Preliminary results on popup satellite archival tagging of striped marlin in the Central North Pacific

Chi Hin Lam[1,*], Clayward Tam[2] and Molly E. Lutcavage[1]

[1] Large Pelagics Research Center, School for the Environment, University of

Massachusetts Boston, P.O. Box 3188, Gloucester, MA 01931, USA

[2] Pacific Islands Fisheries Group, 150 Hamakua Drive, PDN 430, Kailua, Hawaii
96734
*Corresponding author: tim.lam@umb.edu

Tel: +1-978-238-8208

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1. Introduction

Striped marlin, *Kajikia audax*, have been in overfished condition in the western and central North Pacific (WCNP). Although the majority of catches of striped marlin are taken by international fleets, namely Japan and Chinese Taipei, a continued decline in the spawning stock biomass could lead to additional catch reductions and management measures for Hawaii-based fleets, even for small boat fisheries and recreation charter vessels. In Hawaii, striped marlin are important to the islands' economy and cultures, and reduction in allowable harvest would be added hardship for fishing communities and seafood consumers. In addition, the prohibition of sales of Hawaii-landed billfish to the US mainland market by the recent amendments to the Billfish Conservation Act of 2012 have established additional economic hardships.

Even though North Pacific striped marlin are grouped into one genetic stock (Purcell & Edmands 2011), previous conventional tagging has shown that trans-Pacific movement is very rare. Only ten out of 21,000+ tags released by the Southwest Fisheries Science Center (SWFSC) researchers traveled from Southern California and Mexico to Hawaii (SWFSC Billfish Newsletter 2006). No eastward movement from Japan to Hawaii nor to the North American west coast (California and Mexico) has ever been documented. A current challenge for management as well as understanding of spatial aspects of stock structure is identification of the source and composition of Hawaii striped marlin. Juveniles and larger individuals appear differentially in catches of the fleets and in different seasons (recreational and longline, respectively), and an outstanding question is whether juveniles and adults have different origins but mix in the WCNP region.

Tagging effort around Hawaii is almost nonexistent north of 22 °N and south of 15 °N (Bromhead et al. 2004). As far as fishery independent information, published electronic tagging data are limited to a single acoustic (Brill et al. 1993) and one PSAT study (Domeier 2006). Altogether, data from twelve striped marlin were available, covering a duration of 4-51 hrs of tracking (Brill et al. 1993) and 35-122 days of data collection (Domeier 2006). Consequently, details on any longer-term movement (i.e., > 6 months) are missing, preventing any fisheries independent inference regarding migration pathways and connectivity to known hot spots, even though a striped marlin spawning area is found off Kona, Hawaii (Hyde et al. 2006). Our objective is to provide more up-to-date movement information with popup satellite archival tagging of striped marlin intercepted by the Hawaii-based longline fishery.

2. Materials and methods

Twenty-eight popup satellite archival tags or PSATs (4 X-Tags; Microwave Telemetry, Inc. and 24 MiniPATs; Wildlife Computers Inc.) were deployed on adult striped marlin (60-90 lb whole weight or 138-157 cm EFL) between 2016 and 2019 by Hawaii-based longline vessels. Upon retrieval of a set, an individual that was undamaged, assessed to be in good condition, was tagged along the side of the boat via a custom-built tagging pole. Tag tethers and anchors were constructed according to materials and methods we developed for bluefin tuna tagging (Lutcavage et al. 1999), with darts implanted in the musculature at the anterior dorsal region. Fish were immediately released after tagging with the hook removed or line cut. Whole weight was visually estimated by the captain, and converted to eye fork length (Sun et al. 2011).

PSATs were programmed to record relative light level, external temperature and pressure (depth) for 12 months. X-tag sampled time series at 2-minute resolution, and subsequently sub-sampled by manufacturer routines for transmission through the Argos satellites. Transmitted formats included estimated sunrise and sunset times, daily minimum and maximum depths and temperatures, and depth and temperature records available at the 15-minute marks (:00,15,30,45) of the hour. MiniPAT sampled every 60 seconds, and were configured to transmit time series data at 5-minute resolution, light levels at times of sunset and sunset, daily summaries of depth and temperature. All tags had a constant depth failsafe release set at three (MiniPAT) or four days (X-Tag), which would indicate post-release mortality or tag shedding. Returned data were imported into, and managed through Tagbase (Lam and Tsontos 2011).

For X-Tags, positions generated by manufacturer software were refined using a state-space Kalman filter model with sea-surface temperature (SST) matching, *Ukfsst* (Lam et al. 2008) with NOAA Optimum Interpolation (OI) SST V2[1]. For MiniPATs, a state-space Kalman filter model, *TrackIt* was used to estimate positions based on transmitted light data and SST (Lam et al. 2010). To further refine positions that fell on land, bathymetric correction was applied (Galuardi et al. 2010). Since there were gaps in transmitted data, refined tracks were ‘regularized’ to a daily resolution using the R package ‘*crawl*’ (Johnson et al. 2008). This final step used positional error estimates from the state-space models as a priori variance.

3. Results

Average whole weight of tagged striped marlin is 33.5 ± 3.9 kg (mean ± sd), which is similar to the mean size of Hawaii landings (Itoh 2019). Average length is 148 ± 5 cm EFL, and falls short of length at 50% maturity (177 cm; Sun et al. 2011) currently used in assessment.

Of the PSATs deployed, twenty tags have reported as of April 2019 and four tags have not yet reached their scheduled popoff dates. Three MiniPATs and one X-tag failed to report at all at the end their missions. Mission duration ranged 1-365 days,

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[1] http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html

with a median of 69 days (Table 1). One reason for the relatively short mission is the mechanic failure, i.e., nosecone breakage or pin break, for five MiniPATs, delivering mission length between 53 to 99 days.

Geolocation analysis is ongoing and seven tags have been processed to provide movement tracks. Most probable tracks revealed the majority of the striped marlin remained offshore and west of 140 °W, the management boundary under WCPFC, and dispersed mostly in the north-south direction (Fig. 1). The year-long track of Fish 115408 showed it spent its first ten months ranging from 8-38 °N before moving close to the Main Hawaiian Islands the following April (Fig. 2). Another year-long track revealed trans-equatorial and trans-Pacific movement not previously observed for striped marlin (Fig. 3). Fish 115409 was tagged outside of the WCPFC management area, where it spent four months before migrating southwest across the Central North Pacific to the South East Pacific over the course of five months. It spent the last three months off the Gold Coast of Australia before the tag released on schedule.

Based on tagging results, seasonality in striped marlin movements was diverse, and distributed over a vast area. For instance, in July and August, fish were either tagged in, or occupied areas spanning 8 to 43°N, and “pairs” of fish had similar latitudinal range, despite extensive longitudinal separation. . Similarly, in other months, the range of tagged striped marlin often exceeded 35° in latitude.

4. Discussion

Our ongoing work represents the largest effort to date to characterize striped marlin movements in the Central North Pacific. Previous studies have relied heavily on recreational fleets for access to fish, hence biasing the sampling to coastal waters. A strong partnership with our network of fishermen collaborators has enabled us to successfully tag striped marlin offshore over a wide area of striped marlin habitat, despite a perceived tradeoff of not being able to follow a particular cohort of individuals released from one deployment site. It is equally remarkable that our team has succeeded in keeping two tags attached for a full year, delivering long-term movement datasets for billfish only rivaled by archival tagging of striped marlin (Domeier et al. 2019) and PSAT tagging of Atlantic sailfish (Lam et al. 2015). This combination of conducive factors delivered preliminary results highlighting a diversity of horizontal dispersals that were not previously documented, despite matching the characteristic U-shaped spatial distribution that is well established by fisheries catch data (Bromhead et al. 2004).

Connectivity. Despite our finding that most tagged striped marlin staying within the WCPFC management unit, a first documented trans-equatorial, trans-Pacific movement of striped marlin indicated that striped marlin could mix across multiple, large oceanic areas, including midway between Hawaii and California, south of Hawaii, and off the east coast of Australia. Year-long tracks from this study and a 7-

month track from IGFA's great marlin race tagged off Los Angeles (MiniPAT serial 16P1157) showed spatial overlap between 129 and 148 °W, reinforcing the connectivity pattern established by the handful of conventional tag recoveries. More importantly, given the small number of long-mission PSATs available to replicate the same pattern, exchanges between various geographic aggregations of striped marlin may be more frequent than considered in current assessment. This possibility may have been unexplored following earlier studies, on account of short tracking missions when tags fail to remain attached for sufficiently long observation windows, or fail due to hardware or software issues (Lutcavage et al. 2014). Moreover, in this study tagged individual visiting a known spawning area, albeit not during the peak spawning season (Kopf et al. 2012), further complicates the interpretation of movement in relation to the life history requirements. The full implications of potential mixing remain unclear, as genetic stock structure (Purcell & Edmands 2011), tagging (Domeier 2006) and basic biology (Fitchett 2019) are providing incompatible sets of evidence. Spatially- and temporally explicit data on striped marlin dispersals and oceanographic associations, while still limited, provide new insights, and additional work may shift perception regarding mixing and connectivity, as they have for other highly migratory species, such as Atlantic bluefin tuna (e.g., Richardson et al. 2015).

Hardware failure. Tag failure has increasingly become an impediment to our ability to track and observe billfish and tuna (Lutcavage et al. 2014). Electronic tagging still delivers a day-to-day movement perspective that cannot be replicated by the most-advanced genetic and chemical tools, and is much needed to design the spatial parameters for biological sampling. Therefore, it is crucial to ensure our observation window is long enough, i.e., at least 10-12 months, to document a full migration cycle, capturing all seasonal movements, and long-distance dispersals. To ensure the least amount of bias introduced into our results, fisheries managers, assessment scientists and biologists must lean in together to encourage tag manufacturers to provide reliable products with a consistent performance. Equally important is to push for innovation and improvement in tracking technologies beyond that currently available, which for the most part, remain similar to devices developed in the late 1990's, lagging behind advanced technologies available in other fields.

References

Brill RW, Holts DB, Chang RKC, Sullivan S, Dewar H, Carey FG (1993) Vertical and horizontal movements of striped marlin (*Tetrapturus audax*) near the Hawaiian-Islands, determined by ultrasonic telemetry, with simultaneous measurement of oceanic currents. Mar Biol 117:567-574

Bromhead D, Pepperell J, Wise B, Findlay J (2004) Striped marlin: biology and fisheries. Bureau of Rual Sciences, Canberra, Australia

Domeier ML (2006) An analysis of Pacific striped marlin (*Tetrapturus audax*) horizontal movement patterns using pop-up satellite archival tags. Bull Mar Sci 79:811-825(815)

Domeier ML, Ortega-Garcia S, Nasby-Lucas N, Offield P (2019) First marlin archival tagging study suggests new direction for research. Mar Fresh Res. https://doi.org/10.1071/MF18160

Fitchett MD (2019) Estimating age and growth of Central North Pacific striped marlin using tagging data and direct observations of age. Working paper prepared for the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Billfish Working Group Data Prep Meeting in Honolulu, January 14-21, 2019. ISC/19/BILLWGWP1/12

Galuardi B, Lutcavage ME (2012) Dispersal routes and habitat utilization of juvenile Atlantic bluefin tuna, *Thunnus thynnus*, tracked with mini PSAT and archival tags. PLoS One. 7(5), e37829:1-11

Galuardi B, Royer F, Golet W, Logan JM, Neilson J, and Lutcavage ME (2010) Complex migration routes of Atlantic bluefin tuna question current population structure paradigm. Can J Fish Aquat Sci 67:966-976.

Hyde JR, Humphreys R, Musyl M, Lynn E, Vetter R (2006) A central north pacific spawning ground for striped marlin, Tetrapturus audax. Bull Mar Sci 79:683-690

Johnson DS, London JM, Lea MA and Durban JW (2008) Continuous-time correlated random walk model for animal telemetry data. Ecology 89(5): 1208-1215.

Kopf RK, Davie PS, Bromhead DB and Young JW (2012) Reproductive biology and spatiotemporal patterns of spawning in striped marlin *Kajikia audax*. J Fish Biol 81:1834-1858. doi:10.1111/j.1095-8649.2012.03394.x

Lam CH, Nielsen A, and Sibert JR (2008) Improving light and temperature based geolocation by unscented Kalman filtering. Fish. Res. 91(1): 15-25.

Lam CH, Nielsen A, and Sibert JR (2010) Incorporating sea-surface temperature to the light-based geolocation model TrackIt. Mar Ecol Prog Ser 419: 71-84.

Lam CH and Tsontos VM (2011) Integrated management and visualization of electronic tag data with Tagbase. Plos One 6(7): e21810.

Lam, CH., Galuardi, B, Mendillo, A., Chandler, E. and M.E. Lutcavage. 2016. Sailfish connect productive coastal areas in the Northwest Atlantic Ocean. Sci. Reports Nature 6:3816 DOI: 10.1038/srep38163

Lutcavage ME, Brill RW, Skomal GB, Chase BC, and Howey PW (1999) Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: do North Atlantic bluefin tuna spawn in the mid-Atlantic? Can. J. Fish. Aquat. Sci. 56(2): 173-177.

Lutcavage M, Lam CH, Galuardi B (2014) Seventeen years and $3 million dollars later: performance of PSAT tags deployed on Atlantic bluefin and bigeye tuna. Collect Vol Sci Pap ICCAT:SCRS/167/2014

NOAA (2006) Billfish Newsletter. Available at http://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=1199

Purcell CM, Edmands S (2011) Resolving the genetic structure of striped marlin, *Kajikia audax*, in the Pacific Ocean through spatial and temporal sampling of adult and immature fish. Can J Fish Aquat Sci 68:1861-1875

Richardson DE, Marancik KE, Guyon, J., Lutcavage ME, Galuardi B, Lam CH, WalshHJ, Wildes S, Yates, DA, Hare JA (2016) Discovery of a new spawning ground reveals diverse migration strategies in Atlantic bluefin tuna (*Thunnus thynnus*). Proc Natl Acad Sci. doi/10.1073/

Sun, CL, Hsu, WS, Chang, YJ, Yeh, SZ, Chiang, WC, and Su, NJ (2011) Reproductive biology of male striped marlin, *Kajikia audax*, in the waters off Taiwan. Working paper submitted to the ISC Billfish Working Group Meeting, 24 May-1 June 2011, Taipei, Taiwan. ISC/11/BILLWG-2/09

Table 1 Tagging summary for striped marlin.

Tag serial	Whole weight (kg)	Eye fork length (cm)	Date deployed	Date reported	Release latitude (°)	Release longitude (°)	Release latitude (°)	Release longitude (°)	Days at liberty
20139		150	2016-06-03	2017-06-03	23.65	-138.65	-27.18	156.15	365
16P1585	31.8	145	2017-06-09	2017-06-10	27.75	-153.93	27.98	-154.10	1
20138	36.3	151	2017-06-10	2018-06-10	27.97	-154.00	29.79	-159.70	365
20573	31.8	145	2017-06-11	2017-09-25	27.68	-153.90	36.15	-143.67	106
16P1902	36.3	151	2017-07-18	2017-07-27	16.00	-159.45	16.12	-162.48	9
16P1909	31.8	145	2017-07-20	2017-09-27	15.63	-158.49	5.01	-155.34	69
16P1849	36.3	151	2017-12-05	2018-03-09	22.63	-154.38	13.73	-154.89	94
16P1575	29.5	142	2018-02-25	2018-03-11	19.70	-134.57	18.88	-135.74	14
16P1580	31.8	145	2018-05-22	2018-09-11	26.57	-153.22	21.42	-136.72	112
16P1855	40.8	157	2018-05-24	2018-07-29	26.60	-153.53	30.48	-146.96	66
16P1896	38.6	154	2018-05-24	2018-08-31	26.53	-154.16	43.39	-152.79	99
16P1579	36.3	151	2018-05-29	2018-07-27	24.15	-153.66	36.85	-153.24	59
16P1916	31.8	145	2018-05-29	2018-08-30	24.09	-153.67	24.81	-143.49	93
16P1587	38.6	154	2018-06-17	2019-03-25	28.64	-139.77	18.42	-136.08	280
16P1582	31.8	145	2018-11-30	2019-01-05	30.24	-162.17	28.64	-160.60	36
16P2435	27.2	138	2018-12-18	2019-02-09	26.21	-151.66	18.28	-152.73	53
17P0206	27.2	138	2018-12-19	2019-04-08	26.09	-151.58	14.62	-153.30	109
17P0202	34.0	148	2019-01-07	2019-01-20	23.13	-149.44	24.26	-146.67	13
16P1863	31.8	145	2019-01-20	2019-01-29	24.38	-150.16	23.24	-149.81	9

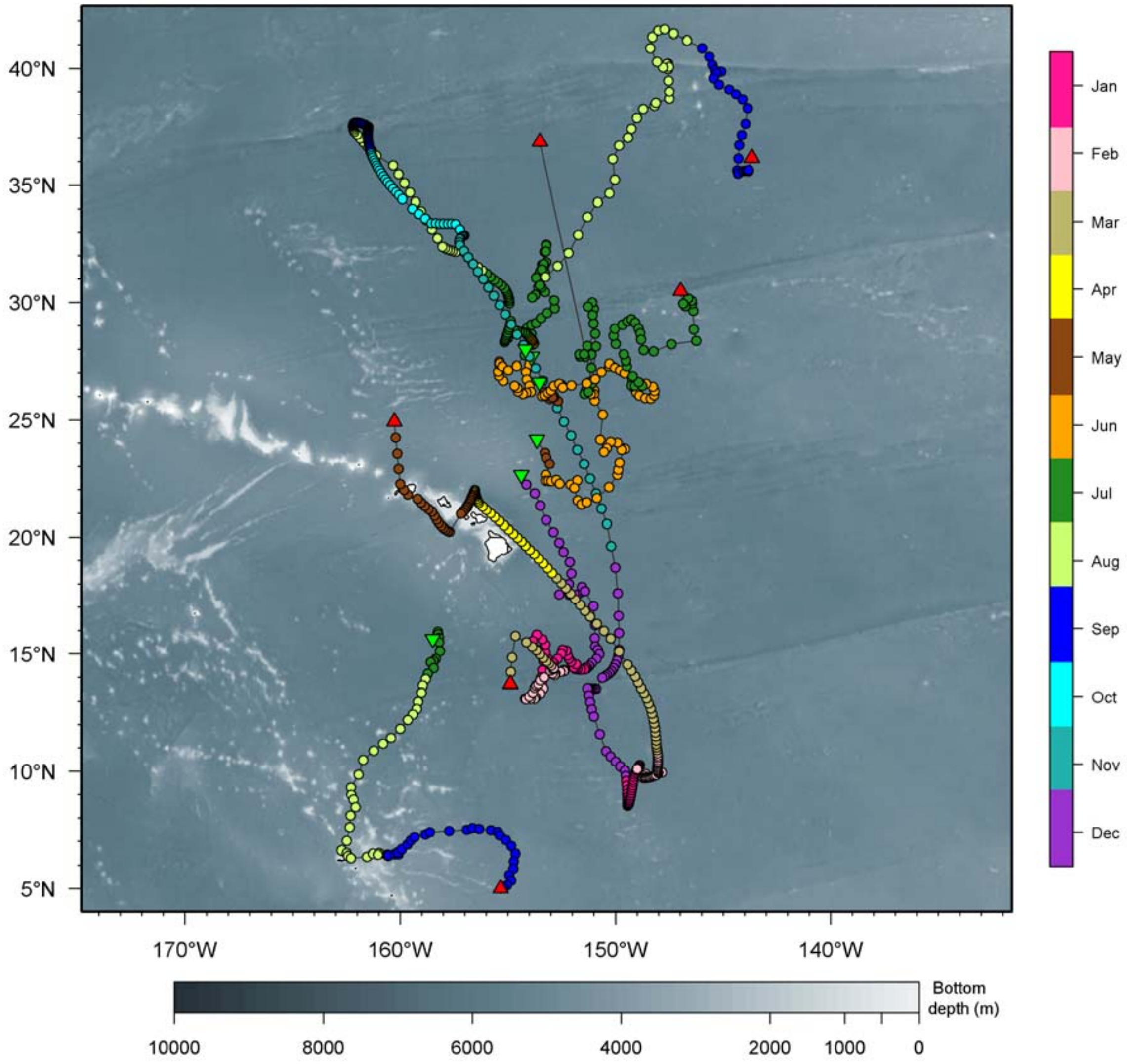

Figure 1 Horizontal tracks for tagged striped marlin. Positions are color-coded by months. Tagging locations, green triangle; popoff locations, red triangle.

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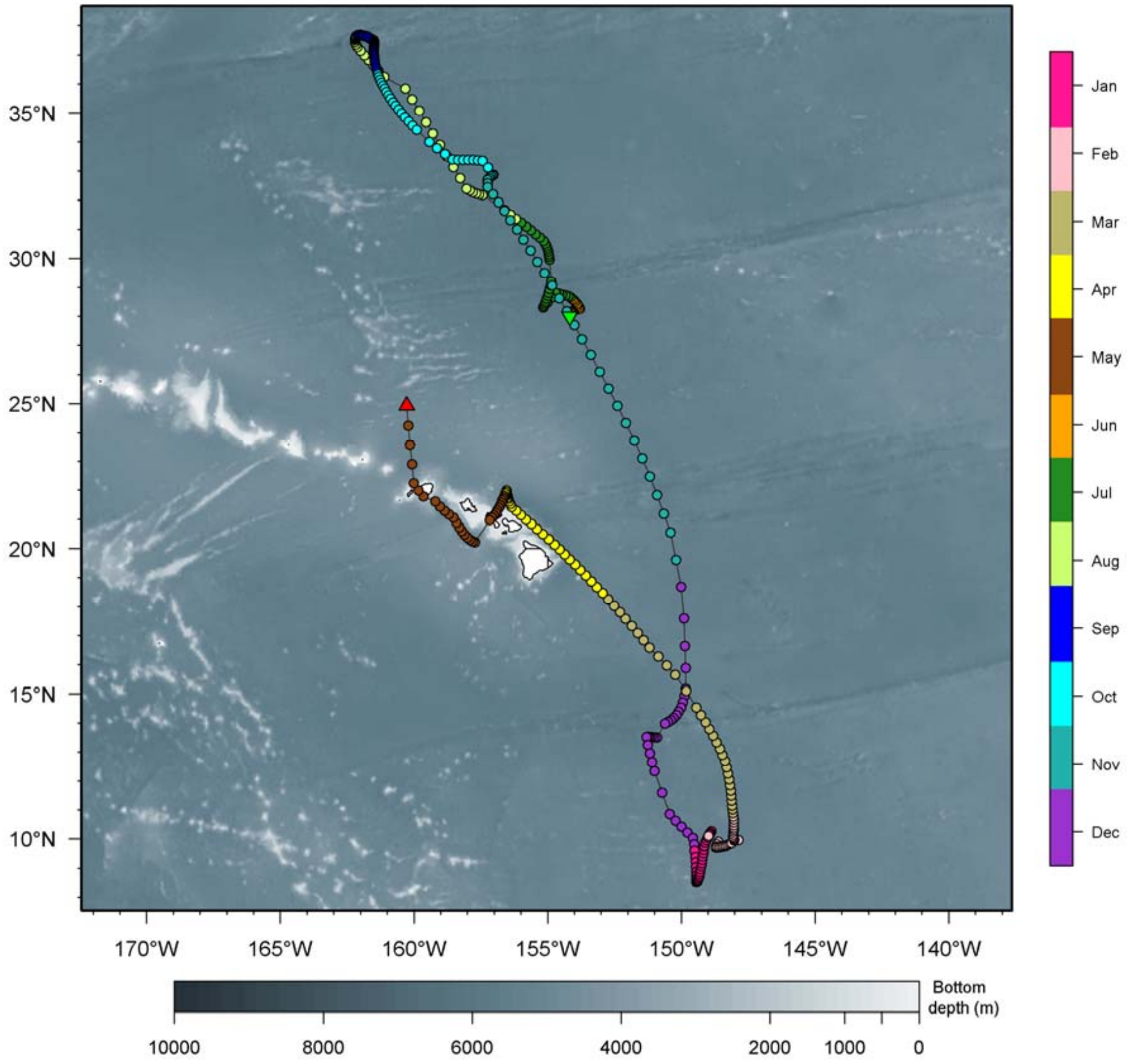

Figure 2 Yearlong track for striped marlin tag 115408. Positions are color-coded by months. Tagging location, green triangle; popoff location, red triangle.

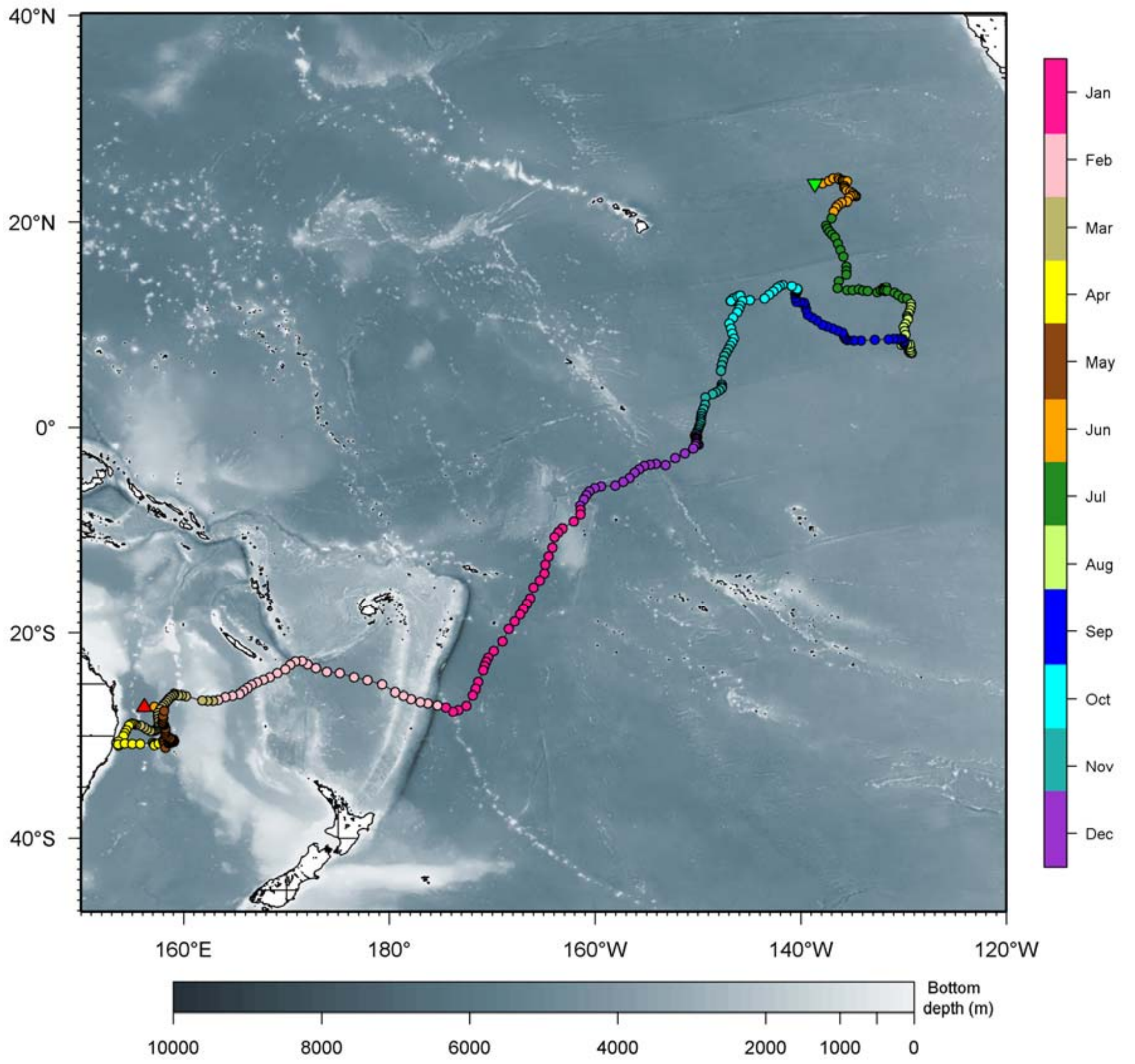

Figure 3 Yearlong track for striped marlin tag 115409. Positions are color-coded by months. Tagging location, green triangle; popoff location, red triangle.