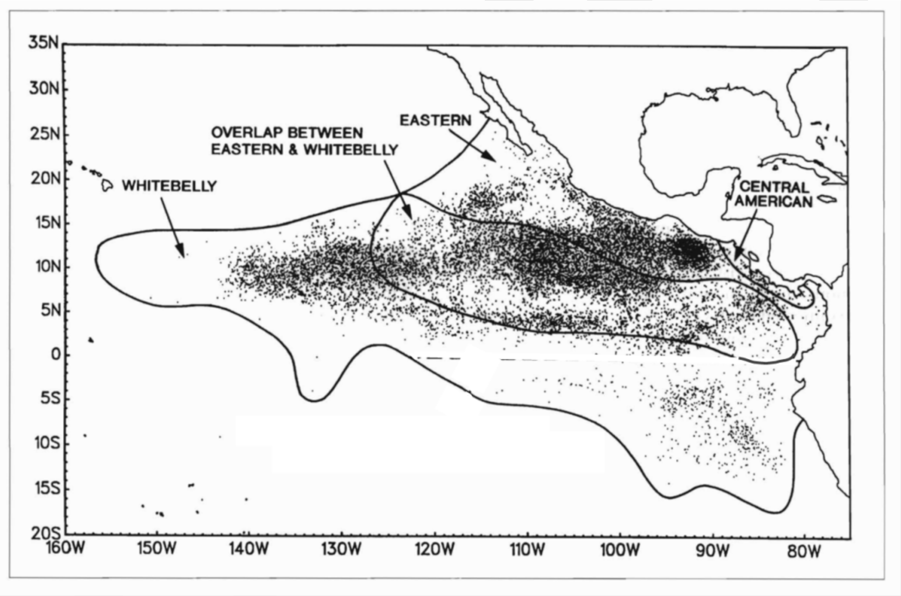


Figure 8-2. Spinner dolphin stocks (Dizon et al. 1994).

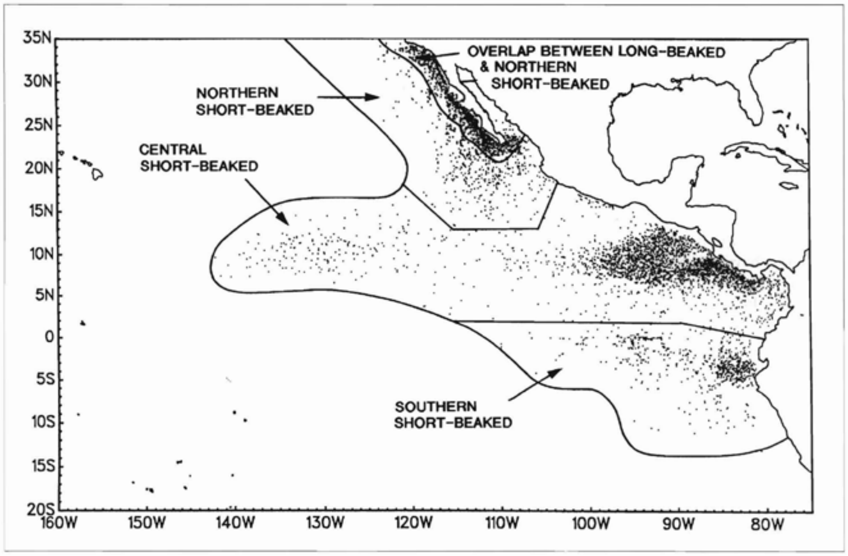


Figure 8-3. Common dolphin stocks (Dizon et al. 1994).

However, there are questions about whether the current boundary between the northeastern and western/southern spotted dolphins is valid (Gerrodette *et al*. 2008), and whether there are additional stocks of coastal spotted dolphins (Escorza-Treviño *et al*. 2005) or island-associated spinner dolphins (Perryman and Westlake 1998).

The first ETP dolphin stocks recognized for management were based on patterns in morphological variation and hiatuses in distribution (see Perrin *et al*. 1984, Dizon *et al*. 1994). The morphological studies that formed the basis for the initial identification and description of populations to manage used data from skulls collected during the 1970s, primarily, and 1980s (Schnell *et al*. 1982; 1985; Douglas *et al*. 1984; 1992; Perrin *et al.* 1991). Osteological specimens were collected by observers through 1992. The carcasses and skulls were prepared at the SWFSC or the National Museum of Natural History and dispersed to museums in several countries. Skulls and complete skeletons (n = 2,434) are archived at 17 museums (Perrin and Chivers 2011).

Age-based Studies

The life history studies of ETP dolphin species have provided age-based reproductive parameters. The combination of age and reproductive data can yield average ages at attainment of sexual maturity, an important life-table and population modelling input. Stock-specific age distributions (Figure 8-4) have revealed that some age classes are more vulnerable to the fishery than others. For example, the under-representation of calves in the age distributions has been investigated to further understand how the fishery might impact reproductive rates or juvenile survival of dolphin populations (*e.g.*, Archer *et al*. 2001). The age distributions are also for population modelling and have been used to refine estimates of mortality and pre-exploitation abundance (Wade 1991, Wade 1993a, b, Wade 1995, Archer *et al*. 2004, Wade *et al*. 2007). For the latter, body length and spotted dolphin color phase have also been used as proxies for age (*e.g.*, Archer and Chivers 2002, Archer *et al*. 2004).

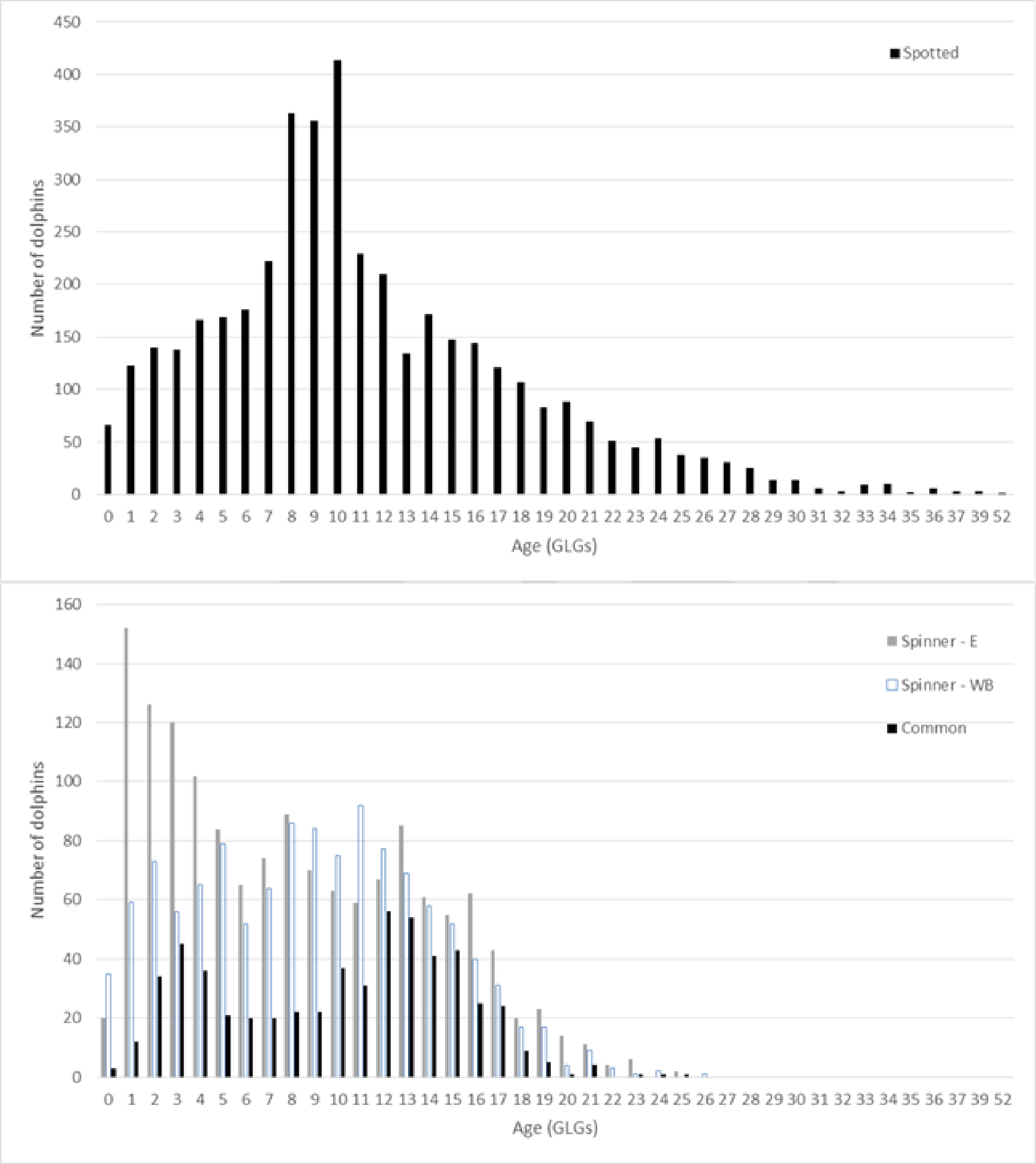
Age was determined by counting growth layer groups (GLGs) in the dentine and cementum of the prepared tooth sections (Myrick *et al*. 1983). GLGs have been interpreted as annual events based on conclusions from calibration experiments on captive Hawaiian spinner dolphins (Myrick *et al*. 1984) and known-age bottlenose dolphins (*Tursiops truncatus*) from the wild (Hohn *et al*. 1989; Hohn 1990), and this model continues to be considered the appropriate model for small delphinids (Hohn 1990; Hohn *et al.* 2016). Table 8-3 provides a summary of NMFS-archived tooth samples.

Hard tissues, such as teeth and bone, not only provide opportunities to estimate age from annual layering patterns, but can serve as recording structures representing the physiological condition of an individual at the time of deposition. It is possible, thus, to decode those conditions when evaluating the characteristics of the tissue and, specifically, to identify life-history parameters (Lieberman 1993). Across a range of mammalian species, including terrestrial mammals, pinnipeds, and cetaceans, Klevezal (1996) summarized structural changes in bone and teeth that correlate with weaning, changes in growth rate, and sexual maturation. Decreases in the width of annual growth layer groups (GLG) have been shown to correspond to decreases in somatic growth rate with age. In particular, a notable change in GLG width in teeth has been shown to correlate with the onset of sexual maturation; that change has been referred to as the transition zone, following terminology of Lockyer (1972) who identified a similar phenomenon in earplugs from baleen whales. Hohn (1980) identified an abrupt change in GLG width coincident with the decrease in growth rate in *Tursiops*. Markers that coincide with the onset of sexual maturation have been found in sperm whales, harbor porpoise and bottlenose dolphins (Gaskin and Blair 1977, Hohn 1980; Luque *et al.* 2013; Hohn, unpub. data). In spotted dolphins from the ETP, Klevezal and Myrick (1984) identified deeply stained bands occurring at the estimated age at sexual maturation, as well as marker lines indicative of parturition.

Table 8-2. Annual collection of dolphin teeth.

Year	***S. attenuata***	***S. longirostris***	***D. delphis***	**Annual Totals**
1966	2	0	1	3
1968	67	18	0	85
1969	10	10	1	22
1970	28	22	7	63
1971	205	165	94	464
1972	904	182	43	1,130
1973	2,074	1,246	303	3,623
1974	1,568	850	170	2,588
1975	298	1,136	155	1,590
1976	1,503	816	117	2,436
1977	1,662	666	314	2,642
1978	886	336	63	1,287
1979	883	318	230	1,432
1980	636	185	34	855
1981	575	240	95	913
1982	854	245	48	1,147
1983	309	178	36	527
1984	428	155	5	588
1985	900	400	95	1,395
1986	574	215	35	825
1987	1,316	677	88	2,082
1988	1,042	630	197	1,869
1989	1,718	1,080	310	3,109
1990	693	408	52	1,153
1991	145	63	41	249
1992	108	45	8	163
1993	20	9	6	36
1994	36	15	0	51
Totals	19,444	10,310	2548	32,327

Figure 8-4. Age distributions for female pantropical spotted dolphins (n = 4,189), eastern spinner dolphins (n = 1,477 eastern (labeled "Spinner – E") and 1,201 whitebelly spinner dolphins (labeled "Spinner – WB") and short-beaked common dolphin (n = 568). Aged specimens were collected between 1968 and 1993 although most of those aged (68%) were collected between 1973 and 1977.



Reproduction

The reproductive characteristics (*e.g.*, pregnancy rates and calving interval) of the dolphin populations impacted by the fishery have been published (Perrin *et al*. 1976, Perrin *et al*. 1977a; 1977b, Perrin and Henderson 1984; Hohn *et al*. 1985, Myrick *et al*. 1986, Chivers and Myrick 1993; Danil and Chivers 2007; Larese and Chivers 2009). Additional references present analyses of the biological data to estimate reproductive rates and/or population growth rates (Henderson *et al.* 1980, Reilly and Barlow 1986, Wade 1993b) and other biological characteristics of pelagic dolphin species, including organ weights (Perrin and Roberts 1972).

Gonads collected from individual dolphins were processed and examined at the SWFSC to determine reproductive maturity (Figure 8-5 and Table 8-2). In summary, the presence of one corpus or more in the ovaries indicates sexual maturity in females (see Perrin and Reilly 1984), and evidence of spermatogenesis in histologically prepared testes tissue indicates sexual maturity in males (*e.g.*, Hohn *et al*. 1985). Details of the ovary processing techniques are in Akin *et al.* (1993). Proxies of sexual maturity using dolphin size and gonad weight (*e.g.*, average length, or gonad weight at attainment of sexual maturity) have also been developed for use when gonads were not collected or examined.

Figure 8-5. Proportion of sexually immature and mature females identified by examination of ovaries collected by scientific observers, 1966-1994, for the three most frequently killed stocks: pantropical spotted dolphin (n = 9,035), eastern spinner dolphins (n = 1,894 "Spinner – E") and whitebelly spinner dolphin (n=1,931 "Spinner – WB") and short-beaked common dolphin (n = 993).

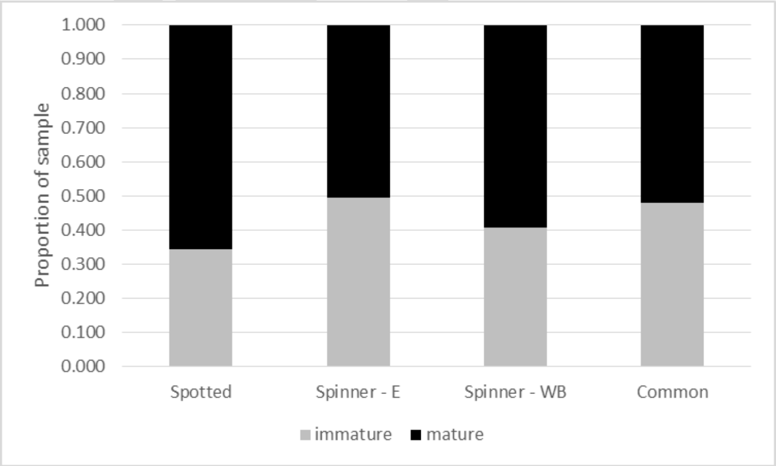


Table 8-3. Annual collection of gonads from male and female dolphins incidentally killed in the eastern tropical Pacific yellowfin tuna purse-seine fishery.

Year	***S. attenuata***	***S. longirostris***	***D. delphis***	**Annual Totals**
1966	2	0	0	2
1968	59	14	0	73
1969	6	10	0	16
1970	23	19	1	49
1971	190	131	84	424
1972	576	128	35	740
1973	1,342	698	244	2,386
1974	1,397	707	197	2,309
1975	813	1,013	139	1,967
1976	975	713	115	1,804
1977	925	374	297	1,600
1978	689	242	67	1,001
1979	799	282	214	1,297
1980	536	170	26	732
1981	487	178	86	757
1982	705	211	41	957
1983	215	107	24	349
1984	316	128	3	447
1985	718	313	82	1,114
1986	487	187	26	706
1987	1,098	573	80	1,755
1988	928	555	199	1,687
1989	1,471	927	301	2,712
1990	543	311	52	906
1991	103	41	40	184
1992	98	33	3	136
1993	19	9	5	34
1994	27	12	0	39
Totals	15,547	8,086	2,361	26,183

Food habits

Dolphin stomach contents were first collected during small-scale studies in the 1960's; Fitch and Brownell (1968) found a diverse number of prey species for several cetacean species and made inferences about feeding depths and times. Perrin *et al.* 1973 revealed that yellowfin tuna, spotted dolphins, and spinner dolphins that were caught in the same sets by purse seiners had consumed some of the same prey items. Since then, food-habits studies conducted by NMFS and the IATTC have greatly contributed to our understanding of overlaps in diet, feeding depths, feeding times, and ecology of yellowfin tuna and dolphin species (Roberts 1994; Robertson and Chivers 1997; Scott and Cattanach 1998; Scott *et al.* 2012), and apparent maternal changes in diet during lactation (Bernard and Hohn 1989).

Analyses of stable carbon and nitrogen isotopes provided a means of measuring trophic overlap that is integrated over a longer period of time than that indicated by stomach contents. An analysis of the stable-isotope data from the study was conducted by Román-Reyes (2005). An analysis of the diet data of co-occurring yellowfin tuna and dolphins showed that the benefits of the tuna-dolphin association were not based on feeding advantages (Scott *et al.* 2012). Studies have also provided information on community-level trophic interactions in the ETP for dolphins, sharks, billfishes, dolphinfishes, wahoo and other tunas (Galván-Magaña 1999, Olson and Galván-Magaña 2002; Olson and Watters 2003, Dambacher *et al.* 2010; Hunsicker *et al.* 2012, Griffiths *et al.* 2013, Duffy *et al.* 2015). The dolphin food habits data that have been apart of these studies of trophic relationships within the ETP and broader ecosystem models have helped define the ecosystem linkages leading to tuna production and the effect of climate variability on fisheries production.

Observers have collected stomachs from a subset of dolphins killed and available on the deck of the purse seiner for biological sampling (Tables 8-4 and 8-5). Stomachs were stored frozen for later processing in a laboratory, which included weighing before and after removal of contents, and identification of the prey remains found in the forestomach. Samples of muscle and liver tissues were also collected on some trips for stable isotope analyses.Stable carbon and nitrogen isotope ratios in the musculature of dolphins were analyzed in two stages. Preliminary analyses were made on 6 *S. attenuata* and 5 *S. longirostris* sampled during 1993. Román-Reyes (2005) analyzed the stable isotopes in 14 *S. attenuata* sampled in 1993 and 8 in 1994, and 8 *S. longirostris* sampled in 1993 and 6 in 1994. Stable isotope analyses were also made on tunas that were also caught in the same purse-seine sets by Román-Reyes (2005).

Population status is affected by the carrying capacity of the environment and the effects of climate change. Stomach samples of ubiquitous generalist predators, such as the tunas, have been used to infer changes in pelagic food webs on a scale that may affect the carrying capacity of the ecosystem. Prey populations that support upper-level predators have been shown to vary over time, and some prey impart considerable predation pressure on animals that occupy the lower trophic levels. A comprehensive analysis of predation by yellowfin tuna on a decadal scale in the EPO was conducted by Olson *et al*. (2014). For the majority of the yellowfin stock in the EPO, a major diet shift was apparent during the decade. Widespread reductions in biological production, changes in phytoplankton community composition, and a vertical expansion and intensification of the oxygen minimum zone appeared to alter the food webs in tropical and subtropical oceans (Behrenfeld *et al.* 2006, Polovina *et al.* 2008, Stramma *et al.* 2008, Polovina and Woodworth 2012, Stramma *et al.* 2012).

Table 8-4. Annual summary of dolphin stomachs collected for NMFS with prey identified.

Year	***S. attenuata***	***S. longirostris***	***D. delphis***	**Annual Totals**
1971			1	1
1973	1			1
1974				
1975	4	7		11
1976	1	1		2
1977	9	2		11
1978	33	5	3	41
1979	11	1	4	16
1980	12	1		13
1981	9	5	1	15
1982	18	16	1	35
1983	17	16		33
1984				
1985	88	3		91
1987	18			18
1988	2	1		3
1989	255	9	1	265
1990	167	4		171
1991	22	10		32
1992	4	2		6
1993	10		1	11
Totals	681	83	12	776

Table 8-5. Annual summary of dolphin stomachs collected for the IATTC with prey identified.

Year	*S. attenuata*	*S. coeruleoalba*	*S. longirostris*	*D. delphis*	Annual Totals
1992	11		7	1	19
1993	37	3	22	3	65
1994	19		7	1	27
2004	1				1
Totals	68	3	36	5	112

Potential costs: Dolphins that have died during fishing operations can be sampled or collected by observers already aboard tuna vessels. The approximate cost for re-instating the sampling program aboard tuna vessels would be $255,000 for each of the first two years, but costs should decrease in subsequent years. One disadvantage is that, because current mortality is so low, the data collection would need to be long-term and continuous to gather a sample size adequate to compare with older data, and to provide ongoing monitoring of the population in the future. The observer collections could supply samples for all of the above life history projects: osteological, age estimation, reproduction, and food habits. Additional funds, approximately $150,000 per year, would be needed to process the samples collected for further life history studies. Laboratory analysis costs for a retrospective study of existing samples to determine whether the age of sexual maturity can be estimated from GLGs in teeth of ETP dolphins would be $60,000.

Sampling of free-ranging dolphins can be done using biopsy and molecular-marker techniques or photogrammetric techniques to evaluate reproductive output, body condition, and potential exposure to stressors. These have been typically a part of the suite of studies conducted by NMFS during cetacean and ecosystem surveys. Sampling dolphins encircled by purse-seine nets could be also be done at the cost of sending an additional scientist or observer aboard purse seiners.

9) Ecosystem Research

(Paul Fiedler, Lisa Ballance)

SWFSC has conducted systematic cetacean line-transect surveys in the ETP since 1986 and ecosystem sampling has always been a part of these surveys (Tables 9-1 and 9-2). The purpose of this sampling has been to facilitate the interpretation of dolphin population trends detected by these abundance surveys, and to provide an ecosystem context for understanding the biological basis of dolphin distribution and abundance. The data have been directly applied to ETP dolphins in assessing causes for the delayed recovery of dolphin stocks for the IDCPA (Reilly *et al*. 2005) and to construct predictive species distribution models for managing risk (*e.g*., Forney *et al.* 2012).

NOAA’s National Centers for Environmental Information collect and make accessible a large amount of oceanographic data collected from research vessels, satellites, and buoys. These data assist in interpreting trophic relationships in the ETP. Spotted, spinner, and common dolphins are predators that feed at a range of trophic levels, but they feed closer to the top of the food chain than the bottom. For these species, relationships to physical features can be (but are not always) indirect, likely mediated by the responses of their prey (and the prey of those prey, in turn) to these physical features. These species are “K-selected,” meaning that they are relatively long-lived, have delayed reproductive maturity, and low reproductive output. This suite of life history traits generally buffers species from environmental perturbation compared to those with shorter lives and higher reproductive output (“r-selected species”). Therefore, oceanographic variation on seasonal and interannual scales is expected to be reflected more by changes in distribution or reproductive output, than by changes in survival. Finally, these species are all year-round residents of the ETP, so that ecological variations within that region can impact all life processes. However, their motility might allow them to move spatially as physical and biological characteristics of water masses change in space and time, so as to remain within their preferred habitat. Predictive models of responses to climate change - in distribution or abundance - are likely applications of ecosystem research data in future work.

The ‘‘tuna-dolphin-seabird assemblage’’ illustrates importance of an ecological context for monitoring eastern tropical Pacific dolphins. This is a multi-species symbiotic association between yellowfin tuna, spotted and spinner dolphins, and a relatively large number of seabird species (Ballance *et al.* 2006, and references therein). The tuna and dolphins in this assemblage occur in mixed-species schools, and are accompanied by flocks of seabirds which feed on prey made available at the surface by the subsurface predators. The primary benefit of the association to tunas and dolphins, however, appears to be predator avoidance (Scott *et al*. 2012).

Potential costs: Ecosystem monitoring has been an integral part of the NMFS line-transect surveys (cost estimated in Section 2). However, for any dolphin monitoring method adopted as an alternative to shipboard line-transect counting, ecosystem research data should continue to provide useful supporting information.

Table 9-1. Ecosystem data collected on NMFS cetacean and ecosystem assessment surveys.

Sampling Method	**Data/Description**
XBT	Temperature profile
CTD	Temperature/salinity profile
Hydrocast	Chlorophyll/phaeophytin, ^{14}C primary productivity, Salinity, Nutrients
Bucket and CTD surface bottle samples	Surface chlorophyll
TSG	Continuous surface temperature and salinity
Flow-through fluorometry	Continuous surface fluorescence
ADCP	Current strength and direction
Multi-frequency acoustic backscatter	Macrozooplankton and fish biomass indices
Towed Nets: manta, bongo, ring net, IKMT	Plankton, Larval fish, Halobates
Dipnet	Flyingfish, myctophids, squids
Visual 300-meter strip transect survey	Seabirds, marine turtles, flyingfish
Visual line-transect survey	Cetaceans (in addition to focal dolphin stocks), marine turtles, seabird feeding flocks
Small boat captures for marine turtles	Stomach, blood, skin, ectoparasite samples, Ultrasound images, Satellite tracks, morphological measurements

Table 9-2. Sample sizes collected for ecosystem variables on NMFS cetacean and ecosystem assessment surveys.

	XBT drops	**CTD casts**	**Chl samples**	**PP samples**	**Manta tows**	**Bongo tows**	**Other tows**	**Fish samples**	**Turtles counted**
1986	1144	294	3763	-	-	-	-	778	1041
1987	1160	280	1927	-	178	-	-	1663	249
1988	835	352	3613	-	149	-	-	1077	165
1989	778	352	3552	-	166	-	-	1107	574
1990	809	368	4448	1180	175	-	-	1428	279
1992	196	430	1916	735	116	-	-	1218	847
1998	895	547	6779	1858	261	167	89	3341	1443
1999	655	393	4668	1306	196	69	78	2161	1001
2000	659	412	4837	1382	193	166	88	2861	940
2003	736	371	2244	-	158	156	-	3725	2141
2006	526	297	3409	-	187	147	-	3818	361

10) Population Stress

(Michael Scott, Karin Forney, Cleridy Lennert-Cody)

Indices of population condition could potentially be developed from individual stress markers as an ancillary measure of population status. A series of studies was conducted by NMFS during 1999-2001 to determine whether fishery-related stress can be detected, whether stress is a possible mechanism to explain mortality and/or reproductive suppression, and whether stress could affect dolphin population status (Reilly *et al*. 2005). During the CHESS research cruise (Forney *et al*. 2002; St. Aubin *et al.* 2013) blood samples were collected to look for biochemical signs of stress in dolphins that were chased and encircled during tuna purse-seiner operations. A necropsy study to find indications of stress-related mortality was undertaken by NMFS (Cowan and Curry 2002). Mechanisms of stress-related mortality and injury (*i.e.*, cardiac injury) were identified and described in the sampled dolphins, but sample sizes from the stress studies were too low to conclude whether population level effects were occurring (Table 10-1). Additionally, biopsy skin samples were collected during NMFS research cruises and examined for potential stress-responsive proteins. However, recent developments to quantify steroid hormones has provided a newer tool to evaluate exposure to potential stressors (Kellar *et al.* 2015).

Table 10-1. Sampling for stress-related studies.

Study	**Study Years**	**Hematology and Serum Chemistry**	**Necropsy**
Cowan and Curry (2002)	1999-2001		56
St. Aubin *et al.* (2013)	1999-2001	72	

These studies could be expanded to gather greater sample sizes. Prior to additional studies, however, preliminary research would be necessary to:

a) establish a direct relationship between any individual-dolphin stress metric and population condition or status (*e.g.*, Kellar *et al*. 2015);

b) establish if stress measures could be differentiated between general stress, the cumulative effects of all possible stressors, and stress specific to fishery operations;

c) establish a sampling design and sample size requirement.

Potential costs: Once the above study determines that an extension of the CHESS study is feasible, and an experimental design is determined, potential costs can be estimated. The two-month-long CHESS cruise cost about $3.5M.

The cost of re-initiating the necropsy study would be comparable to the life history sampling, about $0.5M for two years of sampling (not including laboratory costs to analyze the samples).

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