INTER-AMERICAN TROPICAL TUNA COMMISSION
COMISIÓN INTERAMERICANA DEL ATÚN TROPICAL

Special Report 23
Informe Especial 23

DATA AVAILABLE FOR ASSESSING DOLPHIN POPULATION STATUS IN THE EASTERN TROPICAL PACIFIC OCEAN

DATOS DISPONIBLES PARA EVALUAR LA CONDICIÓN DE LAS POBLACIÓN DE DELFINES EN EL OCÉANO PACÍFICO ORIENTAL TROPICAL

By-Por

Michael D. Scott, Cleridy E. Lennert-Cody, Tim Gerrodette, Susan J. Chivers, Kerri Danil, Aleta A. Hohn, Leanne M. Duffy, Robert J. Olson, Hans J. Skaug, Carolina V. Minte-Vera, Paul C. Fiedler, Lisa T. Ballance, Karin A. Forney, Jenny Hofmeister, Megan C. Ferguson, and Jay Barlow

La Jolla, California, USA

2018

The Antigua Convention, which was negotiated to strengthen and replace the 1949 Convention establishing the Inter-American Tropical Tuna Commission (IATTC), entered into force on 27 August 2010. The IATTC is responsible for the conservation and management of the "stocks of tunas and tuna-like species and other species of fish taken by vessels fishing for tunas and tuna-like species" in the eastern Pacific Ocean, and also for the conservation of "species belonging to the same ecosystem and that are affected by fishing for, or dependent on or associated with, the fish stocks covered by [the] Convention."

The members of the Commission and the Commissioners are listed in the inside back cover of this report.

The IATTC staff's research responsibilities are met with four programs, the Data Collection and Data Base Program, the Biology and Ecosystem Program, the Stock Assessment Program, and the Bycatch Program and International Dolphin Conservation Program.

An important part of the work of the IATTC is the publication and wide distribution of its research results. These results are published in its Bulletin, Special Report, Data Report series, and papers in outside scientific journals and chapters in books, all of which are issued on an irregular basis, and its Stock Assessment Reports and Fishery Status Reports, which are published annually.

The Commission also publishes Annual Reports and Quarterly Reports, which include policy actions of the Commission, information on the fishery, and reviews of the year's or quarter's work carried out by the staff. The Annual Reports also contain financial statements and a roster of the IATTC staff.

Additional information on the IATTC's publications can be found in its web site.

La Convención de Antigua, negociada para fortalecer y reemplazar la Convención de 1949 que estableció la Comisión Interamericana del Atún Tropical (CIAT), entró en vigor el 27 de agosto de 2010. La CIAT es responsable de la conservación y ordenación de las "poblaciones de atunes y especies afines y otras especies de peces capturadas por embarcaciones que pescan atunes y especies afines" en el Océano Pacífico oriental, así como de la conservación de "especies que pertenecen al mismo ecosistema y que son afectadas por la pesca de especies de peces abarcadas por la … Convención."

En la contraportada del presente informe se alistan los miembros de la Comisión y los Comisionados.

Las responsabilidades de investigación del personal de la CIAT son realizadas mediante cuatro programas: el programa de recolección de datos y bases de datos, el programa de biología y ecosistemas, el programa de evaluación de poblaciones, y el programa de captura incidental y el Acuerdo sobre el Programa Internacional para la Conservación de los Delfines.

Una parte importante del trabajo de la CIAT es la publicación y amplia distribución de los resultados de sus investigaciones. Se publican los mismos en sus series de Boletines, Informes Especiales, Informes de Datos, y publicaciones en revistas científicas externas y capítulos en libros, todos de los cuales son publicados de forma irregular, y sus Informes de la Condición de las Poblaciones e Informes de la Situación de las Pesquerías, publicados anualmente.

La Comisión publica también informes anuales y trimestrales, los que incluyen acciones de política de la Comisión, información sobre la pesquería, y resúmenes de trabajo realizado por el personal en el año o trimestre correspondiente. Los informes anuales contienen también un estado financiero y una lista del personal de la CIAT.

Se presenta información adicional sobre las publicaciones de la CIAT en su sitio web.

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CONTENTS

1.   BACKGROUND

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, Punt 2013), and those models have relied on estimates of abundance from fishery-independent cetacean and ecosystem assessment surveys conducted by the Southwest Fisheries Science Center (SWFSC) of the US National Marine Fisheries Service (NMFS) periodically between 1979 and 2006.

Because 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, a Workshop on Methods for Monitoring the Status of Eastern Tropical Pacific Ocean Dolphin Populations was organized (Johnson et al. 2018) to identify methods, both conventional and novel, for monitoring and assessing dolphin stock status.

Experts in the fields of line-transect and mark-recapture surveys, abundance estimation and population modeling, and imagery, tagging, genetics, and life-history methods were brought together to discuss potential options for monitoring dolphin populations.

This document was prepared for, and revised after, the Workshop, and 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 fishery-dependent data from ship-board observers on marine mammal sightings, purse-seine fishing operations, dolphin and tuna life history, dolphin mortality, plus long-term fishery-independent data from cetacean and ecosystem assessment surveys. This document focuses on stocks of the three species with greatest historical involvement with the fishery: pantropical spotted dolphins (*Stenella attenuata*), spinner dolphins (*Stenella longirostris*), and common dolphins (*Delphinus delphis*). This document also describes data types that the Workshop identified as having potential for future assessments of dolphin population status.

2.   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 are recognized: coastal (*S. a. graffmani*), northeastern, and western-southern (Figure 2-1), three stocks of spinner dolphins are recognized: Central American (*S. l. centroamericanus*), eastern (*S. l. orientalis*), and whitebelly, a hybrid of eastern and Gray's spinner dolphins (Figure 2-2), and three stocks of short-beaked common dolphins are recognized: northern (a management unit that includes a separate sub-species, the long-beaked common dolphin, *D. delphis bairdii*), central, and southern (Figure 2-3).

ETP dolphin stocks have historically been recognized for management 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 = 2,454) are archived in 17 museums (Perrin and Chivers 2011).

**FIGURE 2-1.** Stocks of spotted dolphins (*Stenella attenuata*) in the ETP (Dizon *et al*. 1994).
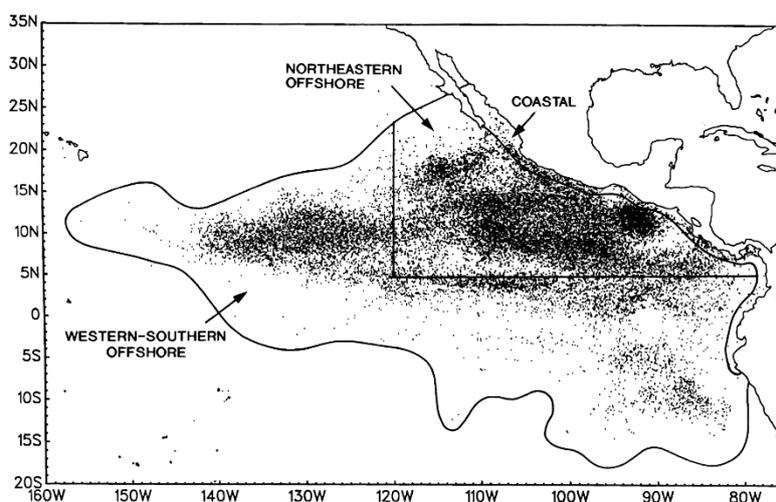
FIGURE 2-2. Stocks of spinner dolphins (*Stenella longirostris*) in the ETP (Dizon *et al*. 1994).
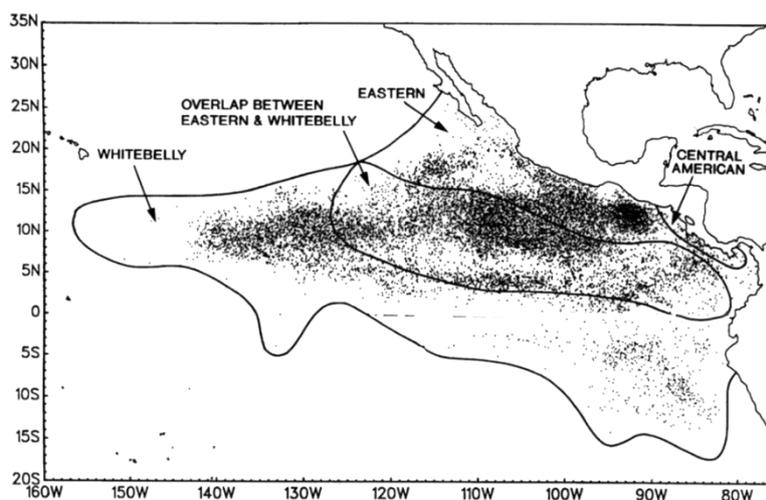
FIGURE 2-3. Stocks of common dolphins (*Delphinus delphis*) in the ETP (Dizon *et al*. 1994).
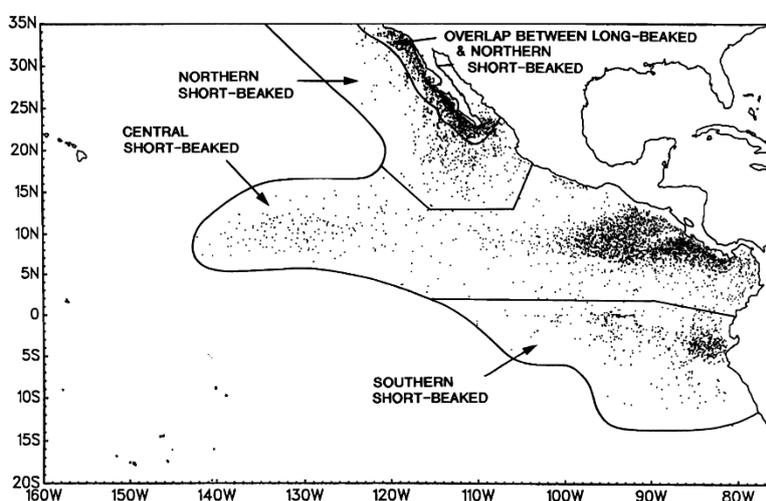
More recently, however, questions have been raised about whether the current boundaries between the northeastern and western/southern spotted dolphins are valid (Gerrodette *et al*. 2008), and whether there are additional stocks of coastal spotted dolphins (Escorza-Treviño *et al*. 2005; Leslie *et al*. in press) or island-associated spinner dolphins (Perryman and Westlake 1998; Chivers *et al*. in press; Leslie *et al*. in press).

3.   DOLPHIN INCIDENTAL MORTALITY DATA

Dolphin incidental mortality data have been collected since the mid-1960s, 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 (IATTC), pers. comm.). Monitoring 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 vessels fishing on tunas with dolphins (Wahlen 1986). The IATTC began placing observers aboard vessels 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

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

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 at 100% under the auspices of the Agreement on the International Dolphin Conservation Program (AIDCP). The AIDCP observer program in the ETP combines the efforts of IATTC observers, the 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, and thereafter in documents for meetings of the Parties to the AIDCP, *e.g.*, IATTC 2016). Small purse-seine vessels have only rarely been sampled by observer programs since the early 1980s; 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 are the number and species of dolphins killed during the set. Additional information is collected on sex and size composition of the kill of spotted dolphins but not for other species. 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 had been based on ratio estimators, including dolphin mortality-per-set and dolphin mortality-per-ton of tuna. The most recent dolphin incidental mortality estimates used 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 (Wahlen 1986; Wade 1995; Wade *et al*. 2007; Lennert-Cody *et al*. 2013).

Despite complete observer coverage of trips by large purse-seine vessels in recent years, it has been suggested that mortality estimates are biased low. Potential mechanisms that could lead to an underestimate of mortality include: unobserved or misreported mortality occurring during fishing operations of large purse-seine vessels; unobserved mortality occurring after fishing operations of large purse-seine vessels; unobserved fishing on tunas associated with dolphins by small purse-seine vessels; and, reproductive suppression due to a variety of causes (Archer *et al*. 2001; 2004; 2010; Reilly *et al.* 2005; Lennert-Cody and Berk 2007; IATTC 2007; Cramer *et al*. 2008; Kellar *et al*. 2013a; Lennert-Cody *et al*. 2013).

4. CETACEAN LINE-TRANSECT DATA FROM NOAA RESEARCH VESSEL SURVEYS

Line-transect surveys conducted by NMFS in the ETP 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 (Table 4-1), 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. These whole-area surveys were conducted annually during 1986-1990 and then, with a different stratification to reflect revised stock boundaries in 1998-2000, 2003 and 2006. Additional surveys were conducted in 1992, 1993, 2007, and 2009, but each of these had different objectives, provided limited coverage of the ETP and did not contribute to monitoring of the northeastern spotted and eastern spinner dolphins. The most recent ETP dolphin abundance estimates for 1986-2006 are presented in Gerrodette *et al*. (2008).

Detailed discussions of the NMFS line-transect survey design can be found in Kinzey *et al*. (2000), Gerrodette *et al*. (2008), and Lennert-Cody *et al.* (in press).

5. CETACEAN LINE-TRANSECT DATA FROM TUNA VESSEL OBSERVER PROGRAMS

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 capacity. These data in aggregate, which span roughly 40 years, represent thousands of vessel trips and hundreds of thousands of dolphin 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 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. Type of searching gear carried aboard the vessel (*e.g.*, radar, helicopter, high-power binoculars);
b. Estimates of dolphin herd 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 and the ship's location;
d. The cue that led to the sighting (*e.g.*, birds, splashes);
e. The method used to first sight a dolphin group (vessel crew using high-powered binoculars, vessel crew in helicopter, vessel crew using bird radar, or other). Observers report which search method they believe to have first detected the dolphin herd.
f. Date and time of the sighting;
g. If the dolphin herd was seen previously;
h. Whether the dolphin herd is later involved in a purse-seine set, so that the original sighting can be linked to the set information.

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.

Despite the large amount of data collected by onboard observers, not all details of the searching process are documented. The following is a 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 tunas were associated with the sighting, for those sightings that did not lead to a purse-seine set (and the amount of tuna);
d. Best estimates of herd size and species composition for all sightings recorded (best estimates are only made by the observer if the dolphin herd 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 herd 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). Detailed discussion of the serious challenges to developing a reliable index from fisheries observer data, which include non-random distribution of tuna vessel search effort and potential differences in availability of sighting information by search, can be found in Buckland and Anganuzzi (1988) and Lennert-Cody *et al.* (2001, 2016).

6. TAGGING DATA

6.1. Visual tags

Large-scale visual tagging of ETP dolphin species was attempted by NMFS (Perrin *et al.* 1979; Hedgepeth 1985; Table 6-1), but early mark-recapture attempts were hindered by low numbers of tag re-sights due to the tags being too small to be read at a distance, high tag loss, and low tag return rates.

TABLE 6-1. Summary of visual tagging effort for dolphins in the ETP. Counts include radio tags but not re-sights made during active radio-tracking.

Study	Study years	Dolphins tagged (resighted or recovered)		
		Spotted	Spinner	Other
Perrin *et al.* (1979)	1969-1976	2,996 (97)	324 (7)	392
Hedgepeth (1985)	1969-1978	701 (102)	25 (1)	16
Scott and 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).

Mark-recapture analyses to estimate abundance have not been attempted in the ETP. A statistical design for a mark-recapture study of spotted dolphins was described in a contract report to NMFS (Southward and Urquhart 1979). They calculated that for a population of one million dolphins, dedicated seiners would need to mark and recapture 9,500 dolphins during combined tagging and resighting cruises. 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.

The potential for conducting large-scale tagging for mark-recapture analysis was discussed in the Workshop (Johnson *et al.* 2018) and some relevant information to note is:
   a. Currently, the tags most used by cetologists to identify 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 (Figure 6-1). 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) can be applied quickly but are labeled with numbers too small to accurately read from a distance.
   b. Some tag types are often quickly shed. For example, crossbow-propelled spaghetti tags can be applied opportunistically to bow-riding dolphins, but spaghetti tags are shed at a high 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 and may lead to dolphin mortality. 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.

    d. The sample-size requirements calculated by Southward and Urquhart (1979) should be re-examined using modern quantitative methods.

FIGURE 6-1. 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-5 TDR 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).
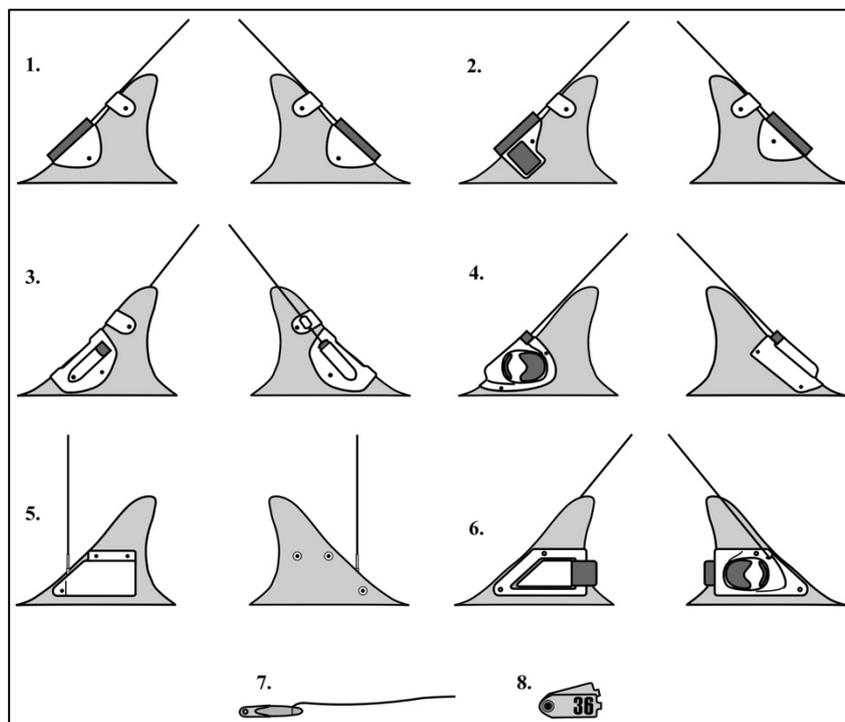
A preliminary one-year study to assess the practicality of large-scale tagging and to estimate the rate of tag loss was proposed at the Workshop (Johnson *et al.* 2018) and at the 36th Meeting of the Parties (IATTC 2017). During two purse-seine cruises, satellite-linked tags would be attached and then monitored to record dolphin movements and premature tag loss.

7. LIFE-HISTORY DATA

Numerous life-history studies have been published describing the morphology and biology of pantropical spotted, spinner and short-beaked common dolphins impacted by the fishery. The age distributions and reproductive rates from these studies can provide basic inputs for integrated population modeling and characterizing fishery selectivity; food habits data have provided insights into trophic relations and environmental changes affecting population condition. Life-history data can provide evidence of population condition when interpreted in light of other data such as current and historical mortality, environmental changes, and previous population estimates. Life-history data can assist in the interpretation of abundance trends when, for example, populations approach the carrying capacity of their environment. This section provides an overview of the life-history data collected and the primary publications describing life-history characteristics of ETP dolphins.

7.1. Biological sampling program overview

U.S. government researchers onboard commercial tuna purse seiners in the ETP collected biological data from dolphins during four fishing trips during the late 1960s. The US observer program began in 1971; life-history data were collected from dead dolphins brought on board, and therefore represent a sub-sample of the total mortality. The original sampling scheme selectively collected large, female

specimens, but life-history collection procedures were standardized in 1974, and the sampling scheme was changed to select the first available dead dolphins brought aboard. The NMFS implemented and coordinated the program at its inception. The IATTC joined the NMFS in placing observers aboard U.S. vessels and collecting life-history data in 1979. Instructions and protocols for collecting life-history data were the same for both NMFS and IATTC observers. Observers recorded dolphin length, sex, and the color phase of spotted dolphins (an indicator of age class, Perrin 1969) and collected reproductive organs (for estimating vital rates), stomach contents (for identifying prey), teeth (for estimating age), and sometimes the entire carcass from over 43,000 dolphins. The NMFS observer program, along with the dolphin life-history sampling program, ended in 1994 as the U.S. fleet moved out of the ETP. AIDCP observers still record body length, girth, sex, and spotted dolphin color phase, but sampling of biological tissues has occurred only occasionally for specific projects.

In recent years the NMFS turned to developing remote sampling technologies and molecular marker techniques to continue its ETP life-history studies. NMFS scientists collected small samples of blubber from wild dolphins using projectile biopsy techniques and developed markers to measure progesterone levels and to identify pregnant female dolphins, and steroid hormone levels to characterize physiological condition (Kellar *et al*. 2006; 2009; 2013a; 2014; 2015). NMFS and IATTC scientists 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 small unmanned aerial vehicles (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.

7.2. Biological data collection

The pantropical spotted dolphin, spinner dolphin, and short-beaked common dolphin have been the most frequently killed and most frequently sampled species in this fishery. 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 tissue samples are archived at the SWFSC, and a list of biological sample types collected is provided in Table 7-1 and sample sizes of lengths, teeth and gonads are presented in Figure 7-1. Osteological material (*e.g.*, skulls and post-cranial skeletons) are archived in museums (see Perrin and Chivers 2011).

TABLE 7-1. 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

FIGURE 7-1. An overview of the life-history data collected by observers, 1966-1994, for females (top)

and males (bottom) of the three most frequently killed species: pantropical spotted, spinner, and short-beaked common dolphins.
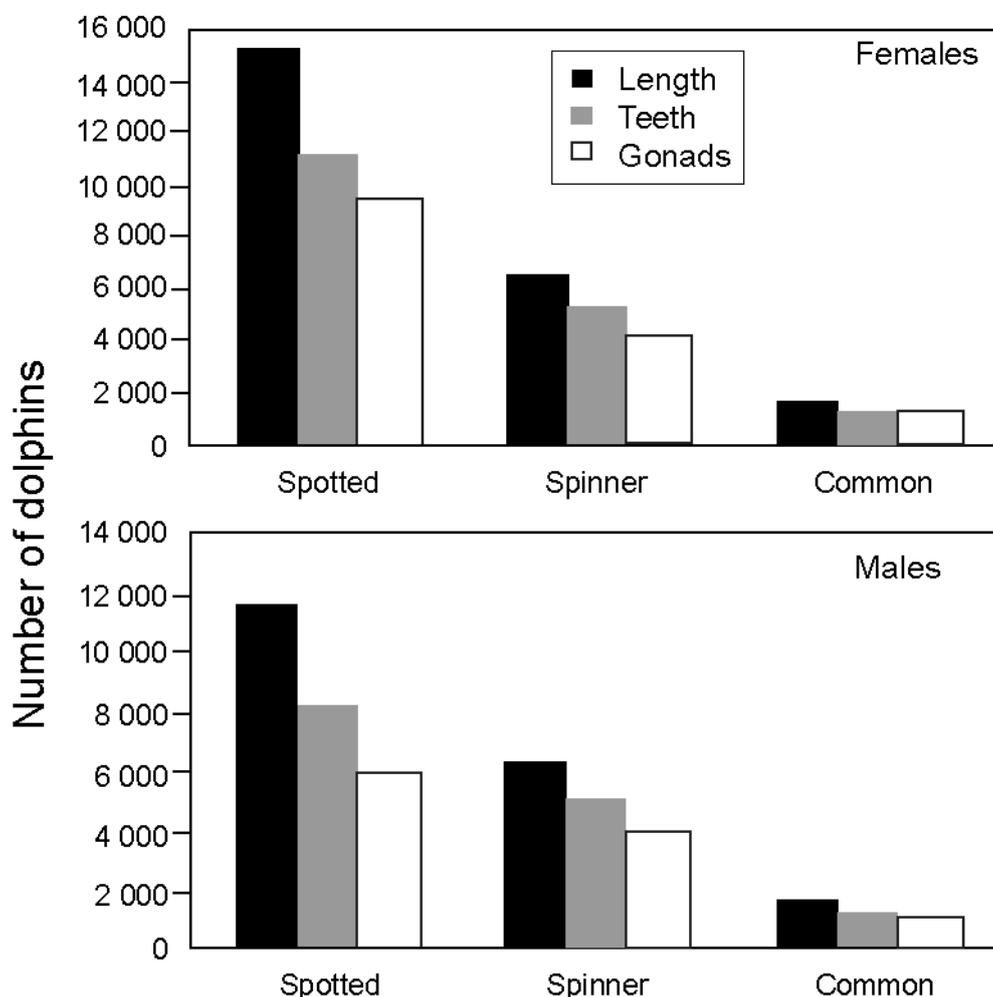
7.3. Age-based studies

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 modeling input. Stock-specific age distributions (Figure 7-2) 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 modeling 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).

FIGURE 7-2. Age distributions for female pantropical spotted dolphins (n = 4,189), eastern spinner dolphins (n = 1,477 eastern (labeled "Spinner – E") and 1,201 whitebelly (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.
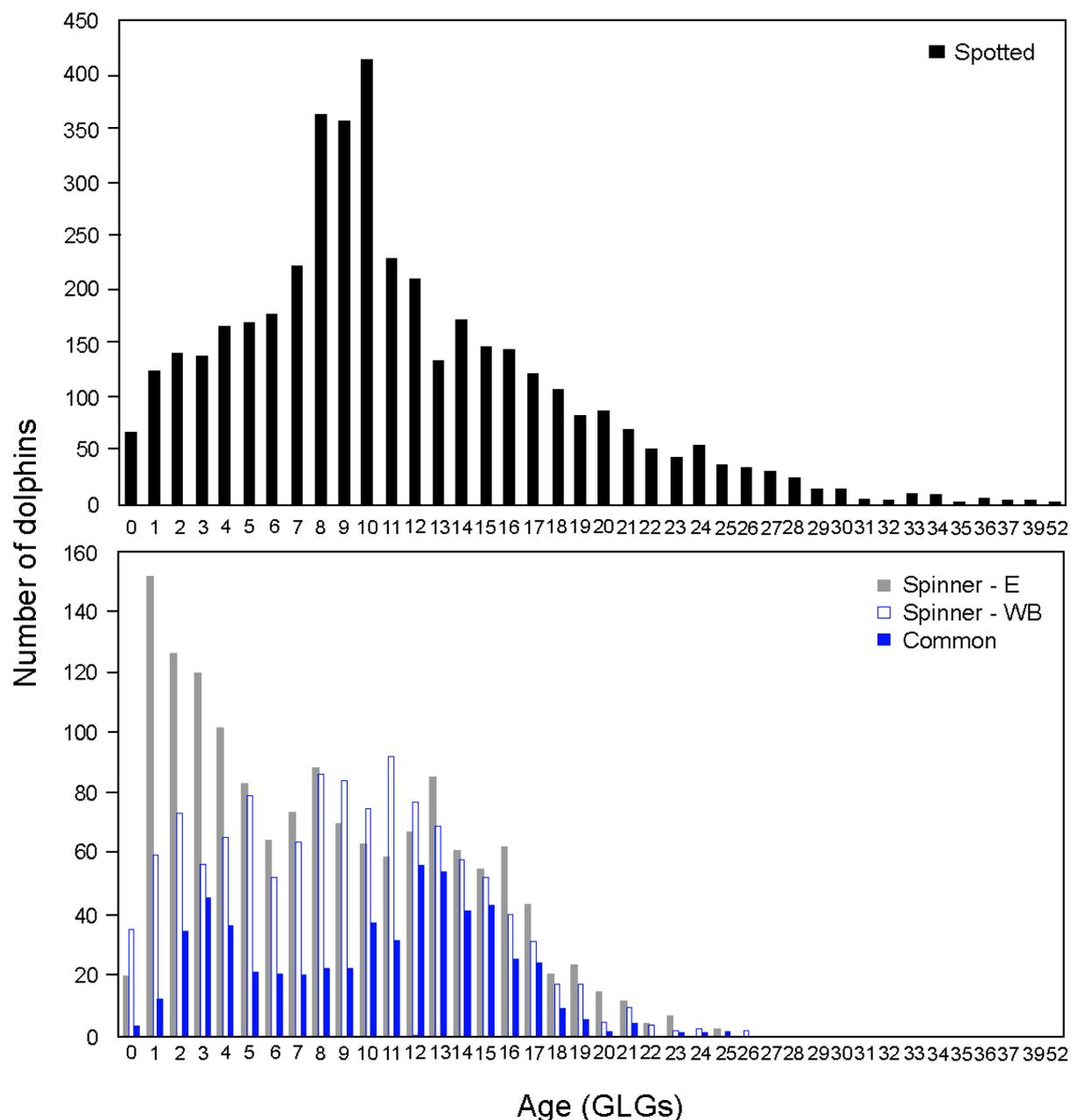
Age was determined by counting growth layer groups (GLGs) in the dentine and cementum of the prepared tooth sections (Myrick *et al*. 1983). GLGs have been interpreted as annual events based on conclusions from calibration experiments on captive Hawaiian spinner dolphins (Myrick *et al*. 1984) and known-age 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 7-2 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 record the physiological condition of an individual at the time of deposition (Lieberman 1993). Across a range of mammalian species, including 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 (GLGs) 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 in the teeth of females coinciding with the births of their young.

TABLE 7-2. Annual collection of dolphin teeth.

	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**	**2,548**	**32,327**

7.4. Reproduction

The reproductive characteristics (*e.g.*, pregnancy rates and calving interval) of the ETP 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 7-3 and Table 7-3). 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 7-3. 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 dolphin (n = 1,894 "Spinner – E") and whitebelly spinner dolphin (n = 1,931 "Spinner – WB"), and short-beaked common dolphin (n = 993).
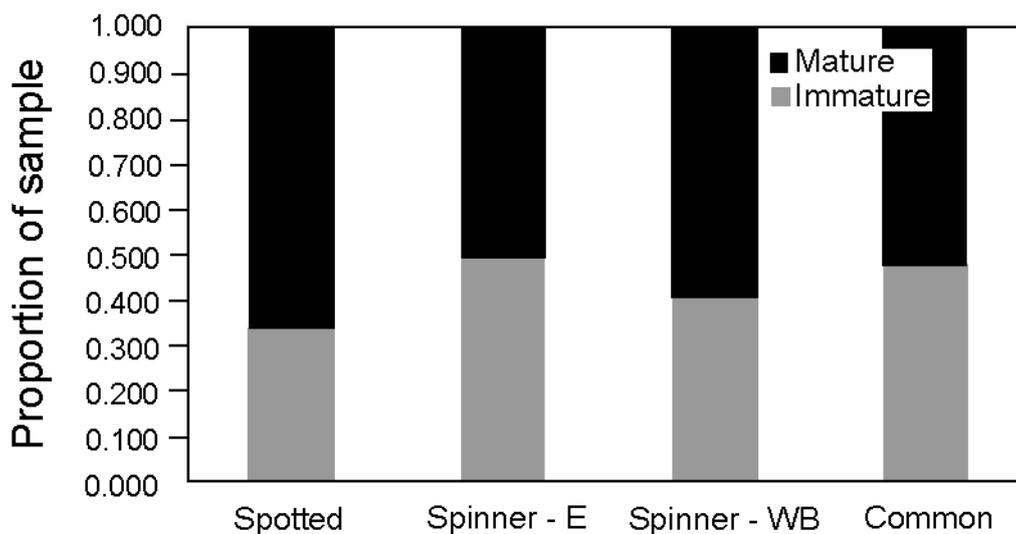
TABLE 7-3. Annual collection of gonads from male and female dolphins incidentally killed in the eastern tropical Pacific yellowfin tuna purse-seine fishery.

	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

	S. attenuata	*S. longirostris*	*D. delphis*	Annual totals
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**

7.5. Food habits

Dolphin stomach contents were first collected during small-scale studies in the 1960s; 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 showed 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 the 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). Food-habits studies have also provided information on community-level trophic interactions, the ecosystem linkages leading to tuna production, and the effect of climate variability on fisheries production in the ETP (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). Stomach samples of generalist predators, such as dolphins and tunas, have also been used to infer changes in pelagic food webs on a scale that may affect the carrying capacity of the ecosystem and the status of populations (Olson *et al*. 2014).

Observers onboard purse seiners have collected stomachs from a subset of dolphins killed and available on the deck for biological sampling (Tables 7-4 and 7-5). Stomachs were stored frozen and later processed in a laboratory where they were weighed before and after removal of contents, and prey remains found in the forestomach were identified. An analysis of 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). Samples of muscle and liver tissues have also been collected on several purse-seine trips for stable isotope analyses. Stable carbon and nitrogen isotope ratios from samples of spotted and spinner dolphins and yellowfin tuna caught in the same purse-seine sets have been analyzed (Román-Reyes 2005). These analyses of stable carbon and nitrogen isotopes have provided a means of measuring trophic overlap that is integrated over a longer period than that indicated by stomach contents.

TABLE 7-4. Annual summary of dolphin stomachs collected for the NMFS with prey identified.

	S. attenuata	*S. longirostris*	*D. delphis*	Annual totals
1971			1	1
1973	1			1
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

	S. attenuata	*S. longirostris*	*D. delphis*	Annual totals
1983	17	16		33
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 7-5. Annual summary of dolphin stomachs collected for the IATTC with prey identified.

	S. attenuata	*S. longirostris*	*D. delphis*	Annual totals
1992	11		7	1
1993	37	3	22	3
1994	19		7	1
2004	1			
Totals	**68**	**3**	**36**	**5**

7.6. Future life-history studies

While the re-initiation of life-history sampling by observers has been encouraged by the Meeting of the Parties to the AIDCP (IATTC 2003, IATTC 2005a, IATTC 2005b), and an updated research design was presented in 2017 (IATTC 2017), the necessary funding has yet to be made available. However, 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 the above life-history projects: osteological, age estimation, reproduction, and food habits.

Sampling of free-ranging dolphins can also be done by combining projectile biopsy techniques and molecular-marker quantification or using photogrammetry to evaluate reproductive output, body condition, and potential exposure to stressors. This type of sampling has typically been a part of the suite of fishery-independent studies conducted by NMFS during cetacean and ecosystem surveys.

8. ECOSYSTEM RESEARCH

Ecosystem research employs both biotic and abiotic information to facilitate the interpretation of dolphin population trends detected by abundance surveys, and provide an ecosystem context for understanding the biological basis of dolphin distribution and abundance. Ecosystem approaches have been used to estimate the environmental impact of different fishery methods (Edwards and Perkins 1998; Hall 1998; Hall *et al.* 2000; Gerrodette *et al.* 2012). Habitat models have been used to study species distribution, risk assessment, and multi-species symbiotic association between yellowfin tuna, spotted and spinner dolphins, and seabirds (Reilly 1990; Ballance *et al.* 2006; Redfern *et al.* 2008; Forney *et al.* 2012). Environmental data has been used to explain dolphin abundance trends (Reilly *et al.* 2005) and the association of tuna and dolphins (Scott *et al.* 2012).

Ecosystem sampling has been a part of the NMFS cetacean line-transect surveys conducted since 1986. The types of data collected during these surveys are listed in Table 8-1, and the sample sizes collected are listed in Table 8-2. Observers aboard purse seiners collect sea-surface temperatures, at least once daily. NOAA's National Centers for Environmental Information also compile and make accessible a large amount of oceanographic data collected from research vessels, satellites, and buoys. All these data can assist in interpreting trophic relationships in the ETP.

TABLE 8-1. 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 8-2. Sample sizes collected for ecosystem variables on NMFS cetacean and ecosystem assessment surveys.

	XBT drops	CTD casts	Chl samples	PP samples	Net tows			Fish samples	Turtles counted
					Manta	Bongo	Other		
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

While oceanographic variation is expected on seasonal and interannual scales that affect dolphin distribution or reproductive output, climate change may bring about longer-term changes. Predictive models of responses to climate change - in distribution or abundance - are likely applications of ecosystem research data in future work.

9. POPULATION STRESS INDICATORS

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 9-1). Additionally, biopsy skin samples were collected during NMFS research cruises and examined for potential stress-responsive proteins. However, recent developments to quantify steroid hormones have provided a newer tool to evaluate exposure to potential stressors (Kellar *et al.* 2015).

TABLE 9-1. Sampling for stress-related studies.

Study	Study years	Results
Cowan and Curry (2002)	1999-2001	Conducted necropsies for stress-related injuries
St. Aubin *et al.* (2013)	1999-2001	Collected hematology and serum chemistry data from live dolphins encircled using a purse-seine set

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.

10. POTENTIAL METHODS FOR MONITORING DOLPHIN POPULATION STATUS

10.1. 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 2005c). 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 modeling (see Lennert-Cody *et al.* 2016).

10.2. 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.* 2017). However, its use for mark-recapture with dolphins, particularly where "resightings" were to be obtained from receivers

aboard tuna vessels, would be non-conventional, 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. However, high-frequency tags (*e.g.*, 180 kHz) that are above the dolphins' hearing range would be required. Detection ranges for high-frequency transmitters are relatively short; 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 tens 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, detection distance, 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 current receivers, data can be recovered remotely, 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 modeling (Lennert-Cody *et al.* 2016).

10.3. 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 being independent of that of adults. Both methods require genetic markers for dolphin species to be developed, and 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). These genetics-based methods can also provide additional information on genetic structure of the population.

Mark-recapture genetics methods could involve a random sampling design to collect the initial samples using either research vessels or dedicated purse seiners, and collect the follow-up (recapture) samples 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.

The Workshop Report (Johnson *et al.* 2018) proposed a 5-year program to collect genetic samples from 50,000 dolphins (Table 10-1) using genetic and close-kin mark-recapture methods. The target of 50,000 dolphins per stock was based on a $20\sqrt{N}$ rule-of-thumb estimate (where N = population size) and assumes an upper limit of about 30 animals could be biopsied per set (based on results achieved

during the NMFS CHESS cruise; Forney *et al*. 2002) from 300-360 sets (10-12 trips) per year, and that a random sampling effort is spread throughout the ETP fishing grounds and throughout the year, yielding about 10,000 samples per year. In addition to the normal observer aboard the selected seiners, 1-2 additional scientists would be required aboard to biopsy the dolphins and store the samples.

TABLE 10-1. Proposed sampling scheme for conventional and close-kin genetic mark-recapture estimation (Table 4 in Johnson *et al*. 2018).

Year	1	2	3	4	5
New marked	2,500	2,500	2,500	2,500	2,500
Surviving marked		2,350	4,559	6,635	8,587
Recaptures		8	15	22	29
Cumulative recaptures		8	23	45	74
CV ($\widehat{N}$) - conventional		0.36	0.21	0.15	0.12
CV ($\widehat{N}$) - close-kin		0.25	0.15	0.11	0.08

10.4. 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 covering large areas such as the ETP. UAVs have been tested in Arctic surveys by a NOAA-led consortium of researchers and agencies (Megan Ferguson, cited in Johnson *et al.* 2018). This study compared observer estimates from manned flights *vs*. imagery estimates from both the manned flight and UAV flights. Beluga whale density estimates from observer data were greater than from the imagery data. While the UAVs do not put human life at risk in hazardous environments, the cost of the survey plus imagery analysis was greater than manned flights. 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 sufficient to cover the ETP, 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 to count individual dolphins and identify species in the imagery?
d. Upon detection of a herd, could the UAV be instructed to circle the herd to gather size information or would it have to continue along the trackline?
e. What are the safety issues of flying an unmanned UAV in areas where purse seiner-based helicopters operate?
f. If a UAV survey is feasible, what would the survey cost?

10.5. Passive acoustic monitoring

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 principal 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 floats (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.

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). 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, survey design and the number of detectors is required to estimate the cost of an acoustic survey.

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