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Horizontal movements, utilization distributions, and mixing rates of yellowfin tuna (*Thunnus albacares*) tagged and released with archival tags in six discrete areas of the eastern and central Pacific Ocean

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Abstract

A total of 1522 yellowfin tuna, *Thunnus albacares*, were captured, tagged, and released with surgically implanted archival tags (ATs), in six discrete areas of the eastern and central Pacific Ocean, during 2002 through 2019. Of 483 ATs returned (31.7%), 227 ATs from yellowfin (48–147 cm in fork length) at liberty from 32 to 1846 d ($\bar{x} = 300.1$ d) provided suitable data sets which were processed using an unscented Kalman filter model with sea-surface temperature measurements integrated (UKFsst) in order to obtain most probable tracks and movement parameters. Although some differences were observed in the movement patterns for fish from within and among the six release areas, 99% of the 227 fish remained within 1000 M of their release locations, indicating limited dispersion and fidelity to release locations. The median movement parameter *D*, which defines dispersion from the UKFsst model, for the fish released in the offshore equatorial areas showed much greater dispersion rates compared to those for the fish released along the coast or around islands. The rates of mixing of yellowfin among the release areas were found to be dependent on the distances between release areas, with, in general, the greatest mixing occurring among areas in closest proximity, whereas for the two areas offshore Mexico and the two offshore equatorial areas, the rates of mixing were nonexistent or negligible.

KEYWORDS
archival tags, eastern and central Pacific Ocean, mixing rates, movement patterns, utilization distributions, yellowfin tuna

1 | INTRODUCTION

Yellowfin tuna, *Thunnus albacares*, is a large highly mobile pelagic species, distributed worldwide in tropical and subtropical seas except the Mediterranean, and is of substantial socioeconomic importance (Collette & Graves, 2019; Miyake et al., 2010). Yellowfin is the principal target species of a large international purse-seine fishery in the eastern Pacific Ocean (EPO), from which the average annual retained catch during 1999–2018 was 253 thousand metric tons (range: 167 to 412 thousand metric tons) (Anonymous, 2019). Yellowfin were caught by purse-seine vessels operating in the EPO during 2013–2018 from about 30°N to 20°S and from the coast of the Americas west to about 150°W (Anonymous, 2019).

Yellowfin spawning in the Pacific Ocean is widespread, occurring throughout the year in the warm northern equatorial and tropical waters, but in the more northern or southern regions, it is seasonal, restricted to periods when sea-surface temperatures (SSTs) exceed 24°C (Schaefer, 2001). Yellowfin spawn throughout the EPO from at least 26°N to 14°S and from the coast of the Americas to 150°W (Schaefer, 1998). Yellowfin do not undertake spawning migrations like the temperate Pacific bluefin (*Thunnus orientalis*) and albacore (*Thunnus alalunga*) tunas which exhibit transpacific migrations and have spatiotemporally confined spawning patterns in the central and western Pacific (Block et al., 2011; Childers et al., 2011; Schaefer, 2001). Tagging studies on yellowfin throughout the EPO, utilizing plastic dart tags (PDTs), have indicated that movements of tagged fish at liberty for more than 30 d tend to be restricted to less than 1000 M of their release positions (Bayliff, 1979, 1984; Bayliff & Rothschild, 1974; Fink & Bayliff, 1970). Those studies indicate regional fidelity to tagging areas, with little exchange of fish between the northern and southern regions of the EPO. A more recent yellowfin tagging study in the northern region of the EPO, from which 126 archival tags (ATs) were recovered from yellowfin (57–162 cm in fork length) at liberty from 90 to 1161 d ($\bar{x} = 273.2$ d), indicated that 95% of the yellowfin remained within 844 M of their release locations, indicating restricted horizontal utilization distributions (UDs) and fidelity to the areas of release (Schaefer et al., 2011).

Analyses of morphometric and meristic data collected from yellowfin have shown differences among fish from the eastern, central, and western Pacific and latitudinal differences for fish from both the eastern and western Pacific (Schaefer, 1991, 1992). Although there is annual variability in the morphometric characters, the results demonstrated that the stocks examined are morphometrically distinguishable and that their phenetic relationships reflect their geographic origin (Schaefer, 1992). Geographic variation observed in morphometric characters and gill raker counts of yellowfin from northern and southern regions of the EPO results from restricted movements, limited mixing, and environmental variation (Schaefer, 1992). In addition, a genomic study utilizing microsatellite variation provided some preliminary evidence of the presence of discrete northern and southern yellowfin populations in the EPO (Díaz-Jaimes & Uribe-Alcocer, 2006).

A benchmark stock assessment for yellowfin in the EPO was recently undertaken (Minte-Vera et al., 2020), utilizing a risk analysis approach, in which a variety of reference models were used to represent plausible alternative hypotheses about the biology of the fish, the productivity of the stocks, and/or the operation of the fisheries (Aires-da-Silva et al., 2020). The overall results of the risk analysis indicate only a 9% probability that the fishing mortality corresponding to the maximum sustainable yield and a 12% probability that the spawning stock biomass corresponding to the maximum sustainable yield have been breached. However, the main uncertainty within the risk analysis (Maunder et al., 2020) which may explain the inconsistencies among catch-per-unit-of-effort indices from the northern and southern regions of the EPO is the degree of spatial mixing. The low mixing and episodic mixing hypotheses that imply the existence of more than one stock of yellowfin in the EPO were not included in the reference models.

Over the past two decades, tagging experiments, utilizing ATs, with large pelagics have provided rich data sets for evaluating spatiotemporal movement patterns and habitat utilization for the species investigated (Arnold & Dewar, 2001; Block et al., 2011; Schaefer & Fuller, 2016). ATs can vastly improve our understanding of movement patterns, UDs, mixing rates, and putative stock structure of tunas, all of which are essential for improving stock assessments (Senina et al., 2012; Sippel et al., 2015; Taylor et al., 2011). Current generation ATs are capable of autonomous sampling of high-resolution data for several years, providing opportunities to evaluate the influence of seasonal and annual environmental variability and ontogenetic changes in movement patterns and habitat utilization (Schaefer & Fuller, 2016). Furthermore, utilizing state-space models such as the unscented Kalman filter model with SST measurements integrated (Lam et al., 2008; Nielsen et al., 2006) for analyses of AT geolocation data sets provides improved estimates of geographic positions and most probable tracks (MPTs) along with their confidence intervals.

Considering the apparent restricted movements and incomplete mixing of yellowfin in the EPO, the importance of developing a spatially structured stock assessment model with mixing incorporated has been noted (Minte-Vera et al., 2020). In order to develop a realistic spatially structured assessment model, it is necessary to better understand yellowfin movement patterns, UDs, mixing rates, and putative stock structure within the region. This can be achieved but requires large-scale tagging studies utilizing ATs, conducted throughout the region of the EPO inhabited by yellowfin.

The objectives of this investigation are to quantify and elucidate the movement patterns, UDs, and mixing rates of yellowfin, based on a total of 1522 fish (30–161 cm fork length) tagged and released with ATs in six discrete areas of the EPO and central Pacific Ocean (CPO), at liberty from 32 to 1846 d ($\bar{x} = 300.1$ d, median = 241.5 d) during 2002–2019. The results obtained are informative and useful to evaluate putative stock structure and connectivity for consideration of incorporating into future stock assessments and for conservation and management measures for yellowfin in the EPO.

2 | MATERIALS AND METHODS

2.1 | Tag releases

The materials and methods utilized for the capture, handling, and tagging of the yellowfin is described in Schaefer et al. (2007). The AT configurations are designed for internal implantation of the tag body into the coelom of fish. The external sensor stalk exits the body of the fish through an incision, from which the ambient light-level and temperature measurements originate. A label with information about reporting the recovery of the AT and the associated reward (US$250) was printed on the main body of the AT. The depth (pressure), ambient and internal temperatures, and light-level data were programmed to be stored in the memory of the ATs at frequencies of either 30 or 60 s, dependent on tag type and available memory.

Yellowfin with implanted ATs were also tagged with one serially numbered 13-cm green PDT manufactured by Hallprint Pty, Ltd., Hindmarsh Valley, South Australia, using tubular stainless-steel applicators. PDTs were inserted, on one side of the fish, into the dorsal musculature with the barbed heads passing between the pterygiophores below the base of the second dorsal fin. A request that the finder report the recapture of the fish and informing him or her that there was a $250 reward for the return of the AT was printed on these tags.

All fish were captured and handled following the guidelines outlined by the National Institutes of Health (NIH), international guiding principles for biomedical research involving animals (NIH, 2012).

2.2 | Baja California, Mexico

The tagging was conducted aboard the San Diego-based sport-fishing vessels FV *Royal Star* (28 m) and the FV *Shogun* (27 m). A total of 644 fish (mean fork length = 76.4 cm; range = 55–135 cm) were captured, tagged, and released with ATs, between October 2002 and December 2008. The ATs used were model LTD2310 manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada). The design, specifications, and performance of those ATs are described in Schaefer and Fuller (2016).

2.3 | Revillagigedo Islands, Mexico

The tagging was conducted aboard the San Diego-based 28-m sport-fishing vessel FV *Royal Star*. A total of 345 fish (mean fork length = 102.3 cm; range = 56–161 cm) were captured, tagged, and released with ATs between February 2006 and March 2013. Two hundred twenty-seven of the ATs were model LTD2310, and 118 were model Mk9 ATs manufactured by Wildlife Computers (Redmond, Washington, United States). The design, specifications, and performance of the Mk9 ATs are described in Schaefer and Fuller (2016).

2.4 | Clipperton Island, France

The tagging was conducted aboard the San Diego-based 28-m sport-fishing vessel FV *Royal Star*. A total of 147 fish (mean fork length = 106.6 cm; range = 69–160 cm) were captured, tagged, and released with ATs between February 2012 and March 2013. The ATs used were models LAT2910 in 2012 and LAT2810 in 2013, both manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada). The design, specifications, and performance of those ATs are described in Schaefer and Fuller (2016).

2.5 | Panama

The fishing and tagging was conducted aboard the 7.6-m *Kihada Maru*, a panga operating out of the IATTC Achotines Laboratory, located on the Azuero Peninsula, Panama (Margulies et al., 2007). A total of 110 fish (mean fork length = 60.0 cm; range = 47–82) were captured, tagged, and released with ATs around the Frailes Islands, Panama, between January 2007 and September 2009. The ATs used were models LAT2510 in 2008 and LTD2310 in 2007, 2008, and 2009, manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada).

2.6 | Equatorial EPO

Tagging was conducted on the chartered *MV Her Grace*, a 17.7-m US west-coast-style live-bait pole-and-line vessel, with home port of San Diego, CA. A total of 95 fish (mean fork length = 50.0 cm; range = 30–80 cm) associated with Tropical Atmosphere Ocean (TAO) moorings, were captured, tagged, and released with ATs in the equatorial EPO from about 5°N to 5°S and 95°W to 110°W between May 2003 and April 2019. Releases consisted of eight LAT1100, 45 LTD2310, 19 LAT2910, and 14 ArcGeo 9 ATs manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada) and nine Mk9 ATs manufactured by Wildlife Computers (Redmond, Washington, United States).

2.7 | Equatorial CPO

Tagging was conducted aboard the chartered *FV Ao Shibi Go* (19 m) and the *FV Gutsy Lady 4* (26 m), longline vessels outfitted for fishing using danglers and short troll lines, with home ports of Honolulu, Hawaii. A total of 181 fish (mean fork length = 63.0 cm; range = 42–115 cm) found associated with TAO moorings were captured, tagged, and released with ATs in the equatorial CPO from about 5°S to 8°N and 140°W to 155°W between October 2009 and October 2015. Releases consisted of 104 LAT2810, two LTD2310, and 56 LAT2910 ATs manufactured by Lotek Wireless Inc. (St. John's, Newfoundland, Canada) and 19 Mk9ATs manufactured by Wildlife Computers (Redmond, Washington, United States).

2.8 | Tag recoveries

Most all recoveries of ATs were made during the unloading of purse-seine vessels while in port, but there were also a few recoveries aboard gillnet, longline, pole-and-line, purse-seine, and recreational vessels at sea. The primary recapture information sought is the recapture date and location, vessel name and type, and the length of the fish. However, most of the tags are recovered by unloaders of purse-seine vessels, and the information commonly provided is the date the tagged fish was found, along with the vessel name and the number of the storage well in which it was found. Comparing that information with observer records from purse-seine trips in the EPO, it is normally possible to verify with reasonable accuracy the recapture dates and locations for most tagged fish recovered during the unloading of purse-seine vessels. Further validation of recovery dates and locations was conducted when reviewing data downloaded from ATs, as it is possible from the depth and temperature data to determine when fish are captured, loaded into cold storage, and subsequently unloaded.

In cases for which a staff member from one of the IATTC field offices received a fish with the tag intact from a finder during the unloading of a purse-seine vessel and the storage well number confirmed, or an observer aboard a purse-seine vessel during a trip was shown a recaptured tagged fish following a set, the recapture information was classified as high confidence. Recaptures by longline vessels were usually found at sea, and accurate recapture details provided. Such recaptures were also classified as high confidence.

2.9 | Data processing

Data sets from ATs returned for fish at liberty for 30 d or greater are included in this study, except those AT data sets from releases off Baja California and the Revillagigedo Islands which are for fish at liberty for 90 d or greater, because of an overabundance of AT returns from those release areas.

Data were downloaded from the recovered tags using software provided by the tag manufacturers. AT data sets were imported into Tagbase for simple, single-point data management (Lam & Tsontos, 2011). Queries were written to extract information from the Tagbase for use in other software packages, including R (R core team, 2017), Microsoft Excel, and the Environmental Systems Research Institute (ESRI) ArcMap.

AT recapture date is determined directly from the time series data downloaded from the tag. Utilizing the date of recapture and the vessel name provided by the finder, recapture position is determined from observer records and/or an abstract of the vessel logbook.

Position estimates provided from the tag manufacturer's proprietary software were based on ambient light-level data, with times of dawn and dusk used to estimate longitude from the estimated time of local noon and latitude from the local day length (Ekstrom, 2004). The raw light-based latitude estimates were highly variable and unreliable around the time of the equinoxes due to the nearly constant 12-h day length at all latitudes. Daily SSTs recorded by the tags matched to SSTs from remote sensing have been shown to significantly improve estimates of latitude (Nielsen et al., 2006; Teo et al., 2004). Daily SST values derived from the AT data were calculated with algorithms provided by the tag manufacturers.

The unscented Kalman filter model with SST measurements integrated (UKFsst) (Lam et al., 2008) was used to obtain improved estimates of positions, MPTs, and movement parameters. The UKFsst model, a state-space model in which the transition equation describes the movements, is very similar to the Kalman filter model, with SST measurements integrated, described by Nielsen et al. (2006). The UKFsst model is a better model for handling nonlinearities and has the advantage that every model parameter is handled within a statistical framework. The UKFsst model can also utilize remotely sensed SST data of various spatial resolutions, and it automatically estimates the amount of smoothing required for the SST field. The UKFsst model parameterizes movement as a biased random walk, with the movement partitioned into directed (u and v) and dispersive (D) movements. The model also estimates the geolocation errors as the longitude (σ_x) and latitude (σ_y) standard deviations. The NCEP Reynolds Optimally Interpolated 8-d SST (R-OI) composite product with 1° area resolution (accuracy of 0.5–0.7°C), derived from Advanced Very High Resolution Radiometer (AVHRR) Pathfinder data and in situ measurements of SST (Reynolds & Smith, 1994), was utilized in the UKFsst model to obtain initial parameter estimates. In an effort to reduce error in latitude and longitude, the UKFsst model was then fit, utilizing the parameters derived within the R-OI model runs, using either the NOAA POES AVHRR Global Area Coverage (GAC) 8-d SST composite product with 0.1° area resolution (accuracy of 0.3–0.5°C) (Vazquez et al., 1998), or the NOAA CoastWatch Blended 5-d SST composite product with an 11 km resolution (NOAA, 2020), to obtain the final MPT and parameter estimates (Schaefer et al., 2011).

Due to the relatively coarse resolution of satellite-derived SST data and the error of light-based estimates, fish released along the coast of Panama had a high incidence of positions occurring on land. To overcome unrealistic positions, a bathymetry correction was applied using the *analyzepsat* package in R, which incorporated the maximum daily depth recorded on each tag, the ETOPO1 Global Relief bathymetry data set, and the UKFsst model fits (Galuardi et al., 2010). The resulting MPTs no longer have position estimates on land without sacrificing the error estimates about each position (Galuardi et al., 2010).

For the 227 yellowfin AT data sets evaluated in this study, a daily position was estimated along the MPTs, except when no position was available due to the lack of a light-based position estimate, or tag failure. The number of estimated positions as a percentage of the deployment period for each fish ranged from 16% to 100%. For the 227 fish, a total of 54,157 estimated daily positions were obtained.

Each set of position estimates along the MPT for individual fish, derived from the UKFsst model, was integrated into ESRI ArcMap 10.0, a Geographic Information System (GIS) platform. ArcMap was used for spatial analyses of all data sets. Volume contours (UDs) were derived from a kernel density function for aggregated positions using a 1° search radius and a 0.01° output cell for each release area.

The mixing rates of fish among the six areas were estimated by evaluating the proportion of fish from a release area whose MPTs entered into the 100% UD of the fish from another release area for a period of 1 day or longer.

3 | RESULTS

3.1 | Releases and recoveries of ATs

The positions where 1522 yellowfin were tagged and released with ATs is shown in Figure 1. The pertinent information associated with the releases and recaptures of fish, with ATs returned and utilized in this study by area, are given in Appendix A. The total numbers of fish released with ATs and subsequent returns by areas are considerably different (Table 1). Of the total 1522 ATs deployed, returns by area to date range from 308 (47.8%) for off Baja California to 8 (4.4%) for the equatorial CPO. For the total 483 (31.7%) fish recaptured with ATs returned, 202 (89.0%) came from purse-seine vessels, one (0.4%) came from longline vessels, one (0.4%) came from pole and line vessels, 22 (9.8%) came from recreational fishing vessels, and one (0.4%) came from a coastal gillnet boat.

3.2 | Length distributions of releases by area

The length-frequency distributions of fish released by areas with ATs are given in Figure 2. The length-frequency distributions for the fish released at the Revillagigedo Islands and Clipperton Island exhibit greater fork length ranges than for the other areas. The median fork length was considerably larger for releases at Clipperton Island, and the median fork length was considerably smaller for releases in the equatorial EPO, compared to the other release areas.

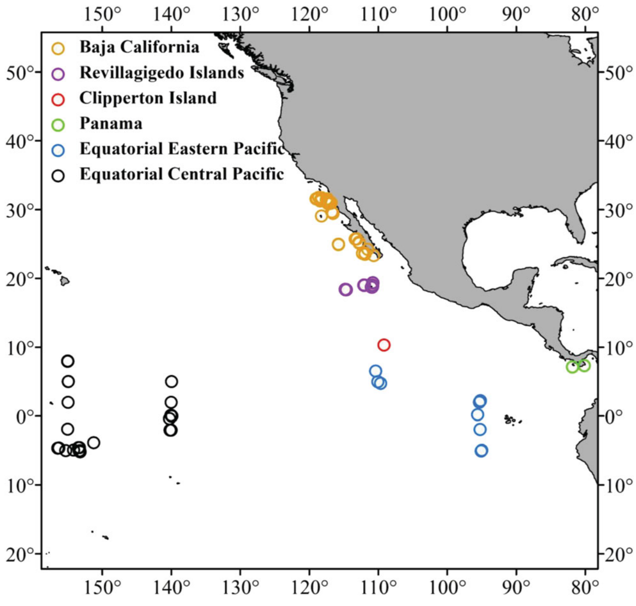

FIGURE 1 Positions where 1522 yellowfin were tagged and released with archival tags

3.3 | Days at liberty

The numbers of fish released with ATs and returns by days at liberty (DAL) are considerably different among release areas (Table 1). For the fish released off Baja California and the Revillagigedo Islands, for which only ATs recovered from fish at liberty for ≥90 d are included in this study, the mean DAL was 323.3 d (range: 90.0–1846.5 d). For the fish released around Clipperton Island, off the coast of Panama, and in the equatorial EPO, for which all ATs recovered from fish at liberty for ≥30 d are included in this study, the mean DAL was 217.0 d (range: 32.2–834.7 d). However, for the fish released in the equatorial CPO, for which all ATs recovered from fish at liberty for ≥30 d are included in this study, the mean DAL was 77.4 d (range: 58–99 d), considerably less than for the other five release areas.

3.4 | MPTs and UDs

MPTs for the fish with the longest linear displacement (LD) and the fish with the longest DAL released off Baja California are plotted in Figure 3a,b, respectively. The fish in Figure 3a was recaptured after 560 d by a purse-seine vessel, 1115 M 211° from the release location, and the fish in Figure 3b was recaptured after 1161 d by a recreational fishing vessel, 151 M 149° from the release location. The kernel density plot for all position estimates along the MPTs for the 126 fish released off Baja California with DAL ≥ 90 d is shown in Figure 3c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

MPTs for the fish with the longest LD and the fish with the longest DAL released around the Revillagigedo Islands are plotted in Figure 4a,b, respectively. The fish in Figure 4a was recaptured after 507 d by a purse-seine vessel 930 M 240° from the release location, and the fish in Figure 4b was recaptured after 655 d by a recreational fishing vessel 8.8 M 57° from the release location. The kernel density plot for all position estimates along the MPTs for the 58 fish released around the Revillagigedo Islands with DAL ≥ 90 d is shown in Figure 4c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

TABLE 1 Releases and returns of archival tags implanted in yellowfin, by release area, and days at liberty

		Returned					
Area	Released	<30	30–89	90–179	180–365	>365	Total (%)
Baja California	644	88	44	35	115	26	308 (47.8)
Revillagigedo Islands	345	9	23	22	14	28	96 (27.8)
Clipperton Island	147	5	10	3	11	5	34 (23.1)
Panama	110	0	2	10	9	3	24 (21.8)
Equatorial eastern Pacific	95	4	4	3	1	1	13 (13.7)
Equatorial central Pacific	181	0	3	3	0	2	8 (4.4)
All	1522	106	86	76	150	65	483 (31.7)

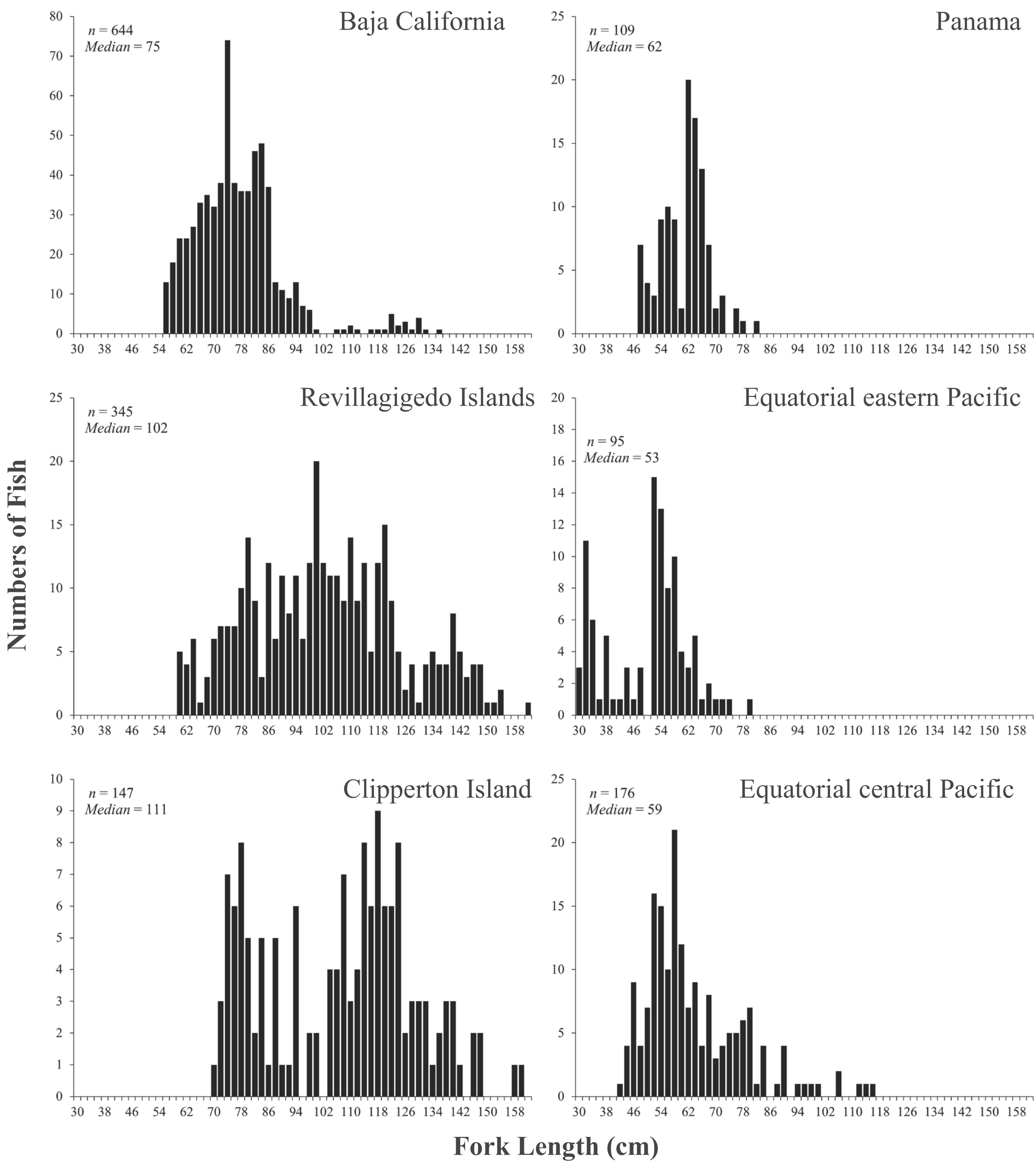

FIGURE 2 Length-frequency distributions, by area, for yellowfin tagged and released with archival tags

MPTs for the fish with the longest LD and the fish with the longest DAL released around Clipperton Island are plotted in Figure 5a,b, respectively. The fish in Figure 5a was recaptured after 88 d by a purse-seine vessel 647 M 269° from the release location, and the fish in Figure 5b was recaptured after 529 d by a purse-seine vessel 632 M 100° from the release location. The kernel density plot for all position estimates along the MPTs for the 13 fish released off Clipperton Island with DAL ≥ 30 d is shown in Figure 5c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

MPTs for the fish with the longest LD and the fish with the longest DAL released off Panama are plotted in Figure 6a,b, respectively. The fish in Figure 6a was recaptured after 177 d by a purse-seine vessel 435 M 298° from the release location, and the fish in Figure 6b was recaptured after 254 d by a purse-seine vessel 85 M 132° from the release location. The kernel density plot for all position estimates

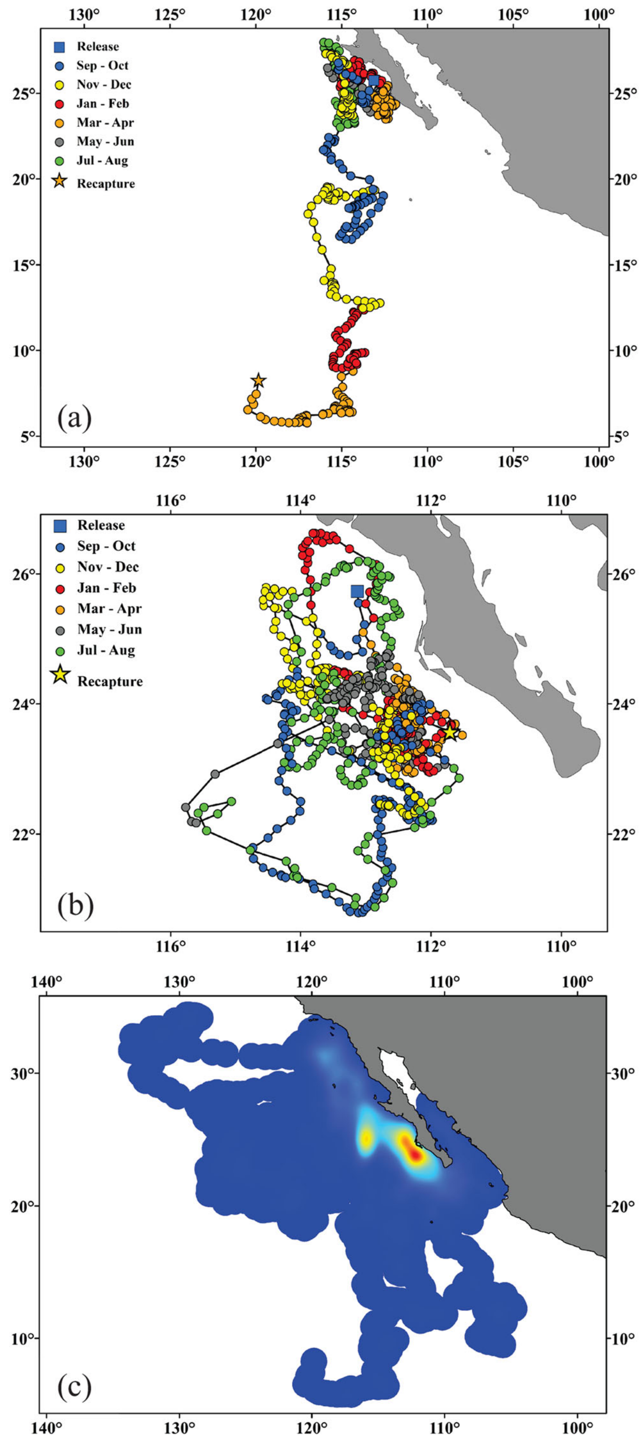

FIGURE 3 Most probable tracks, estimated from the unscented Kalman filter model, for fish released off Baja California, color-coded by bimonthly periods. (a) Tag A0478, the longest linear displacement, 560 days at liberty, 561 position estimates. (b) Tag A0525, the longest days at liberty, 1161 d, 940 position estimates. (c) Kernel density plot for all positions, from 126 fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

along the MPTs for the 17 fish released off Panama with DAL ≥ 30 d is shown in Figure 6c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

MPTs for the fish with the longest LD and the fish with the longest DAL released in the equatorial EPO are plotted in Figure 7a,b, respectively. The fish in Figure 7a was recaptured after 65 d by a purse-seine vessel 491 M 271° from the release location, and the fish in Figure 7b was recaptured after 112 d by a purse-seine vessel 372 M 82° from the release location. The kernel density plot for all position estimates along the MPTs for the eight fish released in the equatorial EPO with DAL ≥ 30 d is shown in Figure 7c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

MPTs for the fish with the longest LD and longest DAL, and the fish with the third longest DAL, as the fish with the second longest DAL experienced a tag failure prior to recapture, released in the equatorial CPO, are plotted in Figure 8a,b, respectively. The fish in Figure 8a was recaptured after 99 d by a purse-seine vessel 523 M 277° from the release location, and the fish in Figure 8b was recaptured after 70 d by a purse-seine vessel 327 M 274° from the release location. The kernel density plot for all position estimates along the MPTs for the five fish released in the equatorial CPO with DAL ≥ 30 d is shown in Figure 8c. The summary statistics describing the movements and dispersion for those fish are given in Table 2.

3.5 | Movement parameters

The median parameter estimates from the UKFsst model for errors in longitude (σx) and latitude (σy), eastward and northward directed movements (*u* and *v*), and dispersive movement (*D*) are summarized by area of release and for all fish pooled in Table 3. Eastward directed movement (*u*) is defined by a negative value, and northward directed movement (*v*) is defined by a positive value.

The median parameter estimates for directed movements (*u* and *v*) for the fish released off Baja California indicate a slight southward component (0.77 M/d) to their movement patterns. The median parameter estimates for the fish released around the Revillagigedo Islands (0.07 M/d) and Clipperton Island (0.02 M/d) effectively indicate no directional movement patterns. The median parameter estimates for fish released off Panama indicate a westward (0.87 M/d) and slight northward movement pattern (0.47 M/d). The median parameter estimates for fish released in the equatorial EPO and CPO indicate pronounced westward (2.27 and 4.74 M/d, respectively) and slight northward (1.08 and 0.91 M/d, respectively) movement patterns.

Error in longitude (*x*) and latitude (*y*) estimated in the UKFsst model for the six release areas ranged from 0.0° to 1.51° and 0.4° to 21.32° (0–91 M and 24–1279.2 M), respectively. The median parameter estimates obtained from the pooled data for the fish from the equatorial EPO and CPO indicate that the expected error in position estimates along MPTs should be within 28.2 M in longitude and 86.4 M in latitude, with an estimated daily dispersion (D) of 453.1 M^2/d. However, the median parameter estimates obtained from the pooled data for the fish from the Revillagigedo Islands and Clipperton Island indicate that the expected error in position estimates along

TABLE 2 Summary statistics for the days at liberty and parameters describing the movements and dispersion of 227 yellowfin by release area, listed in Appendix A

	Release area					
Parameter	Baja California	Revillagigedo islands	Clipperton Island	Panama	Equatorial EPO	Equatorial CPO
Number of fish	126	58	13	17	8	5
Mean days at liberty	273.2	454.9	213.3	213.7	200.8	77.4
Range of days at liberty	90–1161	90–1846	32–529	86–812	36–835	58–99
Latitude range	5.8°N to 34.4°N	6.3°N to 27.5°N	4.1°N to 16.0°N	2.1°N to 10.7°N	2.7°S to 12.6°N	6.2°S to 1.8°N
Longitude range	105–134°W	102–126°W	97–121°W	77–91°W	84–112°W	139–160°W
Number (%) of fish remaining within 1000 M of release	124 (98)	58 (100)	13 (100)	17 (100)	8 (100)	5 (100)
95% of positions are within (M) of release	467	376	438	382	621	263
100% volume contour (M^2)	26,257	20,207	11,093	5197	15,393	5403
50% volume contour (M^2)	844	345	291	355	1811	841

Note: The 100% and 50% volume contours (utilization distributions) were calculated from a kernel density function for all positions, along most probable tracks, utilizing a 1° search radius and a 0.01° output cell size.

MPTs should be within about 28.4 M in longitude and 109.8 M in latitude, with an estimated daily dispersion (D) of about 123.1 M.

3.6 | Mixing rates

The 100% UDs encompassing all position estimates along MPTs for fish from each of the six release areas separately are illustrated in Figure 9. The numbers and percentages of fish by release area which had one or more daily position estimates along their MPTs within the 100% UD for the fish from another release area are given in Table 4. A high percentage of mixing is observed for fish released off Baja California, the Revillagigedo Islands, and Clipperton Island. But there was no mixing observed among fish from those release areas within the UDs for fish released off Panama or in the equatorial CPO. There was a significant amount of mixing observed for the fish released around Clipperton Island and those in the equatorial EPO. There was no mixing observed between fish released in the equatorial EPO and CPO, for which the distance between the nearest release locations within those areas was 1853 M. However, the median DAL for the fish released in the equatorial CPO was significantly shorter than for those from the equatorial EPO or the other release areas (Table 2).

The degree of mixing observed among fish from the six release areas was found to be dependent on the distances between those areas, in conjunction with the restricted 100% and 50% UDs for the fish by release area (Table 2).

4 | DISCUSSION

The results presented herein from tagging experiments undertaken with yellowfin in six discrete areas of the EPO, based on 1522 AT deployments during 2002–2019, provide a better understanding of the movement patterns, UDs, and mixing rates of yellowfin in the EPO. The MPTs derived from the 227 yellowfin AT data sets evaluated in this study, for a wide range of fish fork lengths (48.0–147.0 cm, $\bar{x} = 85.5$ cm) and times at liberty (32.2–1846.5 d, $\bar{x} = 300.1$ d), demonstrate restricted movements, with limited latitudinal and longitudinal dispersion and strong fidelity to release areas, particularly for those fish released in close proximity to coastal areas or islands. The rates of mixing of yellowfin among the different release areas in this study were found to be dependent on the distances between areas, with, in general, the greatest mixing occurring among areas in closest proximity, whereas for those areas separated by more than 1000 M, the rates of mixing were nonexistent or negligible.

4.1 | MPTs and UDs

Analyses of the AT data sets utilizing the UKFsst model (Lam et al., 2008) allowed the reconstruction of MPTs of individual fish, and estimation of movement parameters by release areas, and for the pooled data. The MPTs from the 227 AT data sets from the six release areas demonstrated that 99% of those fish remained within 1000 M of their release locations.

It is evident from the analyses in this study that there is some variation in movement patterns among individuals from within and between release areas. The movement patterns based on the MPTs for the fish released off Baja California showed the largest 100% UD (26,257 M^2) of the six release areas, with 95% of the positions within 467 M of release locations. The movement patterns based on the MPTs for the fish released around the Revillagigedo Islands, Clipperton Island, and Panama showed smaller 100% UDs

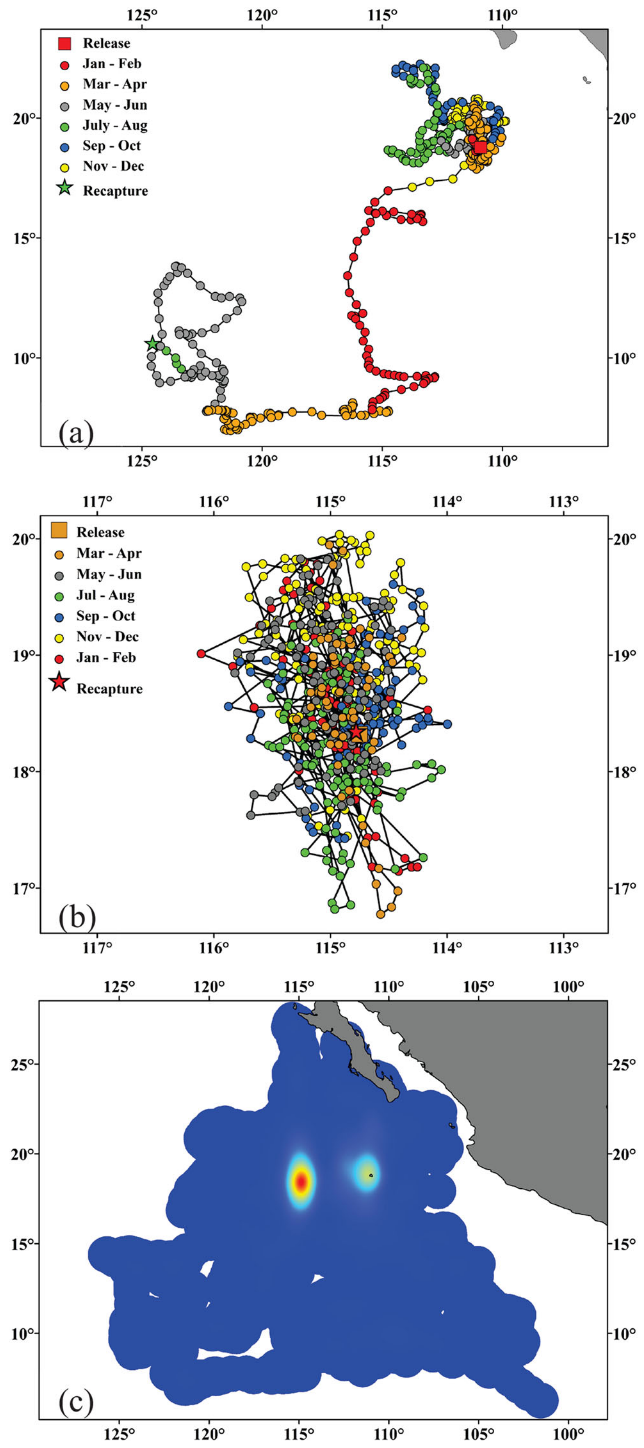

FIGURE 4 Most probable tracks, estimated from the unscented Kalman filter model, for fish released around the Revillagigedo Islands, color-coded by bimonthly periods. (a) Tag D1589, the longest linear displacement, 507 days at liberty, 508 position estimates. (b) Tag 1090062, the longest days at liberty, 655 d, 594 position estimates. (c) Kernel density plot for all positions, from 58 fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

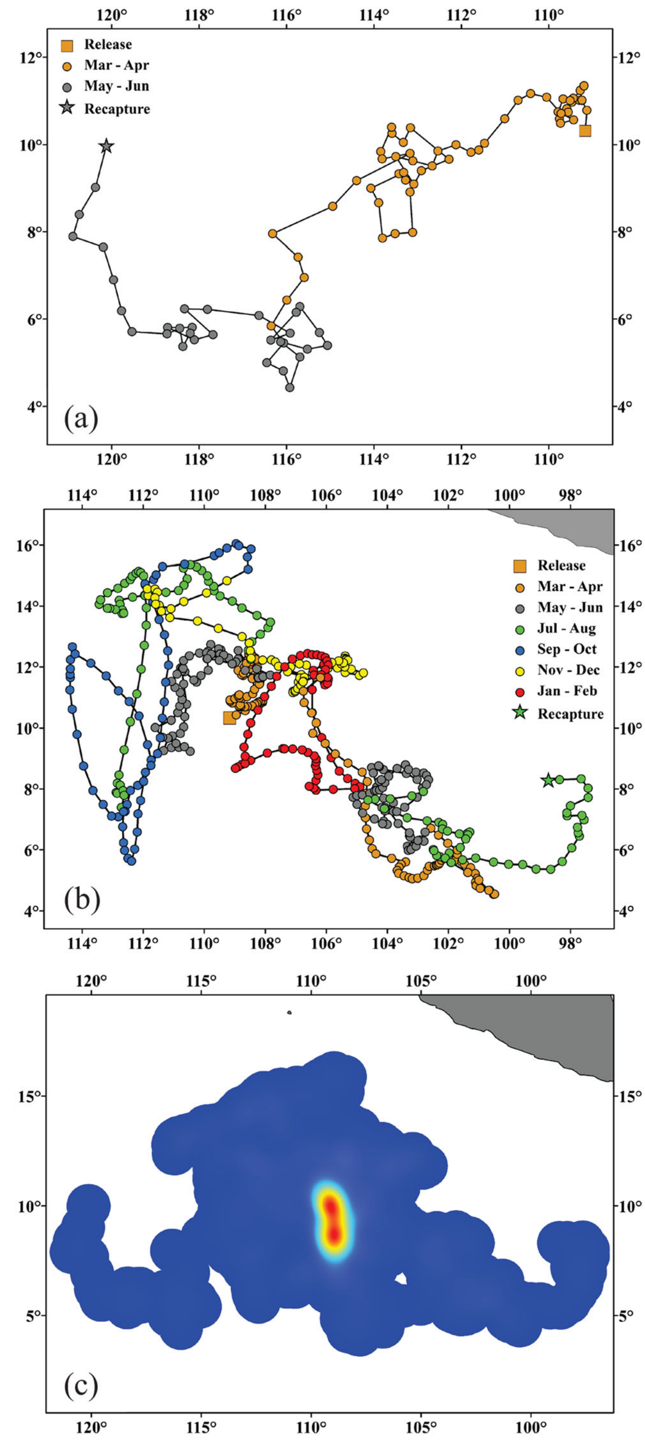

FIGURE 5 Most probable tracks, estimated from the unscented Kalman filter model, for fish released around Clipperton Island, color-coded by bimonthly periods. (a) Tag B1207, the longest linear displacement, 88 days at liberty, 89 position estimates. (b) Tag B1150, the longest days at liberty, 529 d, 528 position estimates. (c) Kernel density plot for all positions, from 13 fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

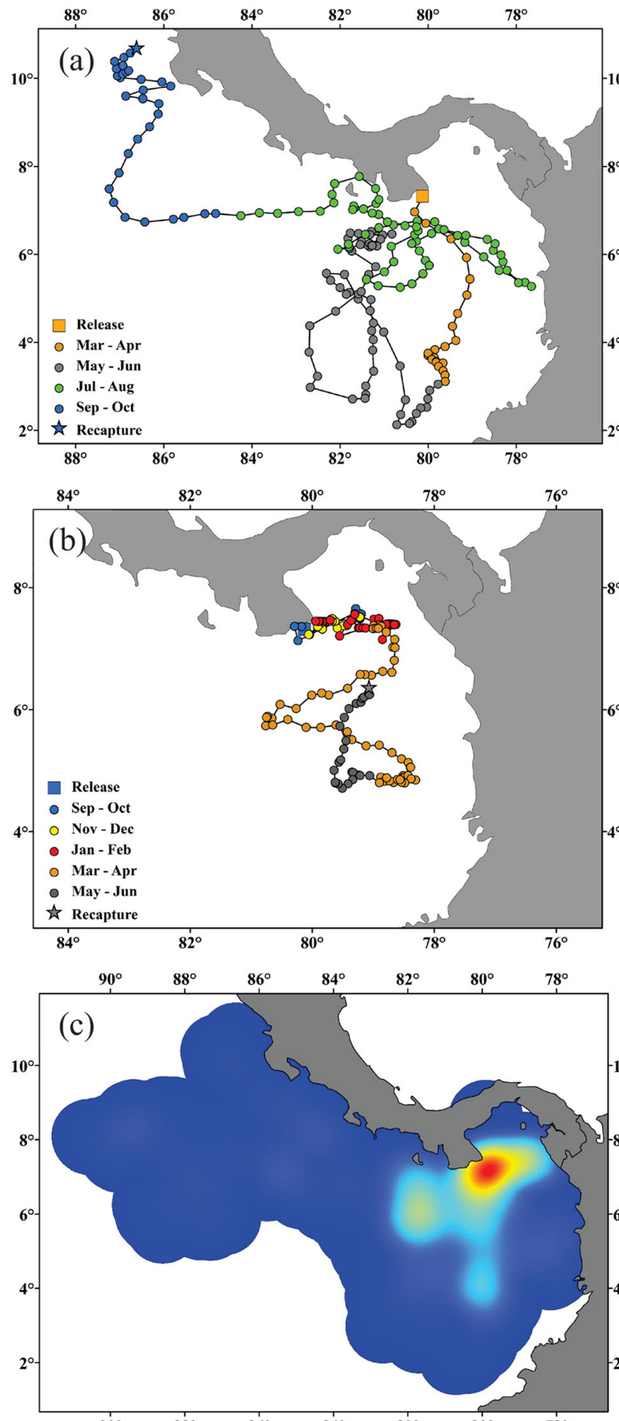

FIGURE 6 Most probable tracks, estimated from the unscented Kalman filter model, for fish released near the coast of Panama, color-coded by bimonthly periods. (a) Tag D0739a, the longest linear displacement, 177 days at liberty, 175 position estimates. (b) Tag D4387, the longest days at liberty, 254 d, 240 position estimates. (c) Kernel density plot for all positions, from 17 fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

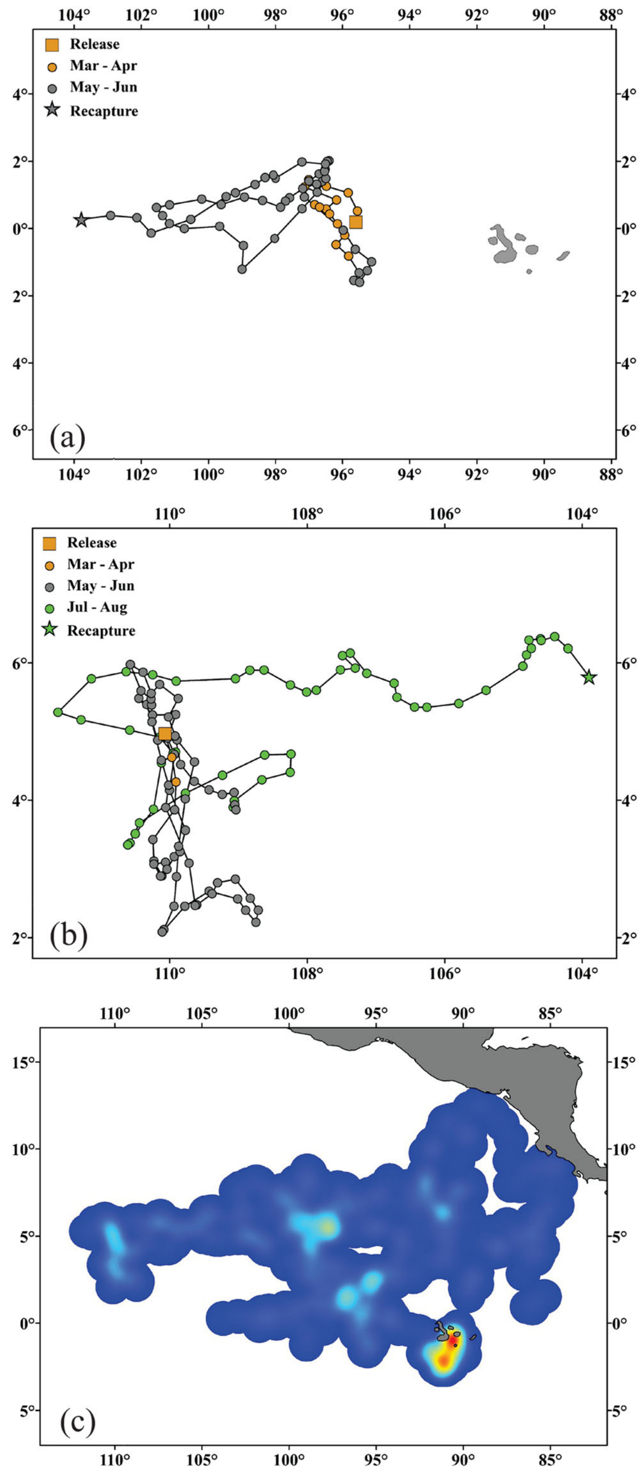

FIGURE 7 Most probable tracks, estimated from the unscented Kalman filter model, for fish released in the equatorial eastern Pacific, color-coded by bimonthly periods. (a) Tag 1890108, the longest linear displacement, 65 days at liberty, 52 position estimates. (b) Tag 1441, the longest days at liberty, 112 d, 114 position estimates. (c) Kernel density plot for all positions, from eight fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

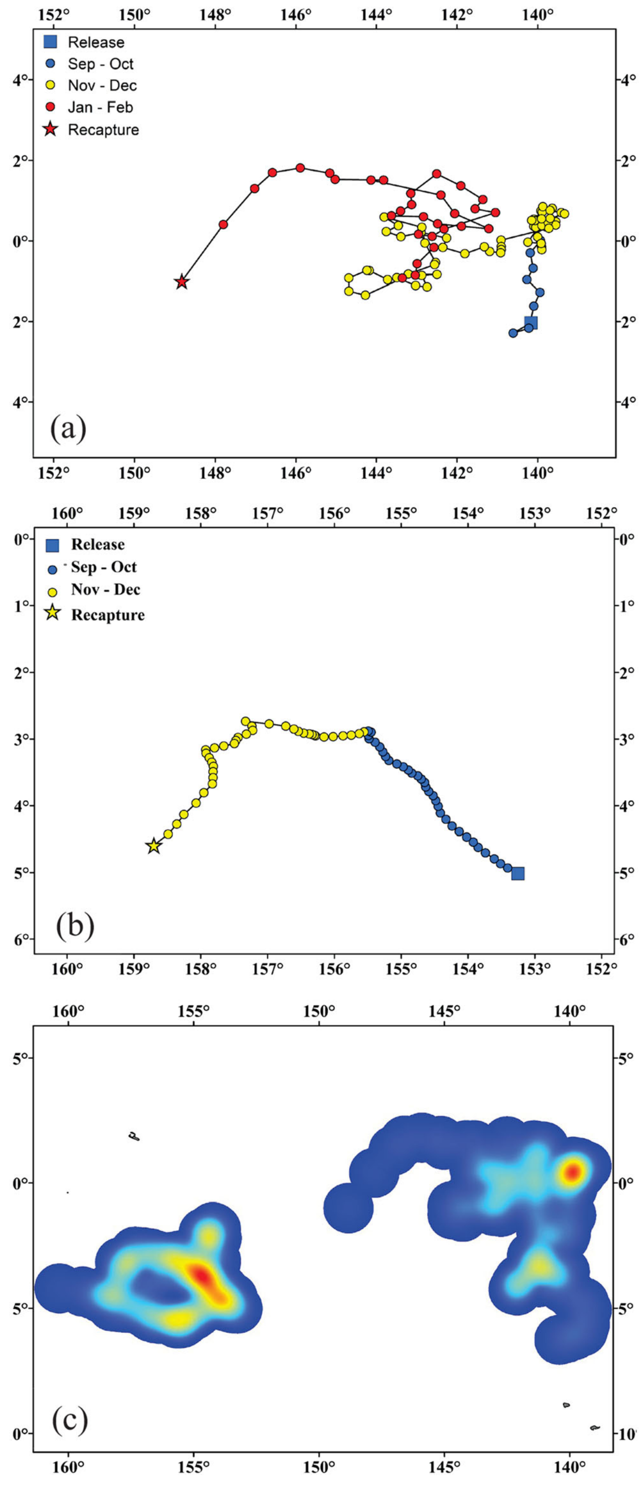

FIGURE 8 Most probable tracks, estimated from the unscented Kalman filter model, for fish released in the equatorial central Pacific, color-coded by bimonthly periods. (a) Tag D0739, the longest linear displacement, 99 days at liberty, 99 position estimates. (b) Tag 1959, the third longest days at liberty, 70 d, 71 position estimates. (c) Kernel density plot for all positions, from five fish, calculated with a 1° search radius and a 0.01° output cell size. Warmer colors indicate higher densities

(5197–20,207 M^2), with 95% of the positions within 376–438 M of release locations. The movement patterns based on the MPTs for the fish released in the equatorial EPO and CPO showed considerable variation in their 100% UDs of 15,393 and 5403 M^2, respectively, with 95% of the positions within 621 and 263 M, respectively, of release locations. These results indicate strong fidelity for fish to their release areas with limited dispersion. However, it should be recognized that the numbers and durations of AT data sets obtained for the fish released in the equatorial EPO and CPO are substantially less than those from the other four areas, and thus, longer term movement patterns for fish from the equatorial areas are less certain than those from the four other areas.

Large-scale historical tagging studies utilizing PDTs with yellowfin in the EPO, extending from Baja California, Mexico, to northern Peru, indicated that movements of tagged fish at liberty for more than 30 d tend to be restricted to less than 1000 M of their release positions (Bayliff, 1979, 1984; Bayliff & Rothschild, 1974; Fink & Bayliff, 1970; Schaefer et al., 1961). Those studies demonstrated fidelity of yellowfin to release areas, with little exchange of fish between the northern and southern regions of the EPO. Similar conclusions regarding restricted movements and a high degree of fidelity to release areas have been reached from evaluations of data obtained from large-scale tagging experiments with yellowfin using PDTs in the CPO (Itano & Holland, 2000) and the western Pacific Ocean (Sibert & Hampton, 2003).

The current study includes 58 MPTs, from a wide range in fork lengths of yellowfin at recapture ($\bar{x} = 138.7$ cm; range: 78–177 cm), tagged and released with ATs in the Revillagigedo Islands and at liberty for relatively long durations ($\bar{x} = 454.9$ d; range: 90–1846 d). The MPTs for those yellowfin indicate restricted movements, low levels of dispersion, and fidelity to the Revillagigedo Islands (Schaefer et al., 2014). To evaluate whether there was a significant relationship between fork length at release and fidelity to the release area, a correlation analysis was performed for the 58 fish released at the Revillagigedo Islands. While the correlation coefficient indicated a slightly positive relationship ($r^2 = .228$, $p = .09$), that relationship was not significantly different from 0. The longest duration AT data set included in this study of 3.2 years is for a yellowfin released off Baja California at 90 cm and recaptured just 167 M from its release location at a fork length of 162 cm. The MPT for that fish indicated that it remained in a relatively confined area (Figure 3b), demonstrating fidelity to the area of release throughout the 3.2 years (Schaefer et al., 2011).

The MPTs from 12 relatively large YFT, estimated weights of 40–90 kg, tagged and released off Kauai, Hawaii, with pop-up satellite ATs attached for short durations of 21–59 d, revealed diverse movement patterns. Seven of the fish remained near the Hawaiian Islands, but five of the fish undertook fairly rapid long-distance movements, predominantly in a northward direction (Lam et al., 2020). However, of the five individuals that moved away from the Hawaiian Islands,

TABLE 3 Summary of the movement parameter estimates from the unscented Kalman filter model, by release area and for the pooled data, for 227 yellowfin listed in Appendix A

Release area	*n*		σ_x (degrees)	σ_y (degrees)	*u* (M/d)	*v* (M/d)	*D* (M^2/d)
Baja California	126	Median	0.32	1.36	−0.27	−0.77	144.28
		Range	0.08–0.83	0.40–5.33	−3.56–2.77	−4.31–2.99	13.34–739.57
Revillagigedo Islands	58	Median	0.46	1.83	−0.03	−0.07	117.99
		Range	0–0.99	0.77–6.81	−2.16–3.19	−3.56–2.17	12.27–824.87
Clipperton Island	13	Median	0.69	1.51	0.02	0.02	168.05
		Range	0.22–1.25	0.12–21.32	−3.09–1.80	−4.96–3.4	12.37–1275.85
Panama	17	Median	0.79	2.07	0.87	0.47	73.57
		Range	0.53–1.26	0.41–6.6	−1.27–4.36	−2.12–1.62	19.4–548.31
Equatorial eastern Pacific	8	Median	0.47	1.61	2.27	1.08	492.15
		Range	0.19–1	0.66–3.25	−5.46–7.39	−1.67–10.42	235.23–1130.54
Equatorial central Pacific	5	Median	0.39	1.44	4.74	0.91	214.12
		Range	0.24–1.51	1.08–1.85	−7.39–6.37	0.11–1.59	27.87–501.76
Pooled	227	Median	0.38	1.44	−0.12	−0.27	134.39
		Range	0–1.51	0.40–21.32	−7.39–7.39	−4.96–10.42	12.27–1275.85

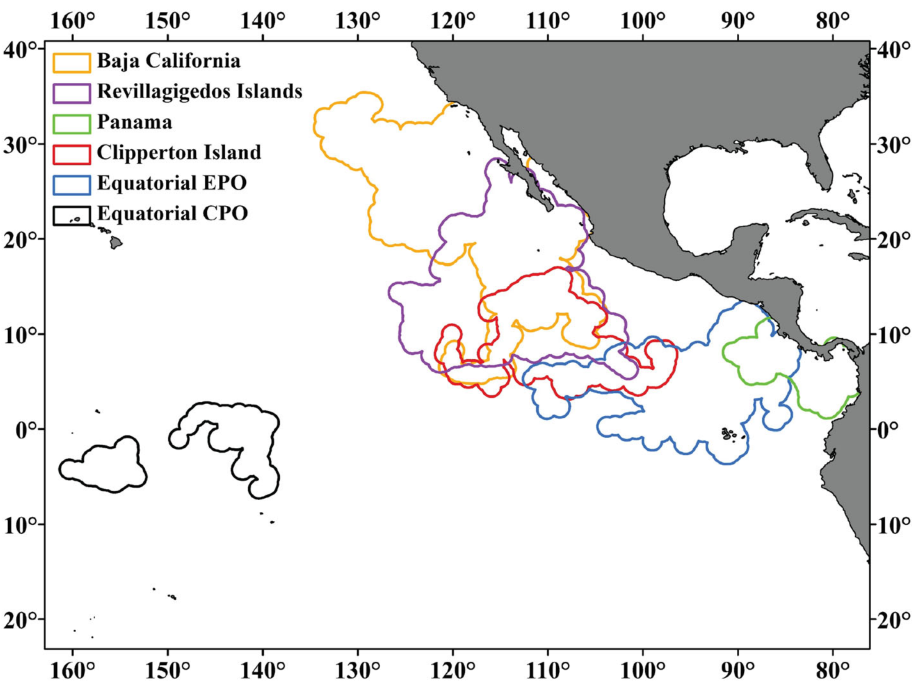

FIGURE 9 The 100% volume contours (utilization distributions) for yellowfin, derived from a kernel density estimate, using a 1°search radius and a 0.01°output cell size, for all positions along the most probable tracks of fish by release area

the largest fish traveled the furthest and headed east, crossing the IATTC management boundary at 150°W after 16 d at liberty, and reached 139°W before the tag release mechanism failed and prematurely released.

We recognize that the movement patterns observed are representative only for the sizes of fish in this study and the locations and timing of the tagging events. Movement patterns for larger and/or older yellowfin from other areas of the EPO, or fish tagged and released during other years, may differ due to ontogenetic changes in behavior or responses to large-scale environmental conditions that impact SSTs, currents, vertical structure, and productivity.

The MPTs and horizontal UDs observed for yellowfin tagged and released with ATs in this study are apparently strongly influenced by geographic features such as gulfs and islands, bathymetric features such as banks, ridges, and seamounts, and dynamic physical oceanographic processes such as gyres, upwelling, eddies, convergence, and frontal zones (Sund et al., 1981). High prey densities have been shown to be associated with these features and processes, providing good foraging areas for which yellowfin exhibit a high affinity (Blackburn, 1968; Blackburn et al., 1970). High concentrations of forage organisms (Alverson, 1963) are obviously an important biotic factor in the fine-scale distribution and abundance of yellowfin and

TABLE 4 Number and percentage of fish by release area which had one or more daily position estimates along their most probable tracks within the 100% utilization distribution for the fish from another release area

	Most probable tracks					
Utilization distribution	Baja California	Revillagigedo Islands	Clipperton Island	Panama	Equatorial EPO	Equatorial CPO
Baja California		58 (100%)	7 (54%)	0 (0%)	0 (0%)	0 (0%)
Revillagigedo Islands	108 (86%)		13 (100%)	0 (0%)	2 (25%)	0 (0%)
Clipperton Island	3 (2%)	16 (28%)		0 (0%)	6 (75%)	0 (0%)
Panama	0 (0%)	0 (0%)	0 (0%)		1 (13%)	0 (0%)
Equatorial EPO	0 (0%)	1 (2%)	4 (31%)	0 (0%)		0 (0%)
Equatorial CPO	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	

Note: The 100% utilization distributions were calculated, by release area, from a kernel density function for all positions along most probable tracks, utilizing a 1° search radius and a 0.01° output cell size.

appears to be one of the primary factors contributing to their observed fidelity to the areas where they were tagged and released in this study. In addition, there is no apparent reason why yellowfin tagged and released in each of the six areas in this study would need to move outside their observed horizontal utilization distributions for reproduction, since yellowfin spawning has been reported to be widespread throughout the EPO (Schaefer, 1998), including the six tag and release areas in this study. Yellowfin tuna evolved a different life history strategy, consisting of restricted movements in subtropical to tropical waters with prolonged spawning periods, compared to that of temperate bluefin tunas exhibiting highly migratory movements in temperate to tropical waters with spatiotemporally confined spawning distributions (Schaefer, 2001). The molecular data support the monophyletic status of the yellowfin tuna group and indicate that these tropical tunas are recently derived taxa relative to that of the ancestral temperate bluefin lineage (Chow et al., 2006).

4.2 | Movement parameters

The median movement parameters from the UKFsst model, by release area (Table 3), define the differences observed in the yellowfin MPTs among release areas. One of the most revealing differences observed in this study is that the median movement parameter *D*, which defines dispersion, for the fish released in the equatorial EPO (492.2 M^2/d) and CPO (214.1 M^2/d), show much greater dispersion rates compared to those for the fish released along the coasts of Baja California and Panama and around the Revillagigedo Islands and Clipperton Island (73.6–168.1 M^2/d).

In the equatorial EPO, the oceanography is extremely dynamic (Fiedler & Talley, 2006), with oligotrophic water (Pennington et al., 2006), and resource limited (Fernandez-Alamo & Farber-Lorda, 2006), resulting in patchy distributions of yellowfin tuna prey (Blackburn, 1968; Blackburn et al., 1970). Investigations of the feeding habits of YFT in the EPO have concluded they are an opportunistic predator (Alverson, 1963; Sund et al., 1981) due to high prey diversity and, in general, low abundance of each prey type in the diet. Olson et al. (2014) reported that prey diversity was higher but proportions consumed lower in the offshore equatorial EPO, opposed to lower prey diversity with higher proportions consumed in the more productive non-equatorial inshore upwelling regions influenced by the California and Humboldt currents. These studies describing spatial differences in the oceanography of the EPO, combined with the spatial patterns of prey diversity and abundance, support the hypothesis that the higher average dispersion rate for YFT in the equatorial EPO results from their higher search rates and spatial coverage required to obtain minimum daily rations to support their high energetic demands (Olson & Boggs, 1986). For comparison to the variability in median movement parameters for yellowfin by release areas in this study, the median movement parameters from the UKFsst model for bigeye tuna (*Thunnus obesus*), tagged and released in the equatorial EPO with ATs (Schaefer & Fuller, 2009), had a similar dispersion rate (464.6 M^2/d) but with a predominantly westward movement component, to those of bigeye tagged and released in the equatorial CPO with ATs (496.7 M^2/d) (Schaefer et al., 2015), but with a predominantly eastward movement component.

4.3 | Mixing rates

The estimated mixing rates of yellowfin among the six areas in this study clearly indicate a lack of complete mixing of yellowfin within the EPO, resulting from limited dispersion and fidelity to home range distributions. A high mixing rate was observed among the fish released off Baja California, the Revillagigedo Islands, and Clipperton Island, but no mixing among fish from those areas with fish released off Panama. A low mixing rate was observed among fish released off the Revillagigedo Islands and Panama with those released in the equatorial EPO. A high mixing rate was observed among fish released off Clipperton Island with those released in the equatorial EPO. There was no mixing observed among the fish released in the equatorial CPO with fish released from the other areas.

The findings in this study regarding the lack of any significant amount of mixing among yellowfin tagged and released off the coast of Baja California and the Revillagigedo Islands, Mexico, with those from off the coast of Panama and in the equatorial EPO and CPO are consistent with the results of an investigation of the morphometrics and gill-raker counts of yellowfin which found there to be significant differences between fish sampled from off Mexico with those from off Ecuador (Schaefer, 1991, 1992). Geographic variation observed in morphometric characters and gill raker counts of yellowfin from northern and equatorial regions of the EPO results from restricted movements, lack of mixing, and environmental variation.

A genomic study of yellowfin in the EPO utilizing microsatellite variation revealed significant differentiation in comparisons between north equatorial samples (10–25°N) and a southern equatorial sample (16–18°S) providing some preliminary evidence of the presence of discrete northern and southern yellowfin populations in the EPO (Díaz-Jaimes & Uribe-Alcocer, 2006). In addition, recent yellowfin genomic investigations utilizing high-throughput genotyping with single nucleotide polymorphism markers have provided evidence of some heterogeneous population structure for yellowfin from the eastern, central, and western Pacific (Anderson et al., 2019; Grewe et al., 2015; Pecoraro et al., 2018).

Various stock identification methodologies have been employed for the principal species of commercial tunas in the Pacific Ocean, from fisheries statistics to data on tagging, spawning, morphometric and/or meristic characters, parasites as biological markers, allozyme variation, genomics, and elemental composition of otoliths (Moore et al., 2020). Each methodology has advantages and disadvantages including how each character set relates differently to the delineation of stocks and their usefulness within stock assessments and fisheries management. Tagging data, particularly that from ATs, appear to have the most merit in providing estimates of home range distributions and delineation of stock structure, diffusion rates, and the extent of mixing between regions. However, as several investigators suggest, a multi-method approach is optimal, which should include genomics together with tagging and life history data for delineation of stock structure and mixing between areas (Begg et al., 1999; Moore et al., 2020).

5 | CONCLUSIONS

Yellowfin in the EPO are not a single well-mixed population, as the results of this study support the hypothesis of multiple stocks. However, latitudinal and longitudinal stock boundaries to date have been difficult to delineate and are no doubt dynamic. To do so will require additional tagging studies utilizing ATs, in conjunction with an investigation of yellowfin genomics, with the success of both lines of investigation dependent on suitable sample sizes from several discrete areas encompassing the distribution of yellowfin in the EPO.

The findings of this study also suggest the importance of shifting to a spatially explicit regional stock assessment model for yellowfin in the EPO that includes area specific movement dynamics, exploitation rates, and life history characteristics. The assumption of a single stock with complete mixing throughout the EPO is unrealistic, and stock assessments based on that assumption may lead to serious biases in stock status, localized depletion and/or underutilization, and inappropriate management advice.

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CONFLICT OF INTEREST

The authors declare to have no conflicts of interest.

AUTHOR CONTRIBUTIONS

KMS and DWF designed the investigation and undertook the tagging experiments. DWF carried out the data analysis. KMS and DWF collaborated on the interpretation of the results and content within the discussion. KMS wrote the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A

TABLE A1 Release and recapture information for 227 yellowfin tuna from which archival tag data sets were included in this study, along with the numbers of positions obtained

		Release				Recapture						
Tag no.	Tag type	Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
Baja California												
A0509	LTD2310	12-Oct-02	25.73°N	113.13°W	93	PSa	6-Aug-03	22.07°N	109.33°W	118	297.7	296
A0806	LTD2310	12-Oct-02	25.73°N	113.13°W	73	PSa	19-Jul-03	20.72°N	111.47°W	107	279.7	265
A0478	LTD2310	13-Oct-02	25.73°N	113.13°W	91	PSa	25-Apr-04	8.27°N	119.83°W	124	559.7	515
A0525	LTD2310	13-Oct-02	25.73°N	113.13°W	90	RF	17-Dec-05	23.58°N	111.70°W	162	1160.7	940
A0644	LTD2310	13-Oct-02	25.73°N	113.13°W	98	PSa	11-Aug-03	20.30 N	109.18°W	128	301.7	294
A0826	LTD2310	13-Oct-02	25.73°N	113.13°W	94	PSu	27-Jul-03	23.38°N	111.17°W	123[a]	286.7	270
A0549	LTD2310	9-Oct-03	29.07°N	118.23°W	85	PSu	25-Apr-04	22.40°N	111.08°W	91	198.4	200
A1425	LTD2310	9-Oct-03	29.07°N	118.23°W	92	RF	26-Jul-04	29.08°N	118.24°W	104	290.6	272
A1448	LTD2310	9-Oct-03	29.07°N	118.23°W	87	PSa	24-Apr-04	22.83°N	110.53°W	108[a]	197.4	186
A1455	LTD2310	9-Oct-03	29.07°N	118.23°W	85	PSu	25-Apr-04	22.40°N	111.08°W	107[a]	198.6	184
A1514	LTD2310	9-Oct-03	29.07°N	118.23°W	83	PSu	26-Jul-04	23.40°N	111.17°W	114[a]	290.5	285
A1550	LTD2310	9-Oct-03	29.07°N	118.23°W	86	PSa	17-Apr-04	22.68°N	110.88°W	107[a]	190.6	192
A1569	LTD2310	11-Oct-03	24.97°N	115.76°W	86	PSa	16-Jun-04	20.47°N	114.15°W	125	248.3	250
A1895	LTD2310	12-Oct-03	24.97°N	115.76°W	130	RF	5-Apr-04	24.98°N	115.77°W	136	175.4	168
A0827	LTD2310	15-Oct-03	25.25°N	112.80°W	76	PSu	17-Mar-04	23.55°N	108.85°W	93[a]	153.7	154
A1506	LTD2310	15-Oct-03	25.10°N	112.75°W	75	PSa	23-Jun-04	24.08°N	112.57°W	103[a]	251.3	235
A1526	LTD2310	15-Oct-03	25.25°N	112.80°W	78	PSa	17-Apr-04	22.55°N	110.97°W	98[a]	184.7	186
A1547	LTD2310	15-Oct-03	25.25°N	112.80°W	77	PSa	8-Jun-04	23.67°N	112.08°W	103[a]	236.7	237
A1559	LTD2310	15-Oct-03	25.25°N	112.80°W	75	PSu	25-Apr-04	22.33°N	110.98°W	96[a]	192.7	191
A1461	LTD2310	16-Oct-03	25.72°N	113.12°W	67	PSu	26-Apr-04	22.75°N	111.25°W	83	192.7	179
B2712	LTD2310	15-Aug-04	30.95°N	116.86°W	62	PSu	10-Apr-06	23.60°N	111.65°W	126[a]	602.5	567
B2767	LTD2310	15-Aug-04	30.96°N	116.85°W	57	PSu	4-Aug-05	30.25°N	116.65°W	75	353.5	315
B2743	LTD2310	16-Aug-04	31.34°N	117.30°W	74	PSu	29-Jul-05	30.57°N	118.00°W	112[a]	346.5	342
C0043	LTD2310	20-Aug-04	31.53°N	117.51°W	60	PSu	7-Jun-05	25.75°N	113.53°W	92[a]	290.5	274
C0055	LTD2310	20-Aug-04	31.46°N	117.53°W	60	PSu	27-Aug-05	30.43°N	116.52°W	82	371.5	355
C0066	LTD2310	20-Aug-04	31.46°N	117.53°W	61	PSu	1-Oct-05	32.27°N	119.05°W	106[a]	406.5	367
B2683	LTD2310	5-Nov-04	24.97°N	115.78°W	68	RF	29-Dec-05	23.58°N	111.70°W	99	418.5	139
B2687	LTD2310	5-Nov-04	24.97°N	115.78°W	69	PSa	27-Mar-06	22.17°N	111.08°W	123[a]	506.4	502
B2711	LTD2310	5-Nov-04	24.97°N	115.78°W	61	PSu	4-Aug-05	31.18°N	118.28°W	91[a]	271.5	260

(Continues)

TABLE A1 (Continued)

		Release				Recapture						
Tag no.	Tag type	Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
B2734	LTD2310	5-Nov-04	24.97°N	115.78°W	64	PSu	16-Sep-05	26.35°N	113.63°W	99[a]	314.4	301
C0003	LTD2310	5-Nov-04	24.97°N	115.78°W	72	PSa	30-May-06	21.18°N	107.08°W	113[a]	570.3	255
C0009	LTD2310	5-Nov-04	24.97°N	115.78°W	75	RF	6-Jul-05	24.96°N	115.77°W	102[a]	242.4	233
C0041	LTD2310	5-Nov-04	24.97°N	115.78°W	68	PSa	25-Jul-05	21.82°N	111.57°W	83[a]	261.4	197
C0046	LTD2310	5-Nov-04	24.97°N	115.78°W	69	PSa	5-Mar-05	23.05°N	111.18°W	82[a]	119.4	115
B2682	LTD2310	6-Nov-04	24.97°N	115.78°W	62	PSa	19-Mar-05	22.57°N	110.68°W	76[a]	132.4	134
B2707	LTD2310	6-Nov-04	24.97°N	115.78°W	68	PSa	19-Mar-05	22.57°N	110.68°W	83[a]	132.7	133
C0026	LTD2310	6-Nov-04	24.97°N	115.78°W	69	PSa	29-Jul-06	24.23°N	113.07°W	89[a]	629.4	184
C0044	LTD2310	6-Nov-04	24.97°N	115.78°W	82	PSa	5-Mar-05	23.00°N	110.85°W	95[a]	118.3	112
C0024	LTD2310	7-Nov-04	24.97°N	115.78°W	96	RF	8-Oct-06	24.95°N	115.77°W	139	699.4	248
A1446	LTD2310	8-Nov-04	25.23°N	112.82°W	67	PSu	27-Oct-05	23.44°N	110.60°W	106[a]	352.4	266
A1504	LTD2310	8-Nov-04	25.23°N	112.82°W	66	PSa	7-Feb-05	23.52°N	111.12°W	76[a]	90.4	86
B2677	LTD2310	8-Nov-04	25.23°N	112.82°W	67	PSu	17-Aug-05	24.03°N	112.37°W	98[a]	281.6	90
B2720	LTD2310	8-Nov-04	25.23°N	112.82°W	66	PSu	9-Apr-06	23.68°N	111.77°W	122[a]	516.5	476
B2730	LTD2310	8-Nov-04	25.23°N	112.82°W	75	PSu	1-Jun-05	21.93°N	112.03°W	98[a]	204.4	191
C0005	LTD2310	8-Nov-04	25.23°N	112.82°W	66	PSa	9-Mar-05	22.35°N	110.88°W	79[a]	120.5	122
C0007	LTD2310	8-Nov-04	25.23°N	112.82°W	73	PSa	29-May-05	23.37°N	109.25°W	95[a]	201.5	192
C0017	LTD2310	8-Nov-04	25.23°N	112.82°W	68	PSa	27-Mar-06	22.17°N	111.08°W	119[a]	503.5	345
C0054	LTD2310	8-Nov-04	25.23°N	112.82°W	68	PSa	21-Feb-05	23.85°N	111.28°W	79[a]	104.6	106
A1514A	LTD2310	9-Nov-04	23.31°N	110.65°W	72	PSa	25-Feb-06	21.80°N	111.35°W	123[a]	472.4	424
C0022	LTD2310	9-Nov-04	23.31°N	110.65°W	98	PSu	27-Oct-05	23.44°N	110.60°W	130	351.6	192
C0036	LTD2310	9-Nov-04	23.31°N	110.65°W	81	PSa	22-Feb-05	23.47°N	112.10°W	92[a]	104.3	105
C0053	LTD2310	9-Nov-04	23.31°N	110.65°W	65	PSu	16-Apr-05	24.68°N	108.68°W	82[a]	157.3	155
C0194	LTD2310	3-Aug-05	31.55°N	118.30°W	80	PSa	3-Apr-06	22.53°N	111.42°W	99	242.5	221
C0202	LTD2310	3-Aug-05	31.63°N	118.27°W	87	PSa	30-Jun-06	23.82°N	109.40°W	122[a]	330.5	328
C0203	LTD2310	3-Aug-05	31.73°N	118.20°W	78	PSu	21-Feb-06	23.57°N	111.53°W	98	201.5	189
C0204	LTD2310	3-Aug-05	31.55°N	118.30°W	83	PSu	8-Apr-06	23.57°N	111.93°W	110[a]	247.5	248
C0908	LTD2310	3-Aug-05	31.63°N	118.27°W	82	LL	12-Mar-06	25.57°N	126.28°W	94	220.5	195
C0911	LTD2310	3-Aug-05	31.55°N	118.30°W	81	PSu	9-Apr-06	23.57°N	111.78°W	108[a]	248.5	243
C0121	LTD2310	4-Aug-05	31.27°N	118.33°W	83	PSu	9-Apr-06	23.50°N	111.80°W	110[a]	247.5	232
C0140	LTD2310	4-Aug-05	31.52°N	118.33°W	85	PSu	9-Apr-06	23.57°N	111.78°W	112[a]	247.5	249
C0174	LTD2310	4-Aug-05	31.50°N	118.31°W	86	PSu	10-Apr-06	23.57°N	111.65°W	113[a]	248.5	250

TABLE A1 (Continued)

		Release				Recapture						
Tag no.	Tag type	Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
C0179	LTD2310	4-Aug-05	31.52°N	118.33°W	84	PSa	8-Apr-06	22.48°N	111.63°W	111[a]	246.5	241
C0953	LTD2310	10-Aug-05	31.57°N	118.95°W	85	PSu	8-Apr-06	23.57°N	111.93°W	111[a]	240.5	224
C1226	LTD2310	10-Aug-05	31.57°N	118.95°W	84	PSu	9-Apr-06	23.63°N	111.82°W	96	241.5	129
D0135	LTD2310	10-Aug-05	31.53°N	118.90°W	85	PSa	10-May-07	16.92°N	112.63°W	111[a]	637.5	240
C1063	LTD2310	11-Aug-05	31.57°N	119.02°W	83	PSa	27-Mar-06	22.30°N	111.52°W	108[a]	227.5	118
D0042	LTD2310	14-Oct-05	24.93°N	115.75°W	61	PSu	13-Jul-06	31.10°N	117.62°W	91[a]	271.6	264
A1565	LTD2310	15-Oct-05	24.93°N	115.75°W	84	RF	2-Sep-06	28.91°N	118.24°W	101[a]	321.3	156
C1029	LTD2310	15-Oct-05	24.93°N	115.75°W	78	PSa	20-Feb-06	22.80°N	111.62°W	92[a]	127.6	119
C1072	LTD2310	15-Oct-05	24.93°N	115.75°W	81	PSu	19-Feb-06	23.52°N	111.70°W	95[a]	126.6	120
C1079	LTD2310	15-Oct-05	24.93°N	115.75°W	78	PSa	22-May-06	28.62°N	116.28°W	102	218.6	171
C1086	LTD2310	15-Oct-05	24.93°N	115.75°W	95	RF	17-Oct-06	24.95°N	115.79°W	134	366.4	368
C1215	LTD2310	15-Oct-05	24.93°N	115.75°W	96	RF	3-Jul-06	24.95°N	115.76°W	117	260.6	250
D0029	LTD2310	15-Oct-05	24.93°N	115.75°W	83	PSu	21-Feb-06	23.57°N	111.61°W	93	128.5	121
D0045	LTD2310	15-Oct-05	24.93°N	115.75°W	80	PSa	25-Feb-06	23.17°N	111.37°W	95[a]	132.7	134
D0064	LTD2310	15-Oct-05	24.93°N	115.75°W	98	RF	6-Jun-06	24.98°N	115.76°W	108	233.6	222
C0980	LTD2310	16-Oct-05	25.25°N	112.80°W	77	PSa	27-Mar-06	22.52°N	110.60°W	93	161.6	134
C0991	LTD2310	16-Oct-05	25.25°N	112.80°W	80	PSu	8-Apr-06	23.57°N	111.93°W	99[a]	173.4	168
C0996	LTD2310	16-Oct-05	25.25°N	112.80°W	83	PSa	10-Apr-06	22.53°N	110.80°W	102[a]	175.6	154
C1033	LTD2310	16-Oct-05	25.25°N	112.80°W	84	PSa	26-Feb-06	22.52°N	112.33°W	104	132.4	130
C1236	LTD2310	16-Oct-05	25.25°N	112.80°W	83	PSa	5-Feb-06	23.02°N	110.70°W	95[a]	111.6	105
D0038	LTD2310	16-Oct-05	25.25°N	112.80°W	72	PSu	19-Feb-06	23.52°N	111.70°W	86[a]	125.3	125
D0043	LTD2310	16-Oct-05	25.25°N	112.80°W	82	PSu	21-Feb-06	23.57°N	111.61°W	95	127.5	127
D1158	LTD2310	5-Aug-06	29.67°N	116.73°W	71	PSu	11-Jun-07	28.45°N	116.42°W	85[a]	309.6	114
D1164	LTD2310	5-Aug-06	29.46°N	116.56°W	72	PSa	23-Jul-07	24.45°N	112.77°W	86[a]	351.7	353
D1178	LTD2310	5-Aug-06	29.46°N	116.56°W	76	PSa	21-Jul-07	24.38°N	113.37°W	114[a]	349.7	334
D1191	LTD2310	5-Aug-06	29.46°N	116.56°W	74	PSu	30-Jul-07	31.75°N	117.30°W	88[a]	358.7	360
D1198	LTD2310	5-Aug-06	29.46°N	116.56°W	74	PSu	11-Jun-07	28.45°N	116.42°W	108[a]	309.7	273
D1215	LTD2310	5-Aug-06	29.62°N	116.70°W	63	PSu	11-Jun-07	26.93°N	115.78°W	97[a]	309.5	311
D1217	LTD2310	5-Aug-06	29.46°N	116.56°W	73	PSu	23-May-07	27.17°N	115.32°W	87[a]	290.7	291
D1245	LTD2310	5-Aug-06	29.46°N	116.56°W	74	PSu	26-Jul-07	31.85°N	117.50°W	88[a]	354.7	356
D1257	LTD2310	5-Aug-06	29.46°N	116.56°W	69	PSa	23-Jul-07	24.18°N	113.18°W	83[a]	351.6	353
D1260	LTD2310	5-Aug-06	29.46°N	116.56°W	65	PSu	14-Aug-07	32.28°N	117.87°W	79	373.7	375

(Continues)

TABLE A1 (Continued)

		Release				Recapture						
Tag no.	Tag type	Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
D1262	LTD2310	5-Aug-06	29.67°N	116.73°W	73	PL	13-Dec-06	25.72°N	113.13°W	86[a]	129.5	124
D1281	LTD2310	5-Aug-06	29.46°N	116.56°W	76	PSu	4-Aug-07	32.18°N	117.50°W	105[a]	363.7	364
D0847	LTD2310	3-Nov-06	24.90°N	115.75°W	71	PSu	22-May-07	21.95°N	110.82°W	94	199.5	196
D1109	LTD2310	3-Nov-06	24.90°N	115.75°W	63	PSu	31-Jul-07	32.08°N	117.42°W	92[a]	269.5	264
D1111	LTD2310	3-Nov-06	24.90°N	115.75°W	60	PSu	31-Jul-07	31.75°N	117.10°W	90[a]	269.5	226
D1144	LTD2310	3-Nov-06	24.90°N	115.75°W	71	RF	31-Jul-07	24.90°N	115.75°W	94	269.5	210
D1153	LTD2310	3-Nov-06	24.90°N	115.75°W	69	PSa	22-Mar-07	23.15°N	110.87°W	84[a]	138.5	131
D1165	LTD2310	3-Nov-06	24.90°N	115.75°W	68	PSu	24-Jul-07	25.42°N	113.25°W	83	262.5	254
D1214	LTD2310	3-Nov-06	24.90°N	115.75°W	61	PSa	23-Jul-07	24.43°N	113.00°W	90[a]	261.5	244
D0609	LTD2310	5-Nov-06	23.63°N	112.28°W	81	PSa	24-May-07	19.65°N	108.88°W	103[a]	199.5	200
D0846	LTD2310	5-Nov-06	23.63°N	112.28°W	86	PSa	13-Mar-07	19.53°N	109.13°W	108	127.5	121
D1184	LTD2310	5-Nov-06	23.63°N	112.28°W	83	PSa	7-Jun-07	17.82°N	114.52°W	106[a]	213.5	204
D1110	LTD2310	6-Nov-06	23.63°N	112.28°W	71	PSa	23-Feb-08	8.70°N	104.97°W	111[a]	473.5	350
D1146	LTD2310	7-Nov-06	25.22°N	112.80°W	71	PSa	23-Jul-07	24.17°N	112.53°W	75	257.5	247
D1199	LTD2310	7-Nov-06	25.22°N	112.80°W	74	PSa	24-Jul-07	24.10°N	112.62°W	89	258.5	212
D1209	LTD2310	27-Nov-07	23.67°N	111.92°W	110	PSa	9-Jun-08	22.92°N	111.50°W	122	194.5	119
D1602	LTD2310	27-Nov-07	23.67°N	111.96°W	122	RF	15-Jan-10	23.77°N	112.07°W	159	780.5	675
D0796	LTD2310	28-Nov-07	23.67°N	111.92°W	77	PSu	11-Jun-08	22.98°N	111.50°W	99[a]	195.5	184
D1104	LTD2310	29-Nov-07	23.50°N	111.92°W	99	PSa	2-Jul-08	22.75°N	112.77°W	121[a]	215.5	193
D1181	LTD2310	29-Nov-07	23.50°N	111.92°W	77	PSu	10-Apr-08	24.32°N	109.07°W	92[a]	132.5	114
D1226	LTD2310	29-Nov-07	23.50°N	111.92°W	90	PSu	15-May-08	23.00°N	109.52°W	108[a]	167.5	166
D1469	LTD2310	29-Nov-07	23.50°N	111.92°W	109	RF	1-Feb-09	23.58°N	111.80°W	127[a]	429.5	216
D1611	LTD2310	29-Nov-07	23.50°N	111.92°W	74	PSa	6-Jun-08	22.20°N	112.23°W	95[a]	189.5	178
D1612	LTD2310	29-Nov-07	23.50°N	111.92°W	67	PSa	10-Nov-08	24.30°N	108.37°W	105[a]	346.5	333
D1641	LTD2310	29-Nov-07	23.50°N	111.92°W	97	PSa	5-Mar-08	22.40°N	110.50°W	107[a]	96.5	98
D1642	LTD2310	29-Nov-07	23.50°N	111.92°W	63	PSu	23-Mar-08	23.40°N	107.55°W	75[a]	114.5	115
D3213	LTD2310	12-Dec-08	25.72°N	113.33°W	65	PSa	10-Jul-09	23.55°N	111.97°W	77	209.5	193
D3217	LTD2310	12-Dec-08	25.72°N	113.33°W	71	PSa	15-Jul-09	24.02°N	112.40°W	95[a]	214.5	202
D3230	LTD2310	12-Dec-08	25.72°N	113.33°W	78	PSa	23-Apr-09	23.83°N	112.40°W	92[a]	131.4	131
D1302	LTD2310	13-Dec-08	24.20°N	111.50°W	74	PSa	14-Apr-09	23.17°N	112.63°W	87[a]	121.7	115
D3185	LTD2310	13-Dec-08	24.20°N	111.50°W	71	PSa	7-Jul-09	23.50°N	111.88°W	94[a]	205.7	194

TABLE A1 (Continued)

		Release				Recapture						
Tag no.	Tag type	Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
D3195	LTD2310	13-Dec-08	24.20°N	111.50°W	74	PSa	12-Aug-09	24.22°N	112.47°W	98	241.7	243
D3212	LTD2310	13-Dec-08	24.20°N	111.50°W	73	PSa	5-Jul-09	23.02°N	111.50°W	96[a]	203.7	195
Revillagigedo Islands												
D0604	LTD2310	19-Feb-06	18.32°N	114.75°W	102	PSu	21-May-07	18.58°N	114.70°W	144[a]	456.0	457
D0742	LTD2310	20-Feb-06	18.34°N	114.69°W	110	PSa	24-Jul-06	20.77°N	114.83°W	125[a]	154.0	155
D0741	LTD2310	20-Feb-06	18.34°N	114.69°W	102	PSu	14-Mar-07	18.62°N	114.88°W	139[a]	387.0	387
D0744	LTD2310	20-Feb-06	18.34°N	114.69°W	139	PSu	19-Mar-07	16.85°N	117.50°W	163[a]	392.0	145
D0755	LTD2310	20-Feb-06	18.34°N	114.69°W	113	PSa	4-Jun-07	18.33°N	114.83°W	152[a]	469.0	470
D0098	LTD2310	20-Feb-06	18.34°N	114.69°W	117	PSa	7-Jun-07	16.98°N	114.30°W	154[a]	472.0	473
D0622	LTD2310	20-Feb-06	18.34°N	114.69°W	113	PSu	14-Nov-07	18.40°N	114.67°W	150	632.0	633
D0606	LTD2310	20-Feb-06	18.34°N	114.69°W	140	PSu	18-Nov-07	18.43°N	114.43°W	163	636.0	636
D0632	LTD2310	21-Feb-06	18.33°N	114.70°W	92	PSu	14-Mar-07	18.62°N	114.88°W	131[a]	386.0	386
D1631	LTD2310	16-Feb-07	18.77°N	110.90°W	127	PSu	20-May-07	19.00°N	112.33°W	135[a]	93.0	94
D1580	LTD2310	16-Feb-07	18.77°N	110.90°W	104	PSa	27-Sep-07	11.18°N	109.70°W	126[a]	223.0	208
D1593	LTD2310	16-Feb-07	18.77°N	110.90°W	140	PSa	24-Mar-08	14.52°N	112.27°W	164[a]	402.0	398
D2050	LTD2310	16-Feb-07	18.77°N	110.90°W	103	PSa	16-Apr-08	17.68°N	109.30°W	142[a]	425.0	425
D1589	LTD2310	16-Feb-07	18.77°N	110.90°W	145	PSa	7-Jul-08	10.62°N	124.55°W	170[a]	507.0	508
D2030	LTD2310	17-Feb-07	18.71°N	110.90°W	142	PSa	12-Mar-08	6.27°N	101.55°W	164[a]	389.0	390
D1627	LTD2310	17-Feb-07	18.71°N	110.90°W	101	RF	2-Dec-11	18.37°N	114.53°W	173	1749.0	543
D2036	LTD2310	17-Feb-07	18.71°N	110.90°W	144	PSa	27-Mar-08	16.07°N	112.72°W	166[a]	404.0	402
C0908	LTD2310	22-Feb-07	18.32°N	114.72°W	147	PSu	18-Nov-07	18.43°N	114.43°W	162[a]	269.0	270
C0121	LTD2310	22-Feb-07	18.32°N	114.72°W	133	RF	1-Jan-12	18.38°N	114.53°W	161	1773.0	323
490916	Mk 9	23-Feb-07	18.32°N	114.72°W	140	PSa	14-Nov-07	18.50°N	114.08°W	157[a]	264.0	190
390081	Mk 9	23-Feb-07	18.32°N	114.72°W	133	PSa	24-Mar-08	14.53°N	112.05°W	160[a]	395.0	395
D1497	LTD2310	16-Feb-08	19.00°N	112.07°W	74	PSu	18-Jul-08	19.00°N	112.07°W	91[a]	153.0	154
D1567	LTD2310	16-Feb-08	19.00°N	112.07°W	75	PSu	18-Jul-08	19.00°N	112.07°W	91[a]	153.0	153
D3099	LTD2310	18-Feb-08	18.32°N	114.62°W	122	PSu	24-May-08	18.50°N	114.65°W	131[a]	96.0	97
D3063	LTD2310	18-Feb-08	18.32°N	114.62°W	120	PSa	24-Feb-10	11.00°N	98.05°W	163	737.0	506
D1477	LTD2310	19-Feb-08	18.32°N	114.67°W	79	PSu	24-May-08	18.50°N	114.65°W	90[a]	95.0	96
D1474	LTD2310	20-Feb-08	18.32°N	114.62°W	118	PSu	23-May-08	18.38°N	114.65°W	126[a]	93.0	94
D3420	LTD2310	23-Apr-08	18.35°N	114.68°W	136	RF	17-Feb-09	18.22°N	114.68°W	152	300.0	301
D3438	LTD2310	24-Apr-08	18.72°N	111.00°W	88	PSa	18-Feb-10	13.90°N	109.48°W	149[a]	665.0	439

(Continues)

TABLE A1 (Continued)

Tag no.	Tag type	Release				Recapture					Days at liberty	Positions
		Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)		
D3436	LTD2310	24-Apr-08	18.72°N	111.00°W	98	PSa	3-Jun-10	18.98°N	113.65°W	161[a]	770.0	153
D4396	LTD2310	15-Feb-09	19.33°N	110.78°W	114	PSa	30-Mar-12	10.33°N	109.17°W	177[a]	1139.0	400
D2050	LTD2310	22-Feb-09	18.32°N	114.73°W	117	PSa	6-Oct-09	14.72°N	115.37°W	137[a]	226.0	218
D5158	LTD2310	17-Apr-09	18.70°N	110.90°W	118	PSa	4-Nov-09	13.70°N	117.12°W	136[a]	201.0	202
D5146	LTD2310	17-Apr-09	18.70°N	110.90°W	109	PSa	8-May-10	16.52°N	109.37°W	140	386.0	387
D5090	LTD2310	21-Apr-09	18.32°N	114.73°W	109	RF	1-Jan-11	18.53°N	114.82°W	139	620.0	542
1090024	Mk 9	15-Feb-10	18.33°N	114.75°W	123	PSu	26-Jul-10	18.55°N	114.48°W	137[a]	161.0	152
1090012	Mk 9	15-Feb-10	18.33°N	114.75°W	111	PSu	27-Jul-10	18.55°N	114.48°W	127[a]	162.0	162
1090025	Mk 9	15-Feb-10	18.33°N	114.75°W	76	PSu	15-Sep-11	18.47°N	114.50°W	150[a]	577.0	565
1090013	Mk 9	15-Feb-10	18.33°N	114.75°W	110	RF	31-Jan-11	18.30°N	114.95°W	128	350.0	351
1090003	Mk 9	15-Feb-10	18.33°N	114.75°W	111	PSa	13-Sep-10	17.92°N	112.70°W	131[a]	210.0	204
1090071	Mk 9	19-Apr-10	18.7°N	110.93°W	86	RF	25-Feb-13	18.47°N	114.50°W	164[a]	1042.5	466
0990284	Mk 9	19-Apr-10	18.7°N	110.93°W	97	PSa	18-Jul-10	18.98°N	109.60°W	106[a]	89.5	90
1090072	Mk 9	21-Apr-10	18.97°N	112.05°W	93	PSa	25-Oct-11	9.47°N	110.33°W	136	552.0	481
1090064	Mk 9	22-Apr-10	18.32°N	114.75°W	114	PSu	26-Jul-10	18.55°N	114.48°W	123[a]	95.0	95
1090062	Mk 9	22-Apr-10	18.32°N	114.75°W	92	RF	2-Feb-12	18.48°N	114.93°W	151[a]	655.0	594
990499	Mk 9	24-Apr-10	18.32°N	114.75°W	142	RF	8-Feb-11	18.63°N	114.92°W	165	290.0	290
1090352	Mk 9	14-Feb-11	18.81°N	110.83°W	128	RF	6-Mar-16	21.83°N	106.77°W	173	1846.5	275
1090391	Mk 9	18-Feb-11	18.33°N	114.74°W	113	PSu	26-Oct-11	18.08°N	114.87°W	136[a]	250.0	247
1090400	Mk 9	18-Feb-11	18.33°N	114.74°W	122	PSa	23-Jun-11	19.73°N	114.27°W	133[a]	125.0	124
1090397	Mk 9	18-Feb-11	19.02°N	112.04°W	65	PSa	20-Jul-11	23.80°N	112.22°W	82	154.0	154
1090441	Mk 9	18-Apr-11	18.77°N	110.90°W	93	PSa	17-Mar-12	16.42°N	109.45°W	132[a]	334.0	307
1090467	Mk 9	22-Apr-11	18.37°N	114.65°W	106	PSu	15-Sep-11	18.65°N	114.65°W	119[a]	146.0	146
1190040	Mk 9	8-May-11	18.77°N	110.90°W	108	PSu	22-Apr-12	19.50°N	110.64°W	139[a]	350.0	303
1190063	Mk 9	8-May-11	18.70°N	110.92°W	122	PSa	23-Apr-12	16.13°N	110.18°W	139[a]	351.0	338
1190051	Mk 9	10-May-11	18.98°N	112.07°W	66	PSa	28-Aug-11	23.00°N	111.25°W	78[a]	110.0	107
B1144	LTD2310	11-Mar-13	18.35°N	114.67°W	77	PSa	5-Aug-13	17.75°N	113.52°W	94[a]	146.5	148
1090441	Mk 9	12-Mar-13	18.97°N	112.02°W	73	PSu	27-Apr-14	18.85°N	112.27°W	117[a]	410.5	345
B1214	LTD2310	12-Mar-13	18.97°N	112.02°W	82	PSa	3-Sep-13	18.60°N	111.90°W	101[a]	174.4	176
Clipperton Island												
A0654	LAT2810	26-Feb-12	10.32°N	109.17°W	140	PSa	30-Mar-12	10.32°N	109.17°W	142[a]	32.7	34
A0702	LAT2810	26-Feb-12	10.32°N	109.17°W	100	PSa	30-Mar-12	10.32°N	109.17°W	103[a]	32.2	34

TABLE A1 (Continued)

Tag no.	Tag type	Release				Recapture					Days at liberty	Positions
		Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)		
B1204	LAT2810	04-Mar-13	10.32°N	109.17°W	88	PSu	20-Sep-13	10.28°N	108.93°W	100	199.5	196
B1207	LAT2810	05-Mar-13	10.32°N	109.17°W	83	PSa	1-Jun-13	9.98°N	120.12°W	93[a]	87.7	89
B1156	LAT2810	05-Mar-13	10.32°N	109.17°W	104	PSu	17-Sep-13	10.32°N	109.17°W	123[a]	195.6	197
B1196	LAT2810	05-Mar-13	10.32°N	109.17°W	97	PSu	28-Sep-13	10.08°N	109.12°W	118[a]	206.5	171
B1198	LAT2810	05-Mar-13	10.32°N	109.17°W	117	PSu	18-Mar-14	10.33°N	109.20°W	149[a]	377.3	210
B1150	LAT2810	05-Mar-13	10.32°N	109.17°W	76	PSa	17-Aug-14	8.30°N	98.72°W	131[a]	529.2	528
B1149	LAT2810	06-Mar-13	10.32°N	109.17°W	108	PSu	28-Sep-13	10.08°N	109.12°W	127[a]	205.6	174
B1137	LAT2810	06-Mar-13	10.32°N	109.17°W	120	PSa	10-Feb-14	12.60°N	107.08°W	148[a]	340.4	342
B1148	LAT2810	07-Mar-13	10.32°N	109.17°W	87	PSu	7-Sep-13	10.23°N	109.22°W	107[a]	183.7	177
B1164	LAT2810	07-Mar-13	10.32°N	109.17°W	118	PSa	12-Sep-13	12.77°N	116.27°W	135[a]	188.6	189
B1180	LAT2810	07-Mar-13	10.32°N	109.17°W	135	PSu	17-Sep-13	10.32°N	109.17°W	150[a]	193.6	177
Panama												
D0849	LTD2310	21-Jan-07	7.12°N	81.84°W	66	PSu	8-May-07	7.58°N	79.58°W	78[a]	106.4	108
D0724	LTD2310	25-Jan-07	7.32°N	80.13°W	65	PSu	25-Jul-07	7.15°N	81.97°W	86[a]	180.6	181
D0736	LTD2310	25-Jan-07	7.32°N	80.13°W	58	PSu	25-Jul-07	7.15°N	81.97°W	78[a]	180.6	180
D0790	LTD2310	25-Jan-07	7.32vN	80.13°W	62	GN	11-Jun-07	8.08°N	80.47°W	78[a]	136.6	135
D0774	LTD2310	25-Jan-07	7.32°N	80.13°W	NA	PSa	29-May-07	7.67°N	78.82°W	NA	123.6	125
D0747	LTD2310	26-Jan-07	7.32°N	80.13°W	61	PSu	5-Sep-07	2.13°N	79.23°W	86[a]	221.6	181
D0776	LTD2310	26-Jan-07	7.32°N	80.13°W	68	PSa	13-May-07	7.05°N	81.18°W	81	106.6	108
D0764	LTD2310	30-Jan-07	7.32°N	80.13°W	58	PSa	21-Apr-09	5.53°N	85.03°W	127	811.6	526
D0739	LTD2310	30-Jan-07	7.32°N	80.13°W	65	PSa	29-May-07	7.67°N	78.82°W	79[a]	118.6	120
D0038	LTD2310	31-Jan-07	7.32°N	80.13°W	61	PSa	27-Sep-07	9.05°N	84.77°W	90	238.6	161
D0737	LTD2310	01-Feb-07	7.32°N	80.13°W	65	PSa	7-Aug-07	9.27°N	85.40°W	88	186.6	179
D0750	LTD2310	01-Feb-07	7.32°N	80.13°W	75	PSu	9-Jun-07	7.20°N	81.97°W	90[a]	127.6	129
A0117	LTD2310	03-Apr-08	7.32°N	80.13°W	64	PSu	6-Aug-09	4.00°N	83.00°W	117[a]	489.6	259
A0180	LTD2310	03-Apr-08	7.32°N	80.13°W	63	PSa	5-Sep-08	9.50°N	86.15°W	81[a]	154.6	151
D2967	LTD2310	04-Apr-08	7.32°N	80.13°W	65	PSa	13-Dec-08	8.72°N	84.70°W	93[a]	252.5	243
D0739a	LTD2310	07-Apr-08	7.32°N	80.13°W	61	PSa	1-Oct-08	10.7°N	86.62°W	81[a]	176.6	175
D4387	LTD2310	15-Sep-09	7.32°N	80.13°W	67	PSu	27-May-10	6.37°N	79.07°W	92	253.6	240
Equatorial eastern Pacific												
D0748	LTD2310	06-Apr-06	2.22°N	95.20°W	55	PSa	19-Jul-08	19.65°N	130.55°W	140[a]	834.7	289
C0112	LTD2310	06-Apr-06	2.22°N	95.20°W	51	PSa	11-Feb-07	8.42°N	94.37°W	85[a]	310.7	229

(Continues)

TABLE A1 (Continued)

Tag no.	Tag type	Release			Recapture							
		Date	Location (dd)		Fork length (cm)	Gear (set type)	Date	Location (dd)		Fork length (cm)	Days at liberty	Positions
C0209	LTD2310	06-Apr-06	2.22°N	95.20°W	52	PSf	21-Aug-06	6.00°N	119.85°W	67[a]	136.7	98
D0040	LTD2310	06-Apr-06	2.22°N	95.20°W	54	PSf	11-Jun-06	4.85°N	90.77°W	54	65.7	67
D0763	LTD2310	06-Apr-06	2.22°N	95.20°W	57	PSf	21-May-06	6.00°N	99.63°W	62[a]	44.7	46
C0949	LTD2310	06-Apr-06	2.22°N	95.20°W	60	PSf	12-May-06	8.02°N	98.37°W	64[a]	35.7	37
1890108	Mk 9	15-Apr-19	0.18°N	95.60°W	64	PSf	20-Jun-19	0.27°N	103.78°W	73	65.3	52
1441	ArcGeo 9	28-Apr-19	4.97°N	110.07°W	48	PSf	19-Aug-19	5.80°N	103.9°W	60[a]	112.4	114
Equatorial central Pacific												
D0739	LTD2310	23-Oct-09	2.03°S	140.17°W	68	PSf	31-Jan-10	1.00°S	148.82°W	79	99.2	101
0121	LAT2810	24-Oct-09	2.03°S	140.17°W	78	PSf	26-Jan-10	2.60°S	146.53°W	88	93.8	71
1950	LAT2810	28-Sep-15	4.58°S	153.45°W	58	PSf	4-Dec-15	4.21°S	160.35°W	66[a]	66.7	68
1959	LAT2810	29-Sep-15	5.02°S	153.25°W	54	PSf	8-Dec-15	4.59°S	158.70°W	62[a]	69.7	71
1985	LAT2810	29-Sep-15	5.02°S	153.25°W	56	PSf	26-Nov-15	4.93°S	158.25°W	79	57.6	57

Notes: Fish at liberty 90 d or longer were included when 20 or more archival tag data sets were available, and fish at liberty 30 d or longer were included when less than 20 archival tag data sets were available, by release area. The locations are given in decimal degrees.

Abbreviations: GN, gillnet; LL, longline; PL, pole and line; PSa, purse-seine set associated with dolphins; PSf, purse-seine set associated with a FAD; PSu, purse-seine set unassociated; RF, recreational fishing.

[a]Predicted length from the growth model of Wild (1986).