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THE REGIONAL TUNA TAGGING PROJECT CONDUCTED BY THE IATTC DURING 2019-2023: SUMMARY REPORT AND FUTURE DIRECTIONS

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CONTENTS

EXECUTIVE SUMMARY

1) Through financial support provided by the European Union and the IATTC, a series of three tuna tagging cruises were conducted to advance the biological information currently used in stock assessments and to help inform management decisions for the tropical tuna fishery in the eastern Pacific Ocean.
2) While tagging skipjack tuna was the primary objective, considerable numbers of yellowfin and bigeye tunas were tagged during each cruise, throughout the eastern Pacific Ocean.
3) Fishing permits provided from Mexico, Panama, France, and Ecuador were necessary for access to territorial waters and within various marine protected areas where tunas have been historically encountered.
4) Catching live bait in the Gulf of Panama was critical to the overall success of the project and will be critical for future tagging endeavors.
5) During the three tagging cruises conducted during 2019, 2020, and 2022, ranging in durations of 80-89 days, 6,181 skipjack, 1,679 yellowfin, and 265 bigeye tuna were tagged with plastic dart tags. An additional 250 skipjack, 471 yellowfin, and 57 bigeye tuna were tagged with electronic, data logging, archival tags.
6) To date, there have been 1,695 (27.4%) skipjack tuna plastic dart tags returned, of which 19.2% (326) were reported as high confidence. There have been 60 skipjack archival tags returned (24.0%), of which 76.7% (46) were reported as high confidence.
7) To date, there have been 277 (16.4%) yellowfin tuna plastic dart tags returned, of which 44.4% (123) were reported as high confidence. There have been 87 yellowfin tuna archival tags returned (18.4%) of which 81.6% (71) were reported as high confidence.
8) To date, there have been 104 (38.6%) bigeye tuna plastic dart tags returned, of which 72.0% (72) were reported as high confidence. There have been 22 bigeye tuna archival tags returned (35.1%), of which 95.5% (21) were reported as high confidence.
9) The staff offers two recommendations to increase the probability of success for future IATTC tagging programs:
    a. Future tagging efforts will require strengthened cooperation with the tuna fishing industry to achieve the scientific goals of the IATTC. Access to marine protected areas, where tunas have been caught historically, will also be advantageous to future success.
    b. Alternative logistics should be evaluated to improve the success of tagging efforts. Specifically, strengthened cooperation with the fishing industry is needed to expand tagging opportunities by providing access to drifting fish-aggregating devices. Methods for catching tunas with purse-seine gear and then holding tunas to be tagged in pens, similar to methods used in bluefin tuna ranching operations, may also be a viable alternative.
    c. IATTC should consider developing relationships with pole-and-line vessels operating from coastal states to expand tagging opportunities. This should provide access to additional fishing areas, expanding spatial coverage, as well as taking advantage of local expertise.

1. INTRODUCTION

Tropical tuna tagging experiments in the eastern Pacific Ocean (EPO) by the Inter-American Tropical Tuna Commission (IATTC) began in 1955 and continued at regular intervals through 1964. During this time, a total of 90,412 skipjack (SKJ) and 59,547 yellowfin tuna (YFT) were tagged and released throughout the operational range of the fishery, mostly along the coastline, from northern Mexico to northern Chile (Schaefer et al., 1961). Most tunas were captured, tagged, and released from live-bait pole-and-line vessels, both opportunistically during regular fishing trips and during chartered tagging trips. From these releases there were 4,781 SKJ (5.3%) and 8,397 YFT (14.1%) tags returned (Schaefer et al., 1961; Bayliff, 1971; Fink, 1965; Fink and Bayliff, 1970). Between 1964 and 1968, there were only a few tuna tagging cruises undertaken on live-bait pole-and-line vessels. Between 1968 and 1974, there were several tuna tagging cruises undertaken aboard purse-seine (PS) vessels through various types of charter arrangements, principally targeting YFT. During those cruises, 30,290 YFT were tagged and released, and 1,449 tags returned (4.8%; Bayliff, 1973). Tuna tagging cruises continued sporadically aboard PS vessels until 1980. During 1979 through 1981, there were several tropical tuna tagging cruises undertaken on chartered live-bait pole-and-line vessels with tagging conducted from Mexico to Ecuador. From 1981 to 1988, little tagging was conducted except for some limited opportunistic tagging aboard sportfishing vessels. In total, between 1955 and 1988, 127,709 SKJ, 110,205 YFT, and 612 bigeye tuna (BET) were captured, tagged, and released and 12,881 (10.1%), 14,746 (13.4%), and 15 (2.5%) were returned, respectively.

During March to May of 2000 and 2002 to 2006 there were six tuna tagging cruises conducted on a chartered live-bait pole-and-line vessel throughout the equatorial EPO, primarily focused on tagging BET. However, during these cruises there were also considerable numbers of SKJ and YFT tagged with plastic dart tags (PDTs), as well as electronic archival tags (ATs). During these cruises, 19,174, BET, 3,425 SKJ, and 2,234 YFT were tagged and released with PDTs and 8,249 (43.0%), 563 (16.4%), and 405 (18.1%) tags returned. An additional 323 BET, 134 SKJ, 53 YFT were released with ATs, and 162 (50.2%), 7 (5.2%), 8 (15.1%) were returned, respectively (Schaefer and Fuller, 2006, 2009, 2010, 2015, and 2022). The objectives of IATTC tagging efforts were to yield information on the movements and stock structure of BET, SKJ, and YFT (Schaefer et al., 1961; Fink and Bayliff, 1970; Bayliff, 1979; Schaefer et al., 2009; Schaefer et al., 2015; Schaefer and Fuller, 2022), while also providing estimates of their growth (Aires-da-Silva et al., 2015; Bayliff, 1988; Maunder, 2001; Schaefer and Fuller, 2006) and mortality (fishing and natural; Fink, 1965; Bayliff, 1971). During the more recent tagging efforts with the advent of AT technologies, studies of behavior and habitat also became a priority (Fuller et al., 2015, Schaefer and Fuller 2009, Schaefer et al., 2009).

Skipjack tuna are notoriously difficult to assess due to their high and variable productivity (*i.e.,* annual recruitment is a large proportion of total biomass). It is challenging to detect the effects of fishing on the population with traditional fisheries data and stock assessment methodologies. This is particularly relevant for assessing the status of the SKJ population in the EPO, primarily due to the absence of age-composition data, reliable indices of abundance, and high-quality tagging data. Therefore, estimates of abundance and exploitation rates obtained from the tagging programs are essential to produce reliable stock assessments for SKJ. Current assessments for all three species are sensitive to both the absolute level of natural mortality and the age- and sex-specific changes in natural mortality. The assumed levels of natural mortality are based on little information and make unconfirmed assumptions about sex-specific differences. Data from well-designed and executed tagging programs are highly beneficial to provide greater confidence in the current assessments by providing data driven estimates for these key parameters.

In the EPO, PS fleet capacity has increased substantially since 1995 (Fonteneau *et al*., 2013; Scot and

Lopez, 2014), along with catches of SKJ and BET (Anonymous, 2022a). Changes in the fishery dynamics over the past thirty years, coupled with biological uncertainties (growth rates, natural mortality, and stock structure), have made it difficult to assess effects on tropical tuna stocks. Assessments conducted in recent years have shown the need for caution in managing the tuna fishery (Anonymous, 2022b), but above all else, highlight the importance of quality scientific information on which to inform management decisions.

Skipjack and other tropical tunas within large multi-species aggregations associated with drifting fish-aggregating devices (dFADs) in the EPO have been exploited by large PS vessels since about 1994, predominantly between 5°N and 15°S (Fonteneau *et al*., 2013, Lennert-Cody et al., 2018). The practice of deploying dFADs and targeting the associated tunas has increased in efficiency over the past decade, primarily due to c The greatest component of the catch within the dFAD fishery is SKJ, but there is also a substantial catch of small BET and YFT (Anonymous, 2022).

Throughout the Pacific Ocean, PS fisheries focus a large proportion of their efforts on tunas associated with dFADs (Lennert-Cody et al., 2018), a fishing strategy which has evolved to become highly efficient at harvesting the three principal species of tropical tunas. These changes have added to the complexities in calculating indices of species-specific catches per unit of effort for the tuna fishery and thus, have amplified the uncertainty in indices of abundance and management recommendations for these species. While partially attributed to a lack of understanding of the characteristics and dynamics of tuna aggregations which are associated with dFADs, poor longline (LL) indices, a lack of reliable PS indices, and insufficient biological knowledge (growth, stock structure, and mortality) further exacerbate uncertainty. Spatial and temporal dynamics of tuna biology should be thoroughly investigated to quantify several important life-history characteristics, including movements, stock structure, behavior, residence times at dFADs, and vulnerability to fishing gear.

Knowledge of current levels of exploitation, as well as movements, natural mortality, fishing mortality, vulnerability, and growth rates of SKJ, YFT, and BET, are essential for stock assessments. Although stock assessments have been performed for these species in the EPO, there are uncertainties in many of the assumptions and parameter estimates used in these analyses that should be improved upon (Sharma et al., 2020). Valid estimates of these parameters would improve confidence in stock assessments, help quantify the degree of interaction between the PS and the LL fisheries, and better inform managers when considering conservation measures.

1.1. Study Objectives

The objectives of the Regional Tuna Tagging Project (RTTP) were to tag and release 15,000 SKJ, and 2,500 YFT and 2,500 BET with PDTs, and an additional 600 SKJ, and 100 YFT and 100 BET with ATs to establish a large, robust mark-recapture data set which would provide information on movements, stock structure, mortality, and growth. These tagging data and derived biological parameter estimates will be incorporated into integrated assessments and utilized to inform future management decisions. Additionally, efforts will be made to develop methods for deriving indices of abundance within a spatiotemporal tagging model (SAC-14 INF-E).

2. MATERIALS AND METHODS

2.1. Cruise planning

Prior to planning and implementing tagging efforts, the IATTC hosted a workshop of invited experts to review the proposed experimental design of the RTTP. The results from the review were incorporated into the final planning of the experimental design. Having a comprehensive experimental design, IATTC staff began planning the first of three tagging cruises. Using information from the IATTC vessel registry, suitable vessels were identified and individually sent a description of the proposed cruise plan and a desired cruise duration. Only three suitable vessels were identified and invited to submit charter bids for staff consideration. To maintain competitive charter pricing for each tagging cruise, invitations to bid were sent eight months prior to the scheduled departure.

Tagging during 2019, 2020, and 2022 was conducted aboard the US-flagged pole-and-line fishing vessel *F/V Her Grace* (Figure 1). *F/V Her Grace* is a traditional west-coast style pole-and-line vessel, having a steel hull with a 72-foot overall length and a 75-ton carrying capacity, capable of cruising speeds up to 8 knots and a maximum speed of 10 knots. The vessel can carry up to 1,000 scoops (approximately 4-5 tons) of live bait in four separate deck boxes and four wells below deck (fish holds). Operational autonomy, depending on conditions, can be up to 60 days, making *F/V Her Grace* an ideal platform for tagging along the coast and far offshore on the high seas.

Having permits for access to territorial waters of several countries, both for catching bait and tagging tunas, was critical to the success of IATTC tagging campaigns. Obtaining these permits can take considerable time and the process was often initiated six months prior to departure. Over the course of the three tagging cruises, Panama, Mexico, and Ecuador provided permits for catching live bait along coastlines within their territorial waters. Mexico, Ecuador, Costa Rica, Panama, and France (Clipperton Island) provided permits for fishing and tagging within their territorial waters. Additional permits were solicited from and provided by Galapagos National Park (GNP) for access to waters within the GNP and from Costa Rica for access to waters within the Cocos Island National Park. Permits were solicited from Mexico for access to waters within the Revillagigedo Islands National Park; however, due to the exhaustive restrictions detailed in the permit, successful fishing and tagging was unlikely and therefore no time fishing effort was conducted within the park. Access to waters within Colombian territorial waters were sought, as well as access to waters within the Malpelo Island Fauna and Flora Sanctuary; however, while Colombia provided authorization to fish within territorial waters during 2019, access in subsequent years was prohibitively difficult.

While each tagging cruise had different itineraries, catching live bait, specifically anchoveta (*Cetengraulis mysticetus*) in the Gulf of Panama (GOP) where it is seasonally abundant, was consistent among all cruises. Anchoveta has proven to be an extremely hardy and desirable bait fish for live bait pole-and-line tuna fishing operations and has been held aboard for periods exceeding 50 days. During the 2019 cruise, Pacific sardine (*Sardinops sagax*), also a very hardy fish for live bait (although lacking the tolerance for high sea-surface-temperatures [SSTs]; >83°F), was captured off southern Baja California, Mexico. Additionally, in an effort to catch bait closer to the fishing grounds during the 2020 tagging effort, IATTC staff explored historical baiting areas within the GNP. Although Pacific sardine was encountered, the abundance seemed limited for the purposes of future tagging cruises.

2.2. Tagging operations

Tunas were tagged with one serially numbered, 12.5-centimeter (cm) yellow plastic dart tag (PDT) (manufactured by Hallprint Pty, Ltd., Victor Harbor, South Australia), using tubular stainless-steel applicators (Figure 2A and Figure 2B). Plastic dart tags have barbed heads (Figure 2B) designed to pass between the pterygiophores below the base of the second dorsal fin (Figure 3), creating a secure attachment that reduces potential shedding. Printed information on each PDT informs the finders on how to report the recapture of a tagged tuna and the reward for returned tags. During tagging operations, most fish less than about 1 meter (m) in length were measured and tagged in aluminum cradles, which are lined with high-density foam padding and marked with 1-cm graduations on a smooth liner for easy and rapid measuring. Cradles were mounted on the stern of the vessel directly behind fisherman in the fishing racks. During most tagging cruises, there were four tagging stations, each with an aluminum cradle. Tunas larger than about 1 m in length, were scooped with heavy-duty, long-handled aluminum-frame nets

(75 cm inside diameter), hung with knotless webbing. These fish were landed directly onto the deck covered with a high-density foam mat with a smooth liner, where measurements were taken with a caliper prior to tagging and release. Tag and release information, including date, time, fishing location, fishing gear type, tagging station, species, length, tag type and number(s) were recorded using digital tape recorders suspended around the necks of taggers. Following tagging events, recorded release data was transcribed to paper forms to later be entered into the IATTC tagging database.

In addition to PDTs, ATs (Figure 4) were implanted in SKJ, YFT, and BET tunas (Figure 3). Archival tags are designed for internal implantation and provide information on movements, behavior, and habitat utilization. Surgical methods described in Schaefer et al. (2007) were used to implant ATs in the coelomic cavity of tunas, as it has been shown to reduce tag shedding and increase fish survival and recovery rates. Three types of ATs were used during the RTTP: LAT2910 and ARCGEO-9TS (Figure 4A and Figure 4B) manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada) and Mk9 (Figure 4C) manufactured by Wildlife Computers, Inc. Because of the high rewards paid for recovered ATs (US$ 250), return rates can be quite high and may be considered as an alternative estimate of exploitation rate, which is free of reporting issues.

2.3. Tag recovery program

Three tag recovery specialists (TRS) were hired during 2019 prior to the departure of the first cruise in the RTTP series, and will continue through at least May 31, 2024. One TRS was stationed at each of the following IATTC field offices: Mazatlán, Mexico; Manta, Ecuador; and Playas, Ecuador. The responsibility of the TRS was to collect high-confidence tag recapture information at the time vessels were unloading. Recovery information validated by the TRS included vessel name, well position and number where tagged tuna(s) were found, and length measurements of recovered tunas while tags are still attached. Tag recovery specialists actively promote the project to make fishers and unloaders aware of rewards for returning tagged fish. Since TRS are at the waterfront for most unloadings, a tiered recovery system was developed, whereby returns validated by the TRS (high confidence) received higher rewards than non-validated (low confidence) returns.

An extensive international publicity campaign was implemented by IATTC staff and the TRS. The intention of the campaign was to inform PS and LL vessel captains and crews, cannery managers/workers, and PS vessel unloaders about the EPO RTTP, including the rewards offered for the return of tags. Reward posters and flyers were widely distributed throughout all major tuna fishing ports, aboard vessels of distant water-fishing nations, and artisanal-fishing locales within coastal fishing nations of the Americas for the duration of the RTTP.

Recoveries are considered high confidence when the tuna is presented to the TRS at the time of detection so that vessel, well, and length can be determined or validated. For high confidence returns, a greater cash reward is paid (US$ 15) compared to unvalidated tag returns (US$ 10). The reward paid for the return of ATs is US$ 250, an amount standardized by most institutions across the Pacific Ocean. In addition to the immediate cash rewards, an annual lottery was held, in which five US$ 1,000 rewards were paid to randomly drawn individuals who had returned high confidence tags. Each returned high confidence PDT provides one entry to win the drawing, where the greater the number of tags returned results in a higher probability of winning. The efficacy of this reward system was demonstrated in previous tagging projects at the IATTC (2000-2006) and proved highly effective in promoting good cooperation from tag finders, while helping to collect a higher proportion of high confidence tag recapture data.

2.4. Data handling and quality control

Recovery data not classified as high confidence is subjected to an additional precautionary step to ensure the largest subset of data is available for analyses. For this purpose, a speed filter was derived using both

ATs and high confidence PDT returns from within the days at liberty (DAL) range shown in Tables 1-6 (< 30d, 30-89d, 90-179d, 180-365d, and > 365d). Linear displacement (LD) was calculated between the release and recapture positions and divided by the DAL to give the mean daily speed in miles per day (M/d). The 95TH percentile of the mean daily speed for each DAL range was used as a conservative threshold to eliminate likely erroneous low confidence PDT tag data, where the mean daily speeds exceeded those values.

Applying the above method for data quality control, the threshold velocities for SKJ within the five DAL ranges were: < 30d (26.51 M/d), 30–89d (16.71 M/d), 90–179d (7.21 M/d), 180–365d (6.75 M/d), and > 365d (5.14 M/d). This resulted in eliminating the following numbers and percentages of recoveries from each of those categories, respectively: 85 (10.3%), 70 (14.4%), 17 (7.5%), 10 (9.1%), and 1 (4.2%). The threshold velocities for YFT within the five DAL ranges were: < 30d (22.84 M/d), 30–89d (18.13 M/d), 90–179d (8.09 M/d), 180–365d (3.19 M/d), and > 365d (4.38 M/d). This resulted in eliminating the following numbers and percentages of recoveries from each of those categories, respectively: 12 (16.9%), 3 (2.4%), 5 (5.7%), 2 (5.6%), and 0 (0%). The threshold velocities for BET within the five DAL ranges were: < 30d (70.82 M/d), 30–89d (27.76 M/d), 90–179d (14.18 M/d), 180–365d (0.95 M/d), and > 365d (1.52 M/d). This resulted in eliminating the following numbers and percentages of recoveries from each of those categories, respectively: 4 (12.1%), 1 (2.4%), 0 (0%), 2 (8.0%), and 0 (0%).

2.5. Reporting rate (seeding) experiments

Concurrent to the RTTP tagging efforts, tag seeding experiments were carried out by trained observers aboard PS vessels to estimate reporting rates of recaptured tunas by fleets and among landing ports throughout the EPO. Observers aboard PS vessels attempted to surreptitiously insert tags into captured tunas before placing the fish into a well of the vessel. Two types of tags were used for seeding: a standard PDT and a plastic intramuscular anchor tag (PIMA, Figure 2.d). Plastic intramuscular anchor tags were used to evaluate in-well shedding in the event the observer did not place the tag properly between the pterygiophores. For each set (totaling up to five sets), two tunas were tagged with a single PDT, two tunas were tagged with a single PIMA, and one tuna was double tagged with one PDT and one PIMA.

3. RESULTS

3.1. Tag releases

A total of 6,181 and 250 SKJ (Table 1 and Table 2), 1,679 and 472 YFT (Table 3 and Table 4), and 265 and 57 BET (Table 5 and Table 6), were tagged and released with PDTs and ATs, respectively, during the three tagging cruises. The average length of SKJ released with PDTs and ATs was 52.3 cm (32-74 cm) and 51.4 cm (39-72 cm), respectively, and length frequency distributions for PDT and AT releases are presented in Figure 6A and Figure 6B. The average length of YFT released with PDTs and ATs was 49.7 cm (30-114 cm) and 52.9 cm (30-117 cm), respectively, and length frequency distributions for PDT and AT releases are presented in Figure 7A and Figure 7B. The average length of BET released with PDTs and ATs was 65.9 cm (39-120 cm) and 84.6 cm (39-116 cm), respectively, and length frequency distributions for PDT and AT releases are presented in Figure 8A and Figure 8B.

3.2. Tag recoveries

Recoveries of PDTs and ATs were primarily made during the unloading process of PS vessels while in port; however, there were some recoveries aboard PS vessels while at sea during fishing operations, and one PDT recaptured on a recreational vessel. There are also instances when tags were not detected during unloading and are subsequently found at various times during processing at canneries. There have been 135 (6.0%) tags recovered at sea during fishing operations, 1,899 (84.5%) tags recovered during vessel unloading, 179 (8.0%) tags recovered at canneries, 32 (1.4%) tags found in other locations during processing, and 2 (0.1%) tags during the unloading of a transportation trailer. On board most PS trips were observers of the IATTC or national programs, who collect data about the trip and fishing operations. Information collected by observers and the TRS were used to determine recapture metrics, which includes date and time of capture, location of capture, set type (dFAD, Dolphin, Unassociated), and total catch loaded. To date, there have been 660 (29.3%) high and 1,587 (70.6%) low confidence tags returned (Tables 1, 2, and 3). Of the high confidence returns, 28 (4.2%) have been recovered at sea, 615 (93.2%) during unloading, 13 (2.0%) at the cannery, and 4 (0.6%) at other locations during processing.

The lower percentage of high confidence PDT returns following the 2020 tagging cruise was likely a result of limited access to vessels and piers during unloading, and the fact that some vessels were granted exemptions from carrying observers for extended periods due to COVID-19. Restricted access started in March 2020 and continued through at least August of 2021.

3.3. Skipjack tuna

To date, 1,695 (27.4%) SKJ have been returned from PDT releases. Returns by DAL are shown in Table 1, and only 20 (1.2%) returns had DAL exceeding one year in duration. Applying the speed filter derived from high confidence PDT and AT returns to reduce the number of unrealistic recapture dates and positions exacerbated by tag reporting errors, 183 (10.9%) SKJ tag returns had mean daily speeds exceeding the filter threshold and were excluded. The distribution of these recoveries is shown in Figure 9A. For SKJ released with PDTs at liberty for 30 days or more, 95 percent were within 1,101.4 nautical miles (nm) of their release positions, and 93.0% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a SKJ was 4,119.9 nm, which was recaptured by a PS vessel during an unassociated school set at 3° 44' N and 163° 10' W after 800.8 DAL.

A total of 60 (24.0%) SKJ have been returned from AT releases. Returns by DAL are shown in Table 2 and none have DAL exceeding one year. The distribution of these recoveries is shown in Figure 9B. For SKJ released with ATs at liberty for 30 days or more, 95 percent were within 1,129.9 nm of their release positions, and 94.3% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a SKJ was 1,643.2 nm, which was recaptured by a PS vessel during a dFAD set at 1° 30' N and 94° 25' W after 192.7 DAL.

Most probable tracks for 25 SKJ derived from AT light level position estimates, modeled using the unscented Kalman filter, are shown in Figure 10.

3.4. Yellowfin tuna

To date, 277 (16.5%) YFT have been returned from PDT releases. Returns by DAL are shown in Table 3, where 17 (6.1%) returns had DAL exceeding one year in duration. Applying the speed filter derived from high confidence PDT and AT returns to reduce the number of unrealistic recapture dates and positions exacerbated by tag reporting errors, 22 (7.9%) YFT tag returns had mean daily speeds exceeding the filter threshold and were excluded. The distribution of these recoveries is shown in Figure 11A. For YFT releases with PDTs at liberty for more than 30 days, 95 percent were within 1,110.1 nm of their release positions, and 92.1% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a YFT was 3,479.8 nm, which was recaptured by a PS vessel during a natural log set at 3° 53' N and 149° 36' W after 546.5 DAL.

A total of 88 (18.7%) YFT have been returned from AT releases. Returns by DAL are shown in Table 4, where 3 (3.4%) had DAL exceeding one year. The distribution of these recoveries is shown in Figure 11B. For YFT released with ATs at liberty for more than 30 days, 95 percent were within 717.7 nm of their release positions, and 100% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a YFT with an AT was 997.0 nm, which was recaptured by a PS vessel during an unidentified dolphin set at 0° 16’ N and 116° 22’ W after 165.7 DAL.

3.5. Bigeye tuna

To date, 105 (39.6%) BET have been returned from PDT releases. Returns by DAL are shown in Table 5, where 5 (4.8%) returns had DAL exceeding one year in duration. Applying the speed filter derived from high confidence PDT and AT returns to reduce the number of unrealistic recapture dates and positions exacerbated by tag reporting errors, 7 (6.7%) BET tag returns had mean daily speeds exceeding the filter threshold and were excluded. The distribution of these recoveries is shown in Figure 12A. For BET at liberty for 30 days or more, 95 percent were recaptured within 1,308.2 nm of their release positions, and 94.2% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a BET was 2,146.6 nm, which was recaptured by a PS vessel during a dFAD set at 4° 33’ N and 131° 9’ W after 152.8 DAL.

A total of 22 (38.6%) BET have been returned from AT releases. Returns by DAL are shown in Table 6, where 1 (4.5%) had DAL exceeding one year. The distribution of these recoveries is shown in Figure 12B. For BET released with ATs at liberty for more than 30 days, 95 percent were within 1,086.8 nm of their release positions, and 89.5% were recaptured within 1,000 nm of their release positions. The greatest linear displacement for a BET with an AT was 1,225.6 nm, which was recaptured by a PS vessel during a set on a raft at 2° 0’ N and 115° 57’ W after 176.2 DAL.

3.6. Reporting rates (seeding)

Seventy-three tag seeding kits have been provided to observers with all 73 completed tag seeding data forms have been received from those trips. Of the 1,752 total tags which have been seeded, 1,534 tags (87.6%) have been returned by finders and 1,231 (80.2%) of those returned tags were reported as high confidence (Table 7). There have been 1,430 (93.2%) seeded tags recovered by unloaders at the time PS vessels were being unloaded, and 347 (22.6%) seeded tags reported from a different port from where the vessel departed. There are 69 (4.5%) instances where low confidence recoveries are reported to boats other than the one where they were seeded (Table 7) and eight (0.5%) instances where high confidence recoveries are reported to boats other than the one where they were seeded.

4. CONCLUSIONS

While the objectives initially defined for the three tuna tagging cruises executed under the umbrella of the RTTP were not fully realized, having set out to tag 15,000 SKJ and 2,500 YFT and 2,500 BET with PDTs, and an additional 600 SKJ and 100 YFT and 100 BET with ATs, the project was relatively successful. Based on the experiences during the execution of the project and the data collected, IATTC staff have concluded the following:

- There were four key factors inhibiting IATTC from meeting the project objectives: 1) Competing against high PS fishing effort throughout the equatorial regions of the EPO, in a smaller, slower tagging vessel is challenging, 2) PS vessels continuing to set Tropical Atmosphere Ocean (TAO) buoys where tagging has historically been conducted successfully, 3) Little industry cooperation in providing dFAD locations for fishing and tagging, and 4) most of the cruise time is spent searching for fish, rather than fishing and tagging.
- A total of 6,181 and 250 SKJ were tagged and released with PDTs and ATs, respectively. To date, there have been 1,695 (27.4%) returned, and 19.2% (326) were reported as high confidence. There have been 60 ATs returned (24.0%) and 76.7% (46) were reported as high confidence. Having collected a robust AT data set, analyses of movements, behavior, and habitat preferences are being conducted.

- A total of 1,679 and 472 YFT were tagged and released with PDTs and ATs, respectively. To date, there have been 277 (16.4%) returned, and 44.4% (123) were reported as high confidence. There have been 87 ATs returned (18.4%) and 81.6% (71) were reported as high confidence. Having collected a robust AT data set, analyses of movements, behavior, and habitat preferences are being conducted.
- A total of 265 and 57 BET were tagged and released with PDTs and ATs, respectively. To date, there have been 104 (38.6%) returned, and 72.0% (72) were reported as high confidence. There have been 22 ATs returned (35.1%) and 95.5% (21) were reported as high confidence. Having collected a robust AT data set, analyses of movements, behavior, and habitat preferences are being conducted.
- Using data collected from tagging conducted between 2000-2006 and from the current RTTP efforts, a spatiotemporal tagging model for SKJ in the EPO (SAC-14 INF-E) has been developed, which may lead to spatially explicit abundance estimates and independent estimates of natural mortality. However, the model is based on tagging data which is restricted spatially (east of 110° W) and for a more reliable spatiotemporal analysis, tagging efforts should be continued across a broader spatial scale.
- The TRS located in the three busiest unloading ports have been instrumental in collecting high confidence tag return data. While access to vessels, piers, and unloading facilities were impacted by prolonged restrictions from the COVID-19 pandemic, TRS have recovered 628 (27.9%) high confidence tags. The publicity efforts, combined with the presence of the TRS during vessel unloadings, have been crucial to the program's success. Data collected through the recovery programs and the efforts of all IATTC field offices, will be used for estimating movements, growth, exploitation rates, and potentially, natural mortality.
- Tag seeding efforts are ongoing and provide estimates for key parameters that are necessary when developing tag-based models. When analyzing mark-recapture data, it is imperative to estimate reporting rates and reporting accuracy. If unknown, subsequent estimates of exploitation, fishing, and natural mortality may be biased. Seeding experiments should be conducted concurrently to any tagging campaign to address the dynamics of tag reporting.

5. RECOMMENDATIONS ON FUTURE DIRECTIONS

To address various deficiencies in the experimental design of large scale, regional tagging efforts undertaken thus far, the IATTC should consider alternative approaches to tag throughout a wider range of the convention area. Most of the tagging in the equatorial waters, beginning in 2000, has been conducted east of the 110°W longitude and proximal to the Shimada Seamount, thus disregarding a large area of high SKJ catches off Peru and west of the 110°W. These tagging efforts have relied on aggregations found in association with TAO buoys and other opportunistic schools found through extensive searching. Having received limited industry support or cooperation has inhibited the success of the RTTP, as access to dFADs with aggregations of SKJ, YFT, and BET, or finding areas where unassociated schools are present, has been left up to chance encounters. During the recent cruises, the bulk of the charter time was spent searching for dFADs and unassociated tuna schools rather than fishing, thus resulting in mostly unsuccessful tagging campaigns.

Future tagging cruises should be conducted with full industry support. This should include cooperation whereby some accessibility to vessel and company dFADs is provided, primarily between 5°N and 5°S from the coast and out to the 150°W. Direct communication with vessels would also be beneficial so that the tagging vessel could be located in productive fishing areas. While it is likely captains would be unwilling to share dFADs with large tuna aggregations while actively fishing, there may possibly be some willingness if the vessel is headed to port fully loaded, whereby access to select dFADS during their absence from the fishing grounds could be considered. Operations under the above scenario would require the tagging vessel to leave all tagged fish associated with the dFAD, making no efforts to disperse the fish. The primary objective being to tag for a period of time and not impact the fishing opportunities for a vessel when returning to the fishing grounds. From observations during 20 years of tagging in the EPO and around dFADs, having a high number of recaptures after short periods at liberty are unlikely due to the dynamic nature of aggregations and frequent immigration and emigration of FAD-associated tunas.

Recommendation:

Future tagging cruises should be conducted with strengthened industry collaboration.

For tagging operations to be successful, the fish need to bite aggressively. In many instances, this can be challenging as behavior can be affected by numerous external influences including heavy localized fishing effort, abundant local forage, or a multitude of unknown reasons. In these cases, it will be imperative for the IATTC to evaluate the potential use of a small, portable sea cage where fish can be held. This too requires industry cooperation, as fish would have to be transferred to the sea cage from a PS set. These methods are well defined from bluefin tuna fishing and ranching operations in northern Baja California, Mexico and Port Lincoln, South Australia. This method will not require bait but does require close collaboration from the fishing industry. In addition to providing tagging opportunities in areas which are not traditionally accessible, additional experiments can be conducted. Knowing the instantaneous tagging mortality is important and returning tagged fish to the sea cage, and holding them for several days, will provide estimates of mortality at the time of tagging.

Recommendation:

In collaboration with the industry, conduct experiments to evaluate the feasibility of using the portable sea-cage as a possible platform for tagging tropical tunas in the EPO (see unfunded proposal in SAC-14-01c).

Over the last several years there have been signs of a possible revitalization of pole-and-line fisheries within some coastal states, including Ecuador. IATTC should consider working with these pole-and-line vessels, either under charter contract, or through opportunistic agreements. These vessels and crews have local expertise that would be valuable for expanding the spatial coverage of tag releases.

Recommendation:

Consider developing partnerships with pole-and-line vessels in coastal states as a possible platform for tagging tropical tunas in the EPO.

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TABLES

TABLE 1. Releases of skipjack tuna with plastic dart tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 1. Liberaciones de atún barrilete con marcas de dardo plásticas por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

Year	Released	Returned							
		<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	177	4	16	5	2	1	2	30 (16.9)	19 (63.3)
2020	5,869	756	468	212	94	20	79	1,629 (27.8)	302 (18.5)
2022	135	28	6	2	0	0	0	36 (26.7)	5 (13.9)
All	6,181	788	490	219	96	21	81	1,695 (27.4)	326 (19.2)

TABLE 2. Releases of skipjack tuna with archival tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 2. Liberaciones de atún barrilete con marcas archivadoras por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

Year	Released	Returned							
		<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	43	5	3	0	2	0	0	10 (23.3)	6 (60.0)
2020	181	10	13	8	8	0	0	39 (21.5)	29 (74.4)
2022	26	9	1	1	0	0	0	11 (42.3)	11 (100.0)
All	250	24	17	9	10	0	0	60 (24.0)	46 (76.7)

TABLE 3. Releases of yellowfin tuna with plastic dart tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 3. Liberaciones de atún aleta amarilla con marcas de dardo plásticas por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

		Returned							
Year	Released	<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	805	9	26	27	22	13	12	109 (13.5)	47 (43.1)
2020	264	11	18	6	7	4	5	51 (19.3)	13 (25.5)
2022	610	20	61	31	5	0	0	117 (19.2)	62 (53.0)
All	1679	40	105	64	34	17	17	277 (16.5)	122 (44.0)

TABLE 4. Releases of yellowfin tuna with archival tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 4. Liberaciones de atún aleta amarilla con marcas archivadoras por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

		Returned							
Year	Released	<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	241	21	14	6	4	3	0	48 (19.9)	34 (70.8)
2020	9	0	0	0	0	0	0	0 (0.0)	0 (0.0)
2022	221	9	10	20	1	0	0	40 (18.1)	38 (95.0)
All	472	30	24	26	5	3	0	88 (18.7)	72 (81.8)

TABLE 5. Releases of bigeye tuna with plastic dart tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 5 Liberaciones de atún patudo con marcas de dardo plásticas por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

Year	Released	Returned							
		<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	142	10	13	11	15	3	0	52 (36.6)	37 (71.2)
2020	9	1	1	0	0	2	1	5 (55.6)	3 (60.0)
2022	114	19	22	5	1	0	1	48 (42.1)	33 (68.7)
All	265	30	36	15	16	5	3	105 (39.6)	73 (69.5)

TABLE 6. Releases of bigeye tuna with archival tags by year and returns by time at liberty. Row totals incorporate all returns, including those classified as low confidence. High confidence return totals represent those which had the vessel and well verified by tag recovery specialists.

TABLA 6. Liberaciones de atún patudo con marcas archivadoras por año y devoluciones por tiempo en libertad. Los totales de las filas incluyen todas las devoluciones, incluidas las clasificadas como de baja confianza. Los totales de las devoluciones de alta confianza representan aquellas en las que el buque y la bodega fueron verificados por especialistas en recuperación de marcas.

Year	Released	Returned							
		<30 d	30-89 d	90-179 d	180 – 365 d	>365 d	Other	Total (%)	Total High Confidence (%)
2019	46	2	1	3	9	1	0	16 (34.8)	15 (93.8)
2020	0	0	0	0	0	0	0	0 (00.0)	0 (00.0)
2022	11	1	5	0	0	0	0	6 (54.5)	6 (100.0)
All	57	3	6	3	9	1	0	22 (38.6)	21 (95.5)

TABLE 7. Deployment of seeded tags by port of vessel departure from 2019-2022. Seeded tags are reported from the port of unloading which can be the same or different to that of the port of departure. Tags may also be reported from the same vessel the tags were seeded (high confidence) aboard, or another vessel (low confidence).

TABLA 7. Despliegue de marcas sembradas por puerto de salida de buques durante 2019-2022. Las marcas sembradas se notifican desde el puerto de descarga, que puede ser el mismo o diferente al puerto de salida. Las marcas también pueden notificarse desde el mismo buque en el que se sembraron (de alta confianza), o desde otro buque (de baja confianza).

		Returned					
Departure Port	**Total Seeded**	**Same Port**	**Different Port**	**Same Vessel**	**Different Vessel**	**Total (%)**	**Total High Confidence (*% of returned tags*)**
Flamingo, PA	25	0	24	24	0	24 (96.0)	23 (95.8)
Manta, EC	942	636	213	821	28	849 (90.1)	665 (78.3)
Manzanillo, MX	30	26	0	26	0	26 (86.7)	5 (19.2)
Mazatlán, MX	705	525	85	569	41	610 (86.5)	515 (84.4)
Paita, PE	25	0	25	25	0	25 (100.0)	23 (92.0)
Puerto Madero, MX	25	0	0	0	0	0 (00.0)	0 (00.0)
Total	1,752	1,187	347	1,465	69	1,534 (87.6)	1,231 (80.2)

FIGURES

FIGURE 1. *F/V Her Grace* at anchor while catching bait in the Galapagos Islands National Park, Ecuador. The racks, where the fisherman stand while fishing with pole-and-line, are visible along the stern of the vessel.

FIGURA 1. *B/P Her Grace* anclado mientras captura cebo en el Parque Nacional Galápagos, Ecuador. A lo largo de la popa del buque se ven las plataformas donde se colocan los pescadores mientras pescan con caña.

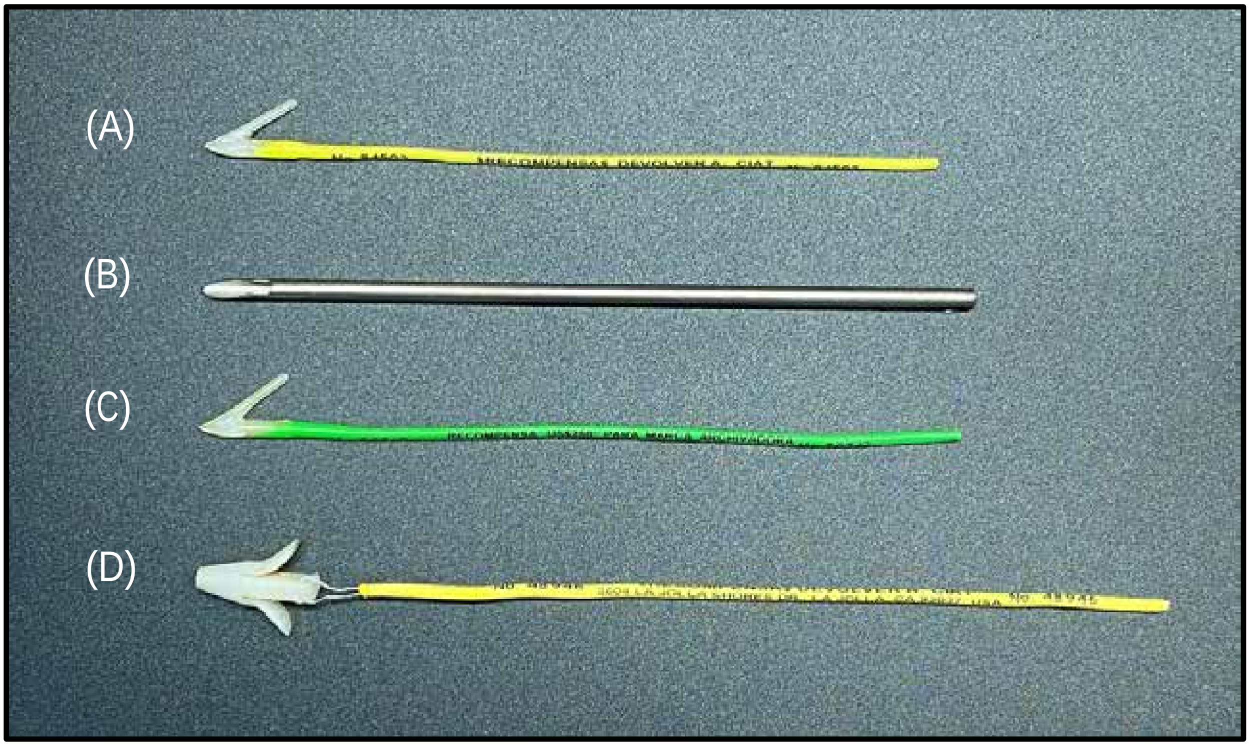

FIGURE 2. Plastic dart tags and the tag applicator used during the 2019, 2020, and 2022, Regional Tuna Tagging Project tagging cruises. (**A**) 12.5-cm Yellow Hallprint PDT used to mark skipjack, yellowfin, and bigeye tunas. (**B**) The 316L stainless steel tag applicator used to insert plastic dart tags (**A** and **C**) at the base of the second dorsal fin. (**C**) Green plastic dart tags accompanied tunas carrying an internally implanted archival tag. (**D**) Plastic intra-muscular anchor tag being used in the tag seeding experiment to assess rates of shedding.

FIGURA 2. Marcas de dardo plásticas y el aplicador de marcas utilizado durante los cruceros de marcado del Proyecto Regional de Marcado de Atunes en 2019, 2020 y 2022. (**A**) MDP de color amarillo de 12.5 cm fabricada por Hallprint utilizada para marcar atunes barrilete, aleta amarilla y patudo. (**B**) Aplicador de marcas de acero inoxidable 316L utilizado para insertar marcas de dardo plásticas (**A** y **C**) en la base de la segunda aleta dorsal. (**C**) Marcas de dardo plásticas de color verde que acompañaban a los atunes que llevaban una marca archivadora implantada internamente. (**D**) Marca intramuscular plástica utilizada en el experimento de siembra de marcas para determinar las tasas de desprendimiento de marcas.

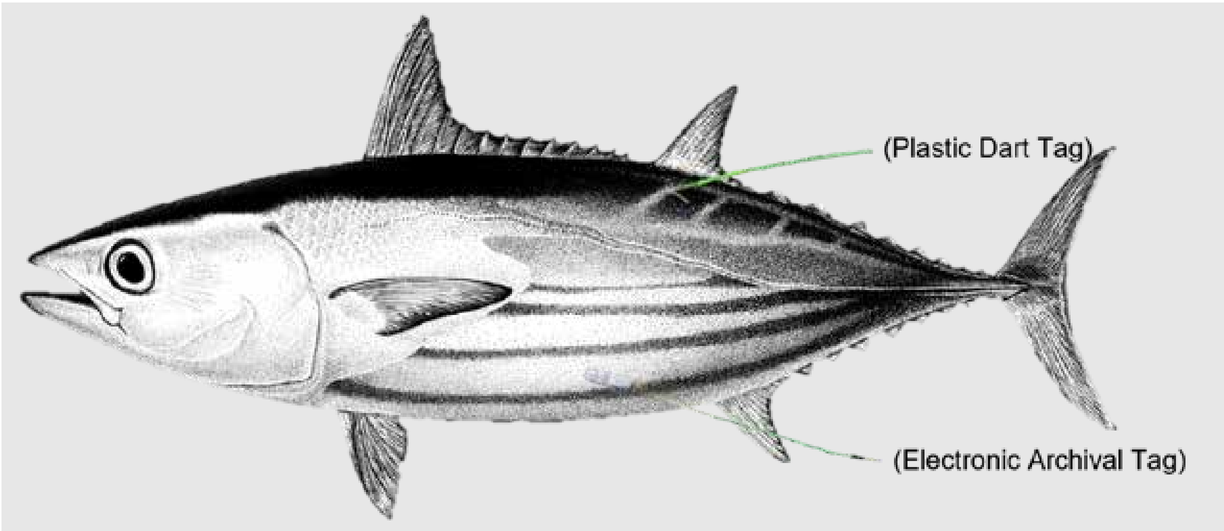

FIGURE 3. Placement of a plastic dart and archival tags in skipjack tuna. All fish tagged with archival tags also received a green plastic dart tag. Fish which do not receive archival tags are tagged with a single yellow plastic dart tag. The body of the archival tag and the anchor of the plastic dart tag are not externally visible and are only shown for visual purposes.

FIGURA 3. Posición de marcas de dardo plásticas y archivadoras en atún barrilete. Todos los peces marcados con marcas archivadoras también recibieron una marca de dardo plástica de color verde. Los peces que no reciben marcas archivadoras son marcados con una sola marca de dardo plástica de color amarillo. El cuerpo de la marca archivadora y el gancho de la marca de dardo plástica no se ven por fuera y solo se muestran con fines visuales.

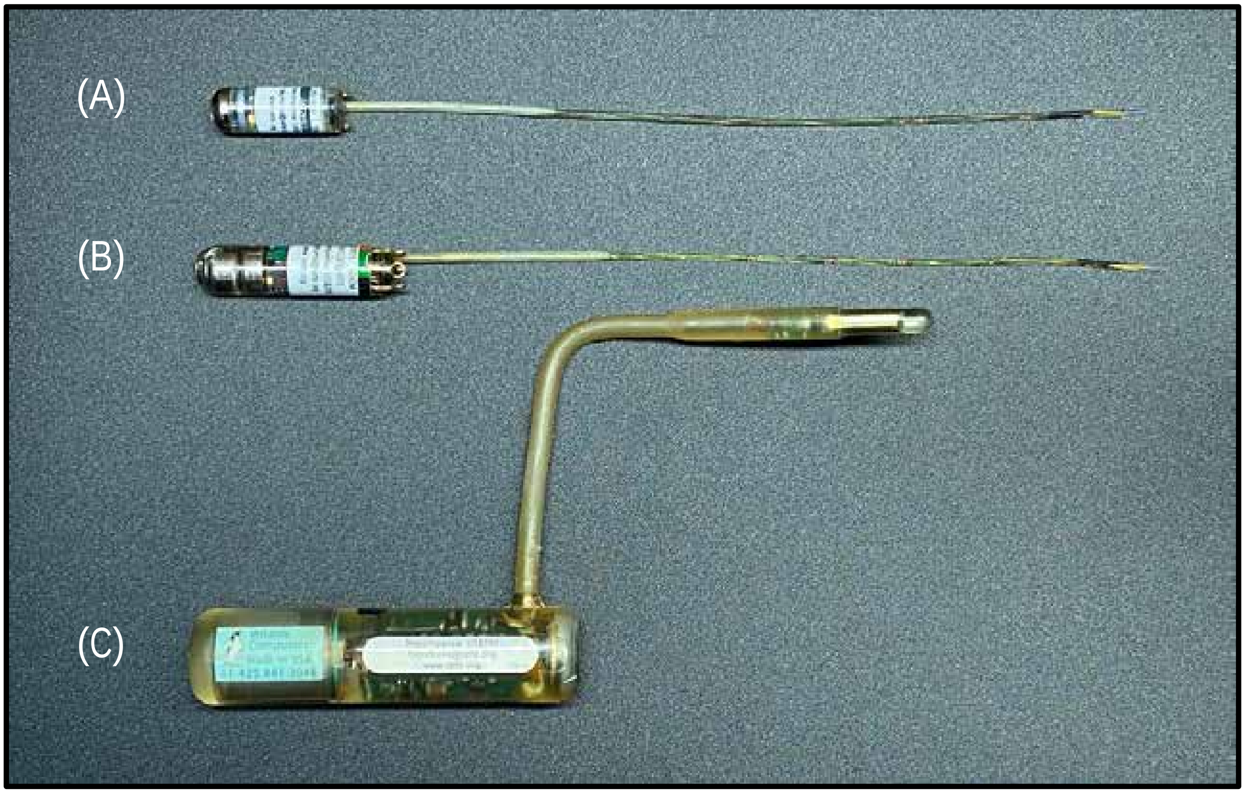

FIGURE 4. Electronic tags used by the Inter-American Tropical Tuna Commission during the 2019, 2020, and 2022 tagging cruises. (**A**) Lotek LAT2910-X, which were used to mark skipjack tuna and smaller (< 66 cm) yellowfin and bigeye tuna. (**B**) Lotek ARCGEO-9TS, used to mark skipjack tuna and smaller (< 68 cm) yellowfin and bigeye tuna. (**C**) Wildlife Computers Mk9, used to mark larger (> 55 cm) yellowfin and bigeye tuna.

FIGURA 4. Marcas electrónicas utilizadas por la Comisión Interamericana del Atún Tropical durante los cruceros de marcado de 2019, 2020 y 2022. (**A**) Lotek LAT2910-X, utilizadas para marcar atún barrilete y atún aleta amarilla y patudo más pequeños (< 66 cm). (**B**) Lotek ARCGEO-9TS, utilizadas para marcar atún barrilete y atún aleta amarilla y patudo más pequeños (< 68 cm). (**C**) Wildlife Computers Mk9, utilizadas para marcar atún aleta amarilla y patudo más grandes (> 55 cm).

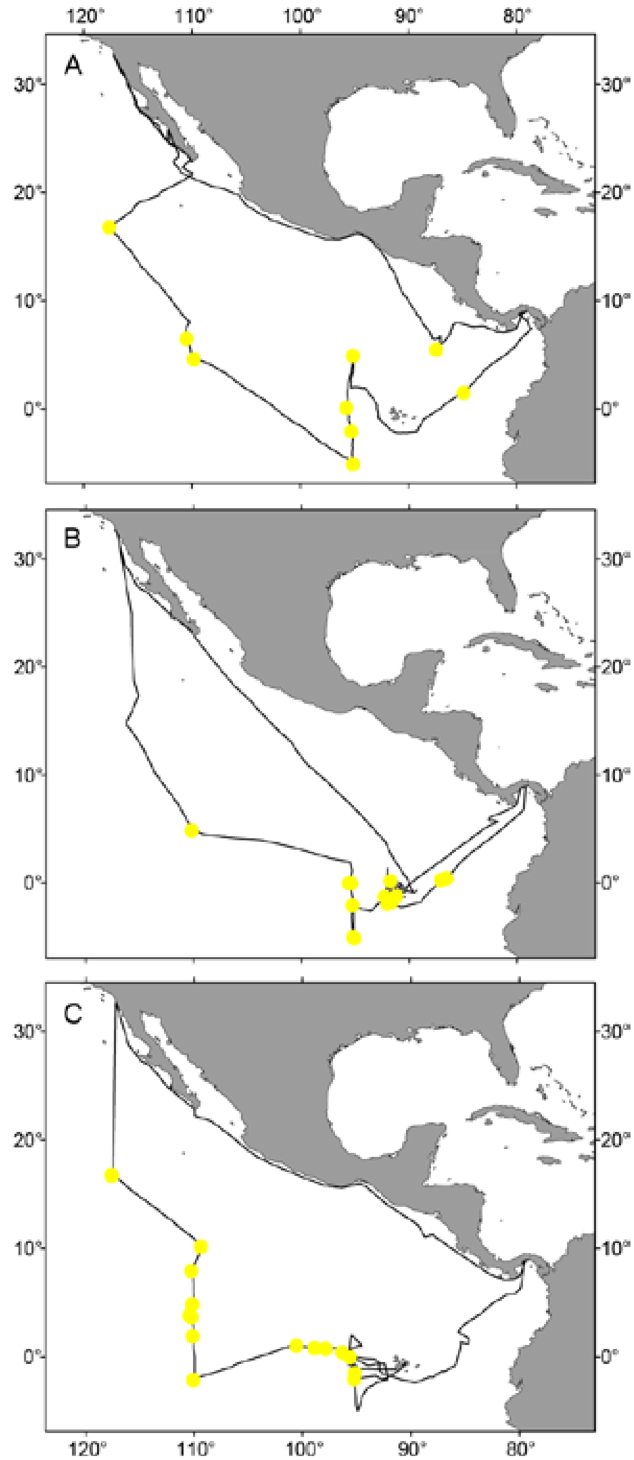

FIGURE 5. Tracks for the 2019 (**A**), 2020 (**B**), and 2022 (**C**) tagging cruises. Yellow circles represent areas where tagging was conducted. All trips departed and returned to port in San Diego, California. Live bait (*Cetengraulis mysticetus*) was caught in the Gulf of Panama during each trip.

FIGURA 5. Trayectorias de los cruceros de marcado de 2019 (**A**), 2020 (**B**) y 2022 (**C**). Los círculos amarillos representan las áreas en las que se realizó el marcado. Todos los viajes salieron y regresaron al puerto en San Diego, California. El cebo vivo (*Cetengraulis mysticetus*) fue capturado en el Golfo de Panamá en cada viaje.

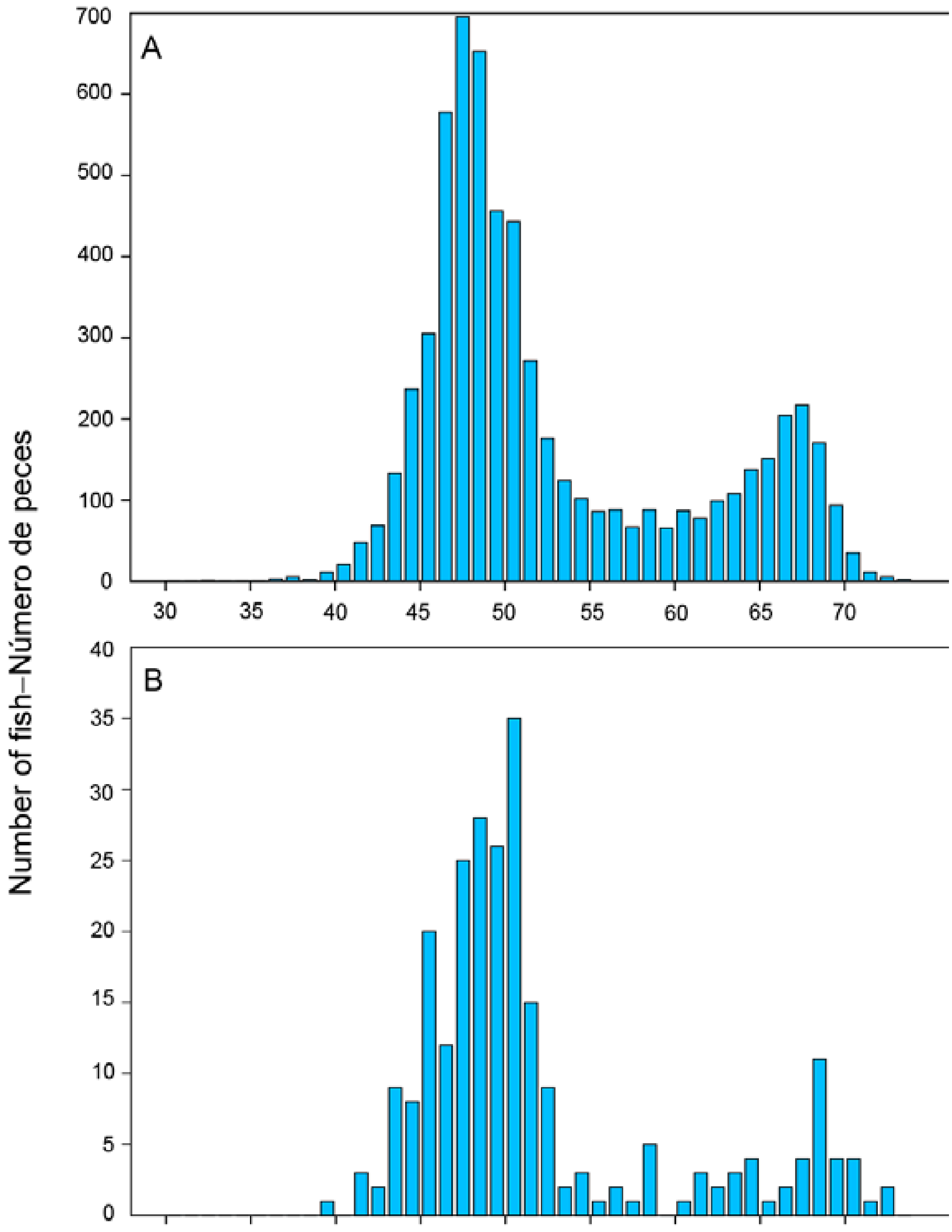

FIGURE 6. Length frequency for (**A**) 6,181 skipjack tuna tagged with plastic dart tags, and (**B**) 250 skipjack tuna tagged with archival tags during three tagging cruises conducted in 2019, 2020, and 2022.
FIGURA 6. Frecuencia de talla para (**A**) 6,181 atunes barrilete marcados con marcas de dardo plásticas y (**B**) 250 atunes barrilete marcados con marcas archivadoras durante tres cruceros de marcado realizados en 2019, 2020 y 2022.

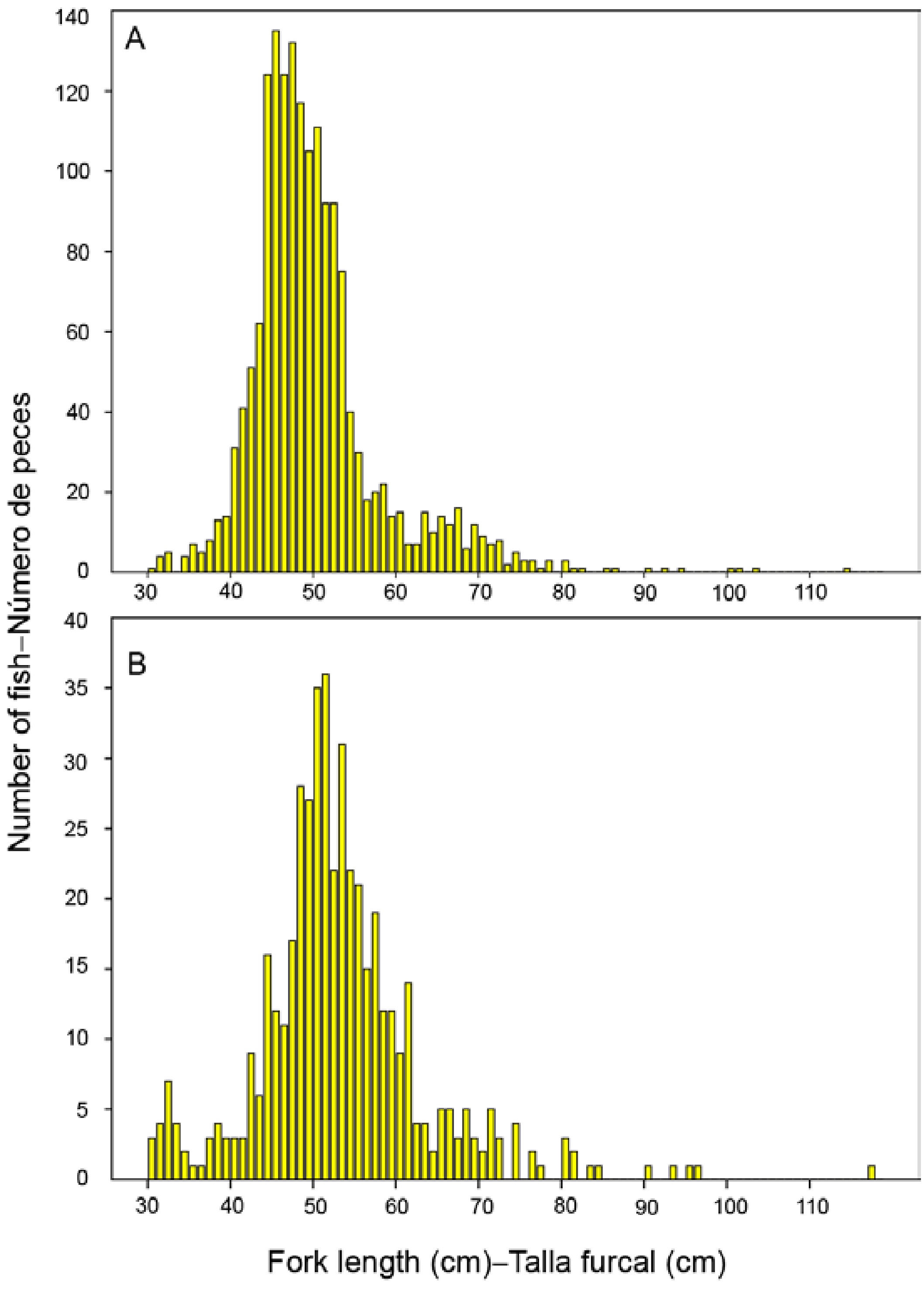

FIGURE 7. Length frequency for (**A**) 1679 yellowfin tuna tagged with plastic dart tags, and (**B**) 471 yellowfin tuna tagged with archival tags during three tagging cruises conducted in 2019, 2020, and 2022.

FIGURA 7. Frecuencia de talla para (**A**) 1679 atunes aleta amarilla marcados con marcas de dardo plásticas y (**B**) 471 atunes aleta amarilla marcados con marcas archivadoras durante tres cruceros de marcado realizados en 2019, 2020 y 2022.

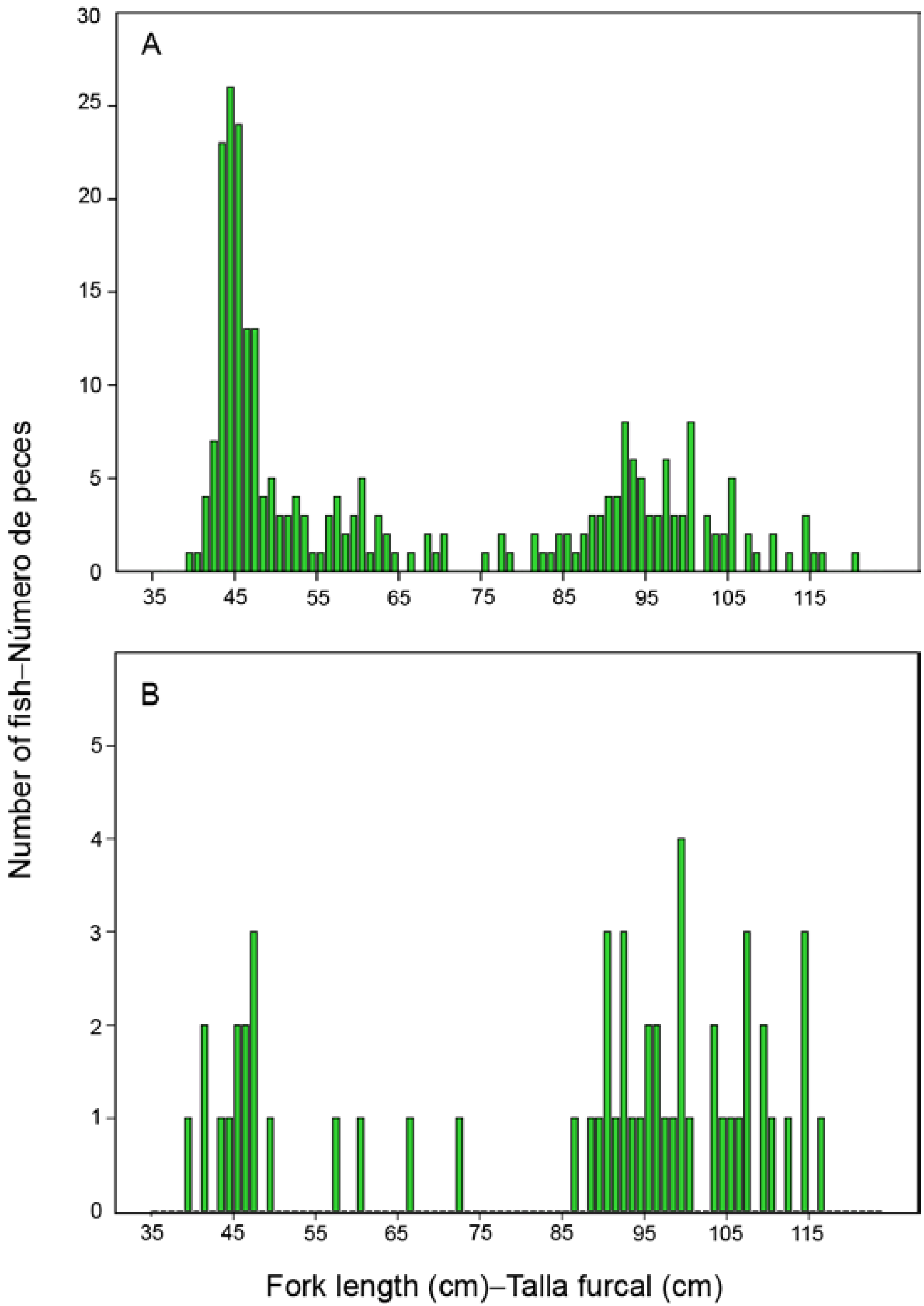

FIGURE 8. Length frequency for (**A**) 265 bigeye tuna tagged with plastic dart tags, and (**B**) 57 bigeye tuna tagged with archival tags during three tagging cruises conducted in 2019, 2020, and 2022.
FIGURA 8. Frecuencia de talla para (**A**) 265 atunes patudo marcados con marcas de dardo plásticas y (**B**) 57 atunes patudo marcados con marcas archivadoras durante tres cruceros de marcado realizados en 2019, 2020 y 2022.

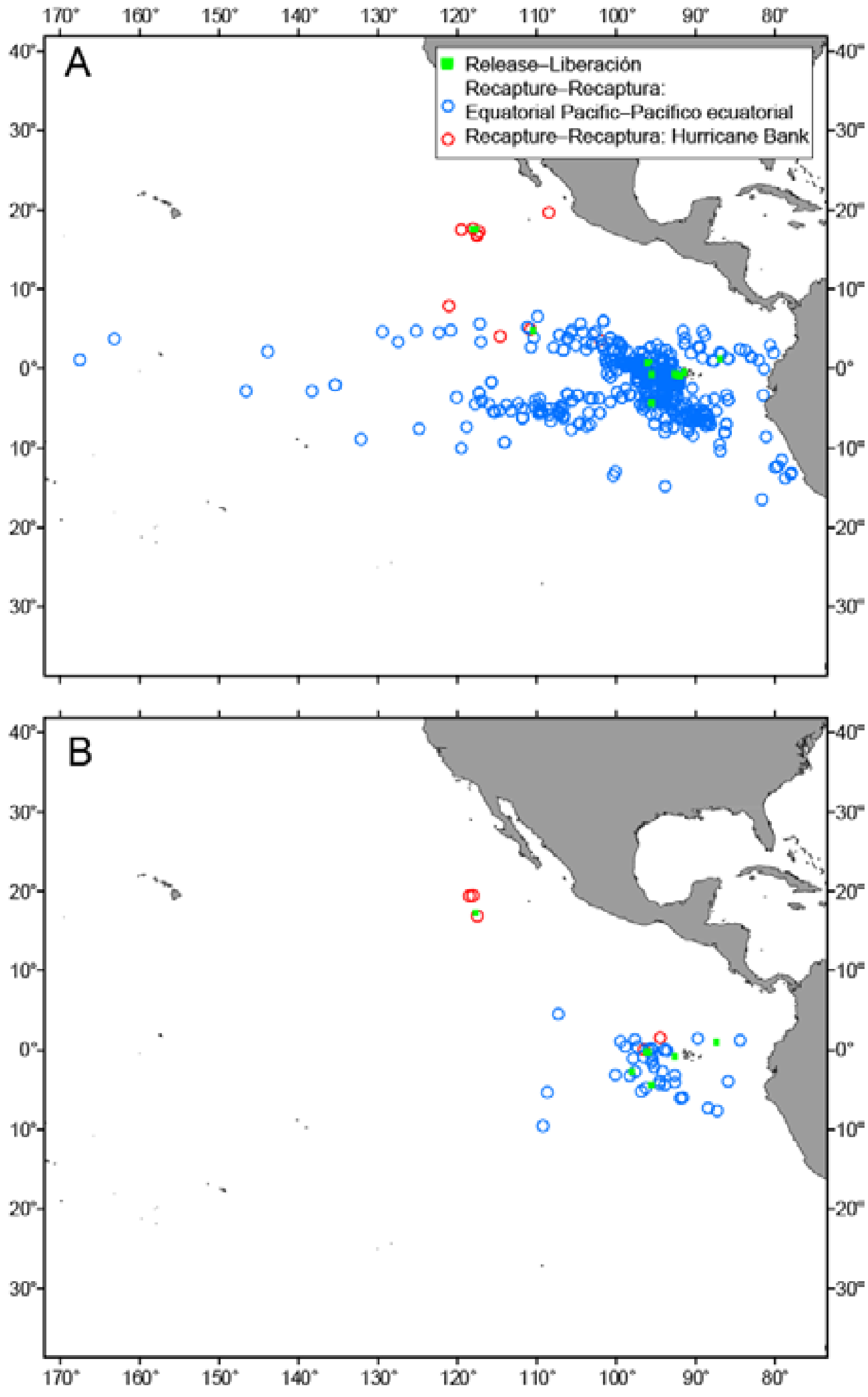

FIGURE 9. Recapture locations for skipjack tuna tagged and released with (**A**) plastic dart tags (*n* = 1436) and (**B**) archival tags (*n* = 54) during three tagging cruises conducted in 2019, 2020, and 2022. Recoveries from releases in two distinct areas, equatorial eastern Pacific and Hurricane Bank, are shown in blue and red, respectively.

FIGURA 9. Ubicaciones de recaptura de atún barrilete marcado y liberado con (**A**) marcas de dardo plásticas (*n* = 1436) y (**B**) marcas archivadoras (*n* = 54) durante tres cruceros de marcado realizados en 2019, 2020 y 2022. Las recuperaciones de liberaciones en dos áreas distintas, Pacífico oriental ecuatorial y Hurricane Bank, se muestran en azul y rojo, respectivamente.

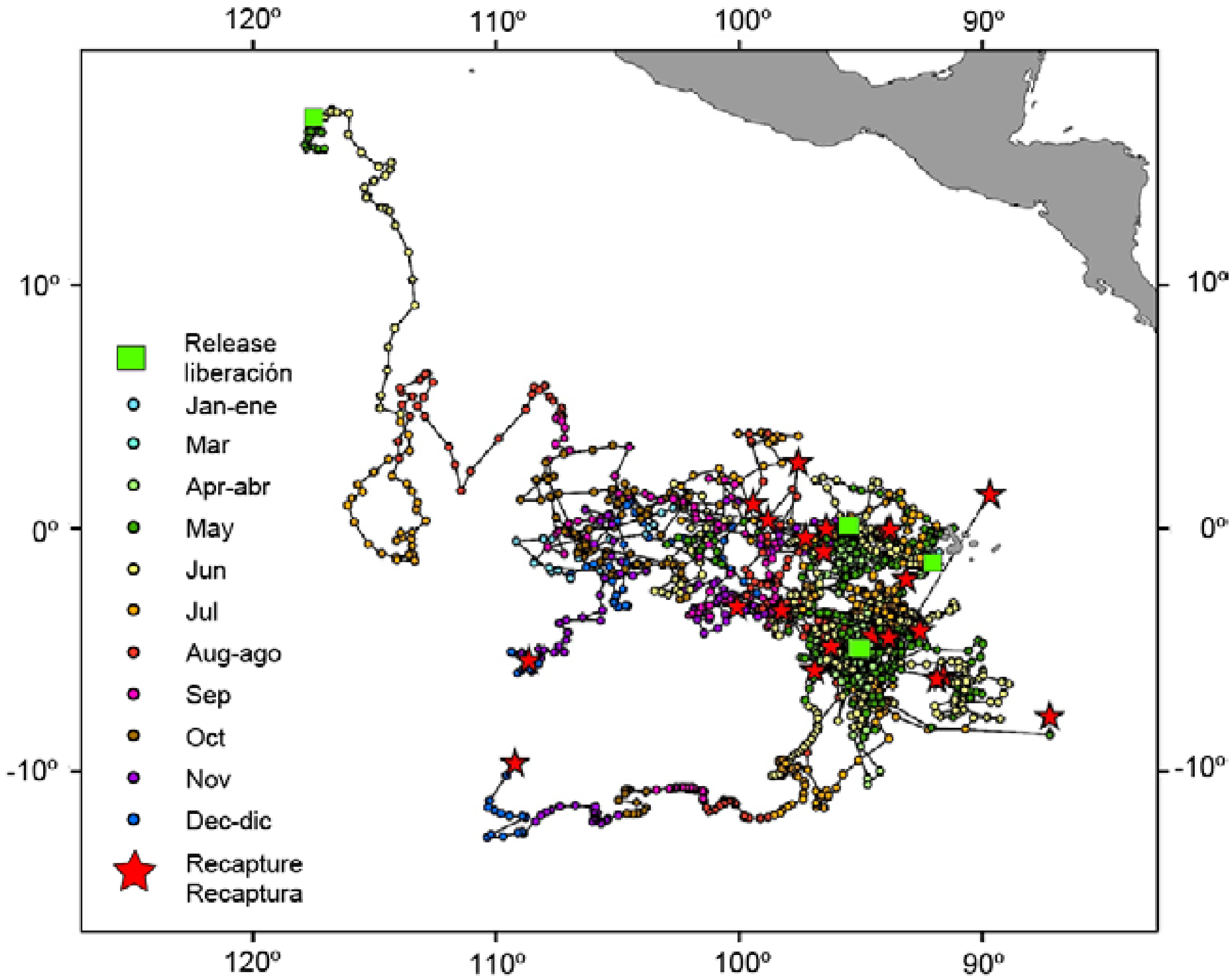

FIGURE 10. Most probable tracks for 25 skipjack tuna, color-coded by month, derived from archival tag light level position estimates modeled using the unscented Kalman filter with SST, from releases during three tagging cruises conducted in 2019, 2020, and 2022. Tracks are shown only for fish at liberty for greater than 30 days.

FIGURA 10. Trayectorias más probables para 25 atunes barrilete, con códigos de colores por mes, derivadas a partir de estimaciones de posición de nivel de luz de marcas archivadoras, modeladas usando el filtro de Kalman no perfumado con TSM, de liberaciones durante tres cruceros de marcado realizados en 2019, 2020 y 2022. Las trayectorias se muestran solo para peces en libertad durante más de 30 días.

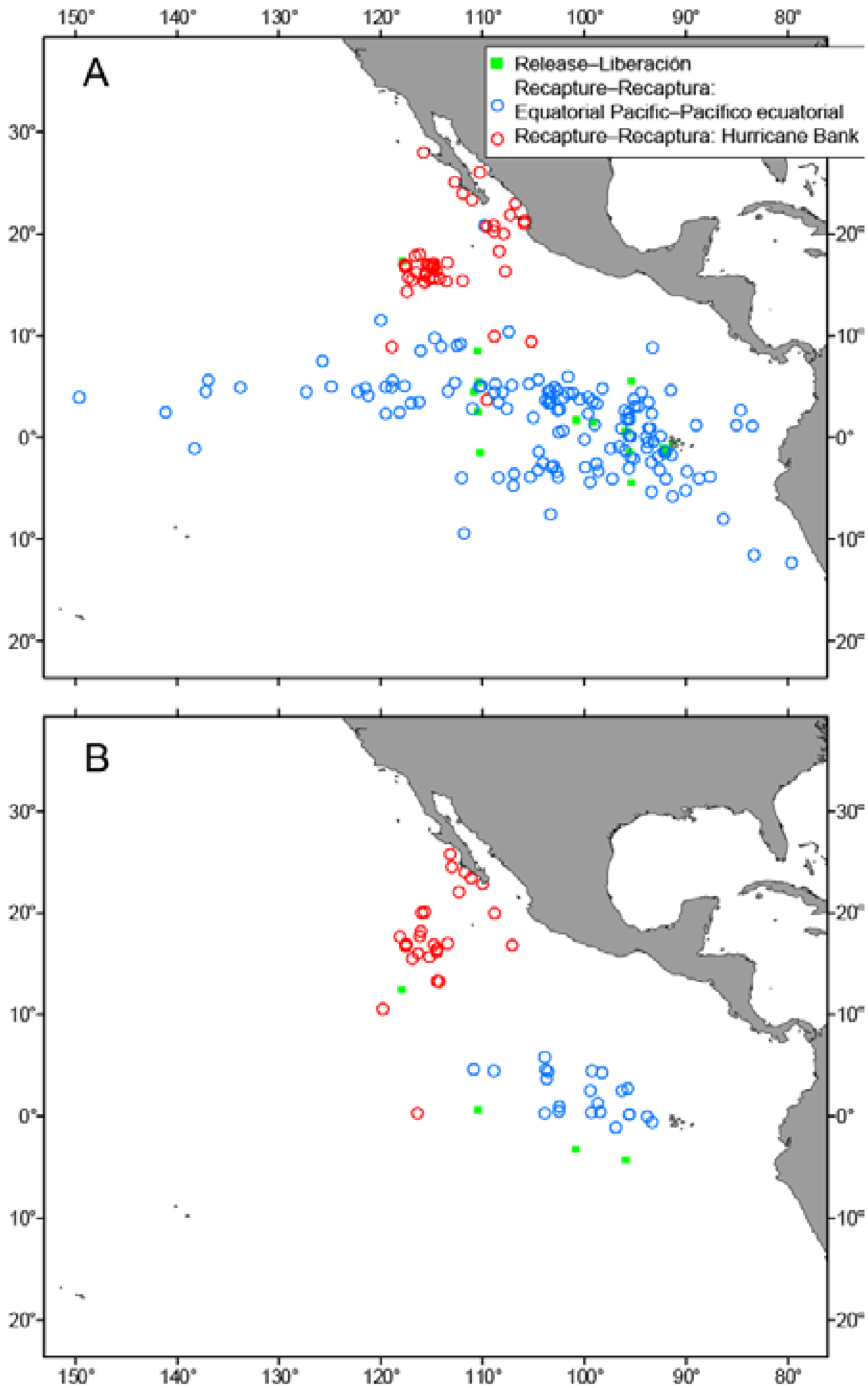

FIGURE 11. Recapture locations for yellowfin tuna tagged and released with (**A**) plastic dart tags (*n* = 246), and (**B**) archival tags (*n* = 72) during three tagging cruises conducted in 2019, 2020, and 2022. Recoveries from releases in two distinct areas, equatorial eastern Pacific and Hurricane bank are shown in blue and red, respectively.

FIGURA 11. Ubicaciones de recaptura de atún aleta amarilla marcado y liberado con (**A**) marcas de dardo plásticas (*n* = 246) y (**B**) marcas archivadoras (*n* = 72) durante tres cruceros de marcado realizados en 2019, 2020 y 2022. Las recuperaciones de liberaciones en dos áreas distintas, Pacífico oriental ecuatorial y Hurricane Bank, se muestran en azul y rojo, respectivamente.

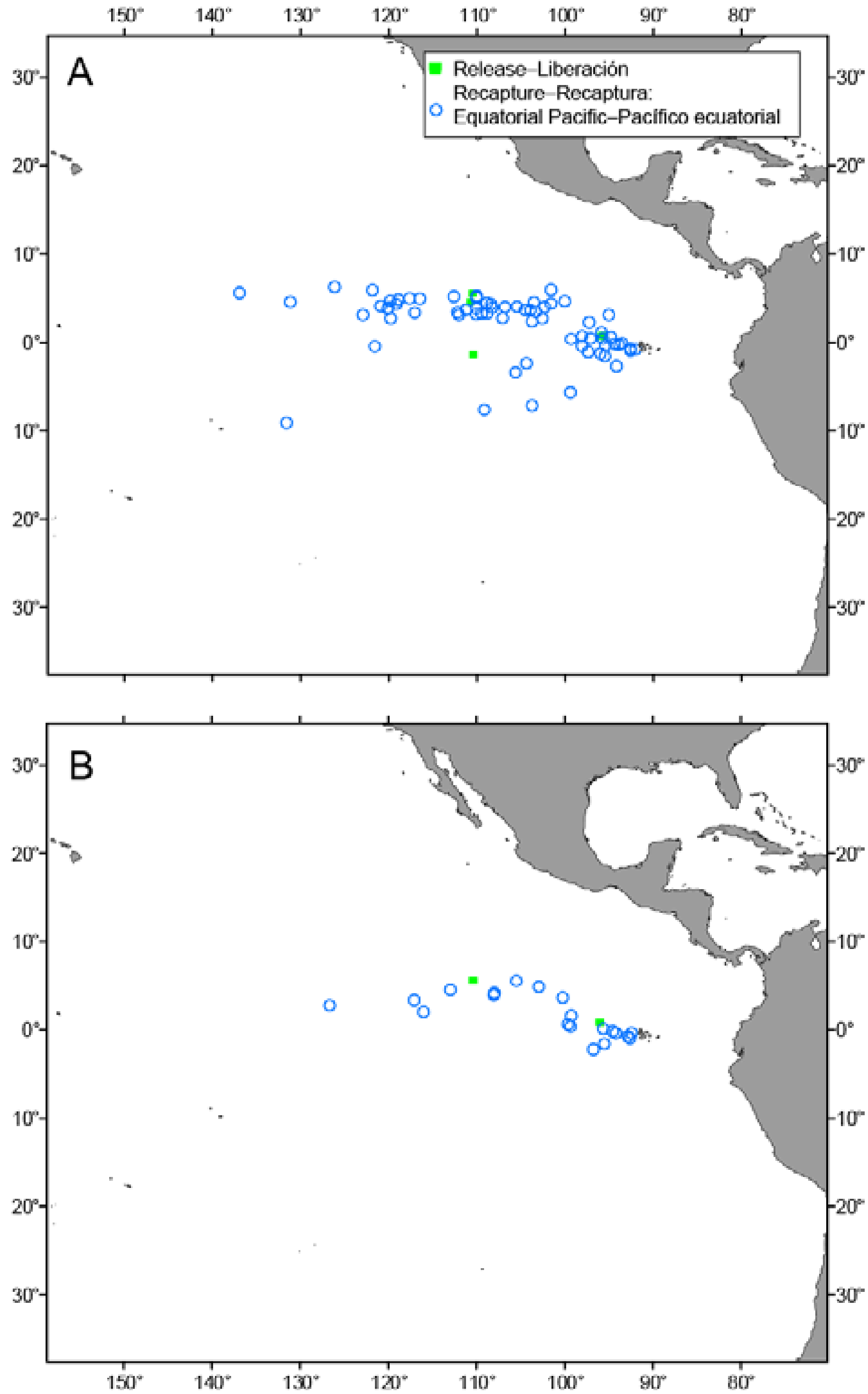

FIGURE 12. Recapture locations for bigeye tuna tagged and released with (**A**) plastic dart tags (n = 966), and (**B**) archival tags (n = 22) during three tagging cruises conducted in 2019, 2020, and 2022.

FIGURA 12. Ubicaciones de recaptura de atún patudo marcado y liberado con (**A**) marcas de dardo plásticas (n = 966) y (**B**) marcas archivadoras (n = 22) durante tres cruceros de marcado realizados en 2019, 2020 y 2022.

APPENDIX: CRUISE SUMMARIES

2019 tagging cruise

The first cruise in the RTTP series departed from San Diego, CA, USA and was conducted from March 6 to May 30, 2019 (Figure 5A). During the first week, searching for live bait along the coast of central and southern Baja California, Mexico, Pacific sardine were located, caught, and loaded aboard. Having procured a full load of Pacific sardine, the cruise headed towards the Cocos Island National Park. Searching along the route through areas traditionally known to be productive for SKJ and YFT, no successful tagging opportunities were encountered. Upon arriving and notifying Costa Rican authorities, the search for signs of SKJ and YFT began, and while some YFT were located, the quantities were insufficient to provide reasonable tagging opportunities. Elevated SSTs (84-87°F) caused much of the Pacific sardine onboard to die. While operating around Cocos Island and within the territorial waters of Costa Rica, Tri-Marine provided access to dFADs that company vessels were unable to fish. Investigations around several dFADs resulted in no tagged tunas, even when the SATLINK echosounder buoys indicated aggregations of 60 to 80 tons were present. Out of bait and in need of fuel, a course was set for Panama City, Panama.

Spending about one week in the GOP to fuel, obtain provisions, and load live bait (anchoveta), a course was set for offshore fishing areas, searching for tuna schools while transiting towards the boundary of the GNP. Having little success in locating dFADs or unassociated schools, efforts were directed to searching around the TAO buoy array located along the 95°W meridian. Having experienced measured success over the course of a couple of weeks and with limited signs of tuna schools in the area, searching continued in a westerly direction towards the TAO array along the 110°W meridian. Continuing to experience limited success along the 110°W TAO array, the search continued towards the Shimada Seamount, a historically productive area for SKJ and YFT fishing.

Spending nearly three weeks tagging YFT and limited numbers of SKJ and being low on fuel and provisions, a course was set for Cabo San Lucas, southern Baja California, Mexico to fuel for the final journey up the coast to San Diego, CA, USA.

2020 tagging cruise

The second cruise in the RTTP series departed from San Diego, CA, USA and was conducted from February 1 to April 30, 2020 (Figure 5B). Lack of success during the 2019 tagging campaign inspired a modification to the cruise plan in 2020, where time would be spent investigating bait resources and evaluating tuna tagging opportunities within the GNP. After arriving in the GNP and clearing safety and environmental inspections, a series of meetings with collaborators were initiated to finalize operations within the area. The first of two observers embarked the vessel and the search for bait began. Based on a review of historical logbooks, probable areas where Pacific sardine might be encountered were identified and baiting efforts focused on those locations. After several days of effort, approximately 700 scoops of Pacific sardine had been loaded and tagging efforts began. After unsuccessfully searching for tunas in the northern area of the GNP, abundant unassociated schools of SKJ were encountered along the southern GNP boundary. Spending about a week fishing and tagging in the area, bait was running low, and it was time to exchange observers.

Upon changing observers, the search for bait resumed. Unfortunately, approximately one week was spent searching historical baiting areas, and no Pacific sardine were located. During this time, the COVID-19 pandemic manifested, and the pending closure of the GNP and other Ecuadorian ports dictated a necessary departure from the area. It was collectively agreed that the observer would disembark, fuel would be loaded aboard, and *F/V Her Grace* would depart the GNP, making the seven-day run to the GOP to catch and load anchoveta for bait. Upon arriving in the GOP, anchoveta were located in the traditional areas and approximately 1000 scoops were captured and loaded aboard over the course of several days.

After departing the GOP, the search for dFADs and unassociated schools resumed while transiting towards the fishing grounds along the southern GNP boundary; however, little signs of tuna were found. Some tagging opportunities were encountered around the GNP boundary, but overall, minimal signs of SKJ and other tunas were found. Having little justification for further searching efforts around the park boundary, searching was refocused to the area near the TAO array located along the 95°W meridian. Several large schools were found in association with the TAO buoys at 5°S and the 0° (equator), where substantial numbers of SKJ were successfully tagged with both PDTs and ATs over a ten-day period. With time running short and having roughly 200 scoops of bait remaining, the search for dFADs and unassociated schools continued towards the TAO buoy at the 5°N/110°W. Upon arriving at the TAO buoy, there was a large mixed-species aggregation associated and most of the remaining bait was utilized while fishing and tagging. After a day of successful tagging, out of time, and looking at an approximate 15-day transit back to San Diego, the aggregation was left at the TAO and a course set for San Diego, CA, USA

2022 tagging cruise

The third and final cruise in the RTTP series departed from San Diego, CA, USA and was conducted from March 1 to May 20, 2022 (Figure 5C). The third tagging cruise followed a similar itinerary as the first, except for baiting along the coast of southern Baja California, Mexico, making the 15-day transit directly to the northern GOP to refuel, for provisions, and procuring anchoveta for live bait. Catching anchoveta for live bait took approximately one week after which searching for tunas began. The search for dFADs and unassociated tuna schools began near a recently identified SST frontal area immediately following the departure from the GOP. No tunas were located in the vicinity of the SST frontal area, so searching was halted for about 26 hours while transiting the territorial waters of Colombia as permits were not provided.

Once back in international waters, the search for dFADs and unassociated schools resumed while transiting to the target area just south of the GNP boundary. Finding numerous natural logs and three dFADs, all of which had robust populations of associated triggerfish and dorado, no SKJ or other tunas were present. Over the course of the next week, the area around the GNP boundary was investigated, finding minimal signs of SKJ. Efforts in the GNP boundary area were abandoned and transitioned to the TAO array located on the 95°W meridian. Arriving at the equator TAO buoy, it was apparent the buoy had been recently set by a PS vessel, having ropes tied to the buoy and plastic bags covering the cameras and scientific equipment. This situation may have significantly affected tagging efforts as experienced during previous tagging cruises. However, during this occasion there was a small aggregation of SKJ and YFT, which was reluctant to bite, and limited time was spent fishing and tagging. After considerable effort and little success, a course was set for the TAO buoy at 2°S.

Arriving at the 2°S TAO buoy, it was presumed that it too had been set by a PS vessel, as the frame holding the scientific equipment was completely missing, leaving only the “donut” portion of the buoy. This type of damage has been known to occur when vessels attempt to separate the tuna aggregation from its association with the buoy. With only minimal amounts of small dorado present and no signs of SKJ, a course was set for the 5°S TAO buoy. Finding no fish and very rough weather at the 5°S buoy, the search continued back towards the east and around the GNP boundary. Several more days were spent searching to the southwest and west of the GNP finding good conditions, but no dFADs or tuna schools. Returning to the equator TAO buoy, it was clear that a PS vessel had once again visited the buoy, as the equipment was again covered in plastic and new mooring gear was affixed. Regardless of the recent activity, there was a SKJ school estimated to be about 30 tons associated with the buoy. The associated tunas were reluctant to bite, and after a full day trying numerous methods with little success, a course was set for the 2°N TAO buoy. The 2°N TAO buoy was determined to be no longer on station after time spent searching for it was unsuccessful.

Having identified a frontal feature within a couple hundred miles, the search resumed in a southwest direction, where several pods of dolphins with large YFT associated were located, but no fish were captured or tagged. The navigator of the PS vessel *TUNAMAR* provided access to fish and tag around a nearby dFAD, which showed 35 tons of aggregated fish on the SATLINK echosounder buoy. Upon locating the dFAD, little was present, and the search continued back towards the equator TAO buoy. Arriving at the equator TAO buoy there were obvious indications the buoy had once again been visited by either a PS or LL vessel, as there was more plastic covering the scientific equipment. There was a small aggregation of tuna present, which was reluctant to bite. Continuing to have limited success, a course was set heading back to the 2°S TAO buoy.

Arriving near the 2°S buoy in the early morning, it was clear a vessel was present immediately adjacent to the buoy based on the radar targets. Unfortunately, it appeared a PS vessel had set the buoy and caught what fish were present. Having found little success during the previous weeks near the TAO buoys and around the GNP boundary, a decision was made to search further west, but *F/V Her Grace* needed fuel to continue safely. Arrangements were made to take on fuel in the GNP at Isla Baltra. Fueling took roughly seven hours total, and once completed, the search resumed outside the GNP southern boundary.

While searching to the west, the TAO buoys were visited one final time, as historically they have been extremely productive, and schools can aggregate in as little as a few days. Upon approaching the 2°S TAO buoy, an Ecuadorian LL vessel was observed tied to the buoy. A quick evaluation indicated there were no fish present and a course was set for the equator TAO buoy. Arriving at the equator TAO buoy there was once again plastic over the scientific equipment, which was removed prior to departing. Having no appreciable SKJ or other tunas associated, a course was set for a strong SST frontal area to the northwest. The frontal area was located late in the day and followed westerly, as it had an east to west trajectory. Searching along the extremely strong (4°F change) front was very productive, in which nine dFADs were found over the course of two days. Unfortunately, no significant schools were associated and only a few small SKJ and YFT were tagged with PDTs and ATs.

Searching to the west continued over the course of several days while headed for the 2°S/110°W TAO buoy. Arriving at the buoy there was a small aggregation (< 2 tons) of mixed BET and YFT present, where several were tagged; however, not being a large SKJ aggregation, the search continued north along the 110°W meridian TAO buoy array. A few YFT and BET were tagged at the equator and 2°N TAO buoys, but with no SKJ present and time running short, the search continued northward. While transiting to the 5°N TAO buoy, a promising area to search for dFADs was located, and three dFADs were found over the course of two days. One dFAD had an approximate 25-ton school of BET and YFT which was not interested in biting well and an aggressive group of sharks made fishing and tagging difficult.

The 5°N TAO buoy had an aggressive tuna school, which provided the best tagging opportunity of the trip. Unfortunately, it was short lived, and the bulk of the fish departed the buoy after 30 hours and what remained was reluctant to bite. Continued efforts and nothing to show for it, a course was set for the 8°N TAO buoy, which lies within the territorial waters of Clipperton Island, France. French authorities were notified of our entry and were updated of daily activities while operating within territorial waters, including around Clipperton Island. There was little associated with the 8°N TAO buoy, where only a couple fish were tagged.

Arriving near Clipperton Island in the early morning hours, the search for SKJ and YFT began, only finding an abundance of YFT throughout the remainder of the day. Locating no SKJ, a course was set for the Shimada Seamount (Hurricane Bank) within the territorial waters of Mexico as there were recent reports of SKJ present in the area.

Arriving at Hurricane Bank in the early morning hours, the search for SKJ began, but very few were found. There were some YFT associated with the seamount and efforts were made to tag fish using rod-and-reel and trolling gear. Searching tirelessly for SKJ over the course of three days, resulted in little yield, in which only some YFT and a few SKJ had been tagged. At this point, the tagging portion of the cruise was completed, and *F/V Her Grace* began the week-long run back to San Diego, CA, arriving on May 20, 2022.