CSIRO PUBLISHING

Marine and Freshwater Research
https://doi.org/10.1071/MF18160

First marlin archival tagging study suggests new direction for research

Michael L. Domeier[A,D], *Sofia Ortega-Garcia*[B], *Nicole Nasby-Lucas*[A] *and Paxson Offield*[C]

[A]Marine Conservation Science Institute, PO Box 7140 Kamuela, HI 96743, USA.
[B]Instituto Politecnico Nacional, Centro Interdisciplinario de Ciencias Marinas (CICIMAR), Avenida IPN s/n, Colonia Playa Palo de Santa Rita, La Paz B.C.S, C.P., 23096. Mexico.
[C]Deceased. Formerly at Offield Family Foundation, 151 Kalmus, Suite A-204, Costa Mesa, CA 92626, USA.
[D]Corresponding author. Email: ml.domeier@gmail.com

Abstract. Decades of billfish tagging studies have been hindered by below-par conventional tag recovery rates and high rates of premature satellite pop-up tag shedding. With hopes of obtaining long-term tracking data, we performed the world's first archival tagging study on an istiophorid, surgically implanting 99 archival tags into the peritoneal cavity of striped marlin (*Kajikia audax*) off the coast of Baja California, Mexico. Marlin were also tagged externally with a conventional tag before release. Ten archival tags (10.1%) were recovered with days at liberty (DAL) ranging from 400 to 2795. Nine recoveries were from Mexican waters, whereas one marlin was recaptured off Ecuador. In total, 100% of the light stalks on the archival tags failed, with nine failing within the first 3 months of deployment; because the light data are used to estimate the geographic position of the tagged fish, tracking data were compromised. The absence of conventional tags on all recaptured marlin indicates that studies of marlin using conventional tags have been hindered by tag shedding rather than tagging-associated mortality or underreporting. Our high recapture rate and long DAL suggest istiophorid science could be greatly advanced by archival tagging if new tag designs or methods can eliminate tag failure.

Additional keywords: archival tag, billfish, conventional tag, growth rate, stock structure, striped marlin.

Received 16 April 2018, accepted 15 October 2018, published online 7 December 2018

Introduction

Fish tagging is an important method for obtaining information that can be used to manage fisheries at both a species and stock level. Conventional tagging, the practice of deploying a simple numbered tag on individuals, can lead to estimates of population size, mortality (primarily based upon 'Jolly-Seber' models; Seber 1982) and movement patterns. The introduction of electronic tagging devices has led to detailed analyses of habitat preferences and movement patterns. However, all tagging studies are reliant upon recovery of tag data, either in the form of physical tag recoveries or automated transmission of data to a network. Because fish may exhibit migration patterns that occur over 1 or 2 years, the longer the tag deployment the more valuable the resulting data.

Billfish (Istiophoridae) are highly prized by recreational anglers and landed in some commercial fisheries, making them a valuable marine resource throughout the world's tropical and subtropical oceans. Extensive conventional tagging programs targeting marlin have been initiated worldwide under the auspices of the National Marine Fisheries Service's (NMFS) Cooperative Tagging Center in the Atlantic Ocean, the NMFS's Cooperative Billfish Tagging Program in the Pacific and Indian oceans, the Australian Cooperative Tagging Program in the Pacific and Indian oceans, the New Zealand Cooperative Game Fish Tagging Program in the Pacific Ocean and The Billfish Foundation's tagging program in the Atlantic, Pacific and Indian oceans. Between 1954 and 2002, these programs had deployed 317 000 conventional tags, which led to 4122 (1.3%) tag recoveries (Ortiz *et al.* 2003). A 1.3% recovery rate over a span of decades is poor when compared with other fisheries that routinely have 5% or better tag return rates. For example, the historical Atlantic Bluefin tuna *Thunnus thynnus* conventional tag return rate over a similar time span was reported at 12.7% (5–10% annually when purse seine recoveries were excluded; Jones and Prince 1997).

Electronic tagging studies of billfish have been equally problematic. Hundreds of satellite pop-up archival transmitting (PAT) tags have been deployed on striped marlin (*Kajikia audax*), blue marlin *Makaira nigricans*, black marlin *Istiompax indica*, white marlin *Kajikia albidus* and sailfish *Istiophorus platypterus*, with exceptionally high premature tag shedding rates. The longest days at liberty (DAL) for PAT tags on billfish are 365 for sailfish (Lam *et al.* 2016), 334 for blue marlin (Kraus *et al.* 2011), 365 for black marlin (Chiang *et al.* 2015), 259 for striped marlin (Domeier 2006) and 150 for white marlin (Hoolihan *et al.* 2012). These maximum DAL are exceptions; most of the billfish PAT tag datasets are much shorter. For example, two of the most comprehensive PAT tagging studies involved striped marlin ($n = 245$; Domeier 2006) and black marlin ($n = 67$; Domeier and Speare 2012); the average DAL for striped marlin was 49 days, with 6% remaining on the fish for the programmed duration, and the average DAL for black marlin was 55 days, with 13% remaining on the fish for the programmed duration. Identifying migratory pathways, potential spawning areas and stock structure is impossible with such short tag retention.

The reason for such poor data recovery on tagged billfish is unknown. In the case of conventional tagging, possible causes include underreporting by commercial fisheries or a high rate of tag shedding. Tag shedding is certainly an issue with PAT tags. New tagging methods are needed to advance our understanding of billfish migrations and stock structure. Internal anchor tags (a form of conventional tag that is anchored in the peritoneal cavity) have been found to have better retention rates than conventional tags anchored in the dorsal musculature (Waldman *et al.* 1991). Similarly, surgically implanted electronic tags (acoustic and archival) have resulted in multiyear datasets for several tuna species (e.g. Schaefer and Fuller 2010; Childers *et al.* 2011; Cermeño *et al.* 2012). However, the handling required to surgically implant an archival tag in a billfish is problematic given the large size of the fish and the potential fragile nature of the fish. Furthermore, there is a risk of injury to researchers who attempt handling billfish in the manner necessary for the surgical implantation of tags.

Holland *et al.* (2006) conducted trials to develop methods and demonstrate that surgical implantation of tags in billfish is possible. Using a rod and reel, Holland *et al.* (2006) captured, restrained and tagged four striped marlin between 120 and 180-cm lower jaw fork length (LJFL). Acoustic tags were surgically implanted in the peritoneal cavity of each fish before the fish were tagged with a PAT tag and released. The purpose of the PAT tag was to collect data that would allow determination of the fate of each fish. Although none of the tagged marlin were detected on acoustic receivers, the PAT tag data revealed that three of the four of the marlin survived the procedure.

Striped marlin have been the subject of more PAT tag studies than any other billfish. In all, nearly 300 PAT tags have been deployed on striped marlin in Australia, New Zealand, Hawaii, California, Mexico, Costa Rica, Panama and Ecuador (Domeier 2006; Sippel *et al.* 2007; Lam *et al.* 2015). Short retention times for these PAT tags have hampered data analyses, but the absence of ocean basin-scale migrations suggest that striped marlin may have a regional stock structure rather than a single Pacific-wide stock (Domeier 2006). Genetic studies (mitochondrial DNA and microsatellite DNA) also support the presence of at least three separate striped marlin stocks in the Pacific (Graves and McDowell 1994; McDowell and Graves 2008; Purcell and Edmands 2011): (1) Japan–Southern California; (2) Australia–New Zealand; and (3) Central and South America. Striped marlin also occur in the Indian Ocean, but no studies or samples have been taken from marlin from that region.

Given the success of the trial of Holland *et al.* (2006), we developed and conducted the first large-scale archival tagging study of any billfish species in an attempt to obtain multiyear migration data to help identify spawning regions and confirm stock structure. Here we present the findings of our study, which involved surgically implanting archival tags in striped marlin off the coast of Baja California, Mexico.

Materials and methods

Striped marlin were targeted off Magdalena Bay, Baja California, Mexico (24.69°N, 112.22°W) using rod and reel, live bait and circle hooks. Once a marlin was hooked, it was brought alongside the side of the fishing vessel and lifted from the water by hand; one person lifted from the base of the bill while a second person lifted the fish by grasping the caudal peduncle. The fish was then set down on a soft mat on the deck of the fishing vessel. A hose was placed in the mouth of the fish to pump raw seawater over the gills. LJFL and girth were measured and recorded. An incision was made in the epidermis, just off centre of the ventral midline and forward of the anal fin (approximately in line with the posterior tip of the pectoral fin when laid along the side of the fish). A stainless steel trocar was used to separate the muscle and penetrate the lining of the peritoneal cavity. A Wildlife Computers Mk9 archival tag (Redmond, WA, USA) was inserted into the peritoneal cavity and the incision was then closed with Vycril (Ethicon, Inc., Somerville, NJ, USA) sutures. The Mk9 tags were configured with a sensor stalk that emerged from the tag body perpendicular to the tag, but then bent 90° so that the stalk was parallel to the tag body. This allowed the stalk to lie flat against the body of the fish, thereby reducing drag. The body of these tags, which is inserted into the peritoneal cavity, consists of the battery, the microprocessor, a pressure sensor and an internal body temperature sensor. The stalk of the tag incorporates an external temperature sensor and the light sensor. After the incision was closed, each fish was tagged with a numbered conventional tag that described the location of the archival tag and announced a US$500 reward. The conventional tag comprised a Domeier-style umbrella dart (Domeier *et al.* 2005) tethered to a plastic Hallprint tag (Hallprint Pty Ltd., Hindmarsh Valley, SA, Australia) with stainless steel wire. After tagging, fish were lowered into the water and restrained alongside the boat as the boat moved forward to irrigate the gills. The fish was released when sufficiently recovered to swim away from the boat.

Ninety-nine archival tags were surgically implanted into the peritoneal cavity of striped marlin off the coast of Baja California, Mexico, between 2008 and 2010. All marlin were tagged during the month of November ($n = 50$ in 2008; $n = 2$ in 2009; $n = 47$ in 2010). LJFL ranged from 150 to 228 cm (mean 187 cm). Location data were derived from light data from recovered Mk9 tags using GPE3 geolocation processing software (Wildlife Computers, see http://wildlifecomputers.com/wp-content/uploads/manuals/Location-Processing-User-Guide.pdf, accessed 20 March 2018).

Permits for tagging were authorised by Comision Nacional de Acualcultura y Pesca (CONAPESCA) through the fishing permit DGOPA/13308/210905.

Results and discussion

Ten archival tags (10.1%) were recovered from striped marlin with DAL ranging from 400 to 2795 (1.1–7.7 years; mean 4.3 years; Table 1). Nine tagged striped marlin were recovered in Mexican waters and one was recovered in Ecuador (Fig. 1).

Table 1. Deployment and recovery data for archival tagged striped marlin
DAL, days at liberty; LJFL, lower jaw fork length; SST, sea surface temperature

Tag	Deployment				DAL	Data duration (days)			Maximum depth (m)	SST (°C)		Minimum water temperature (°C)
	Date	Latitude	Longitude	LJFL (cm)		Light	Depth	Temperature		Maximum	Minimum	
890271	11 Feb. 2008	24.35	−111.93	183.0	1148	56	522	56	196	27.2	23.4	12.8
890272	11 Feb. 2008	24.35	−111.92	181.0	2386	85	530	85	320	27.3	21.2	11.7
890289	11 Aug. 2008	24.33	−111.95	174.0	2794	81	2795	81	352	28.6	23.3	10.6
890295	11 Aug. 2008	24.32	−111.95	173.0	479							
890381	11 June 2008	24.22	−111.87	201.0	2594	66	323	66	184	27.5	21.4	12.7
990317	11 Dec. 2010	24.10	−111.37	162.6	2410	286	299	286	264	31.4	21.5	12.3
990333	11 Aug. 2010	24.17	−111.55	180.3	400	32	102	32	184	26.4	23.2	12.3
990339	11 Dec. 2010	24.10	−111.33	200.7	1951	45	1951	45	328	26.1	21.1	12.1
990357	11 Dec. 2010	24.10	−111.35	172.7	660	47	462	47	280	26.4	20.5	12.8
990363	11 Dec. 2010	24.10	−111.38	185.4	872	52	518	52	250	25.9	22.2	12.3

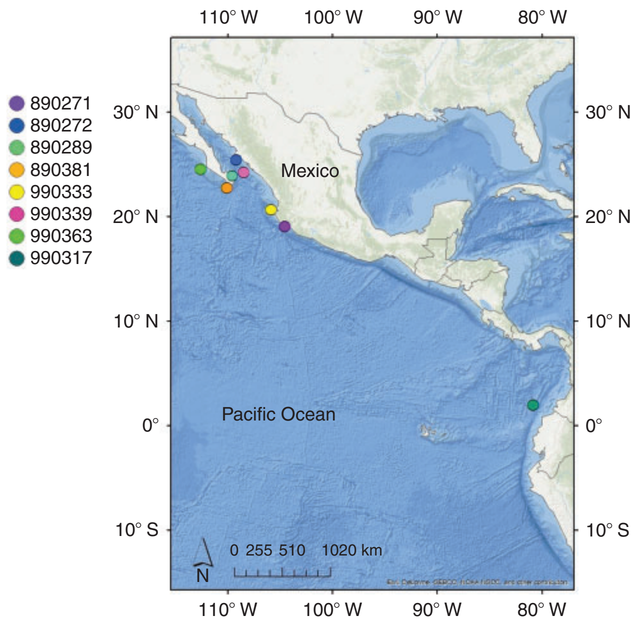

Fig. 1. Recovery locations available for eight archival tagged striped marlin.

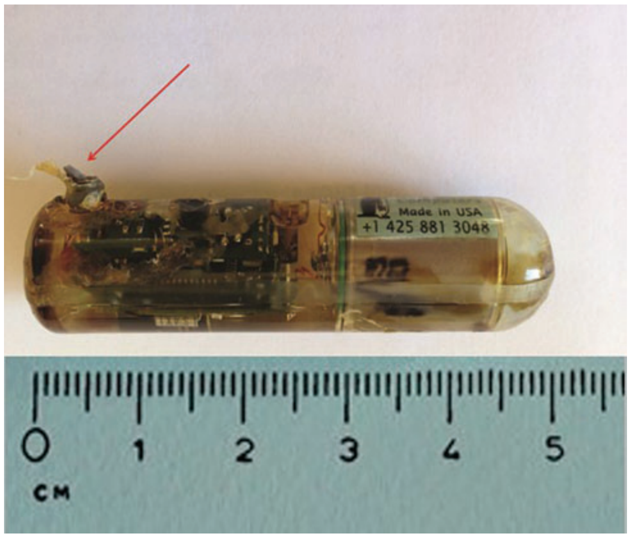

Fig. 2. A recovered Mk9 archival tag showing where the sensor stalk has broken off (arrow). All 10 tags recovered had identical stalk failures.

None of the recovered marlin were carrying conventional tags at the time of recapture.

Data were recovered from 9 of the 10 tags. No data were recovered from Tag 890295; a bug in the Wildlife Computers data retrieval software caused all data to be erased during the download process (the bug has since been identified and fixed). In total, 100% of Mk9 tags experienced sensor stalk failure before recovery, with the light and temperature sensor stalk separating from the tag body at the point of attachment (Fig. 2). The temperature and light sensors failed simultaneously at the time of stalk failure. Tag failures occurred early in the deployment periods, between 32 and 286 DAL (mean 83 days; Table 1). Temperature data indicated the sea surface temperature ranged from 25.9 to 31.4°C, with a minimum temperature experienced of 10.6°C. Depth data covered the entire deployment period for two tags (1951 and 2795 days into deployment) but stopped recording early for seven of the tags (102–530 days into deployment; mean 447 days; Table 1); saltwater intrusion from the sensor stalk likely killed the pressure sensor. Maximum depth values ranged from 184 to 352 m (mean 262 m).

Eight of the tagged marlin were recaptured by commercial fishing vessels and two were recovered by recreational fishing vessels. The precise location of recapture is known for eight of the marlin (Fig. 1); seven tags were recovered off Mexico and one was recovered off the northern coast of Ecuador (Tag 990317). Precise recapture location was unknown for two tags that were recovered by fish processors; the fish processors could confirm the tags were recovered from a Mexican fishing vessel fishing in Mexican waters, but they could not determine the exact location. Location data were calculated for the period of time before light stalk failure. Tracking data showed that nine of the tagged marlin remained in Mexican waters, moving from the Pacific side of Baja California into the Sea of Cortez. Tag

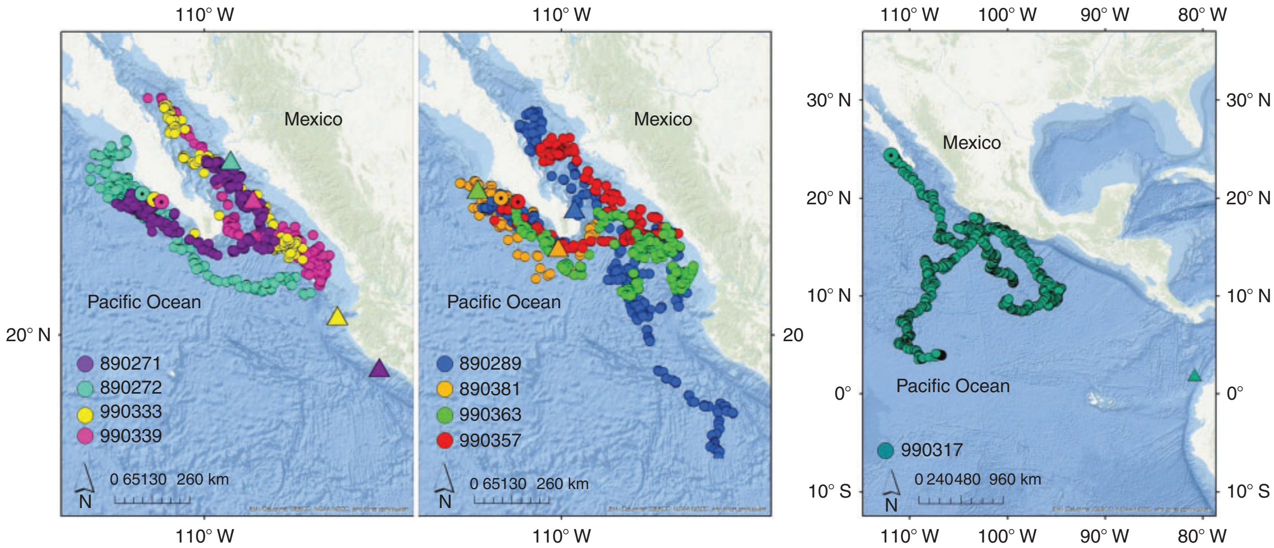

Fig. 3. Calculated location estimates for the nine recovered striped marlin archival tags with data.

890289 moved to a location 700 km south-east of the tip of the Baja Peninsula before turning back and entering the Sea of Cortez (Fig. 3). The fish recovered in Ecuador (Tag 990317) moved 2200 km south of the tip of the Baja Peninsula before the light sensor failed.

Electronic tag failure normally results in a failed experiment, but comparisons with previously published electronic tagging datasets for striped marlin allowed for new insights into the biology of this species, as well as generalisations regarding istiophorid tagging in general. Certainly our goal of tracking this species for multiyear durations was not met, but this study was an important first attempt at achieving that goal. An archival tag recovery rate of 10.1%, with an average DAL of over 4 years, provided promising results for the use of archival tags in istiophorids.

Wildlife Computers Mk9 archival tags have been used in tuna without stalk failure (e.g. Schaefer and Fuller 2010; Childers *et al.* 2011). The 100% failure of the sensor stalk in our tagged marlin is perhaps explained by the difference in the swimming motion between tuna and billfish. The swimming pattern of istiophorids has not been described previously, but certainly there is more movement of the aft portions of the body than that exhibited by tunas. Because the archival tags were implanted 4–8 cm anterior to the vent (to avoid interfering with the major organs), they were subjected to more motion than tags placed on tuna. It is our opinion that the constant motion of the tags caused stress and fatigue at the base of the stalk, resulting in separation of the stalk from the tag in as little as 32 days.

None of the recaptured marlin were carrying the conventional tag that was inserted into the dorsal musculature. The conventional tag was intended to alert the person who recovered the fish that a valuable electronic tag was in the coelomic cavity; had the conventional tags not been shed, the recovery rate of archival tags would likely have been higher. The Domeier-style umbrella dart (Domeier *et al.* 2005) has been found to provide multiyear tag retention in serranids (Y. Sadovy, pers. comm.) and sharks (M. L. Domeier, pers. comm.) and was also deemed the most effective tag anchor in a study that compared several different dart types (Musyl *et al.* 2011). The tags differed from typical Billfish Foundation (TBF) tags only by the dart head and the use of a stainless steel wire tether. Wire was selected to eliminate any potential tag loss from other marine animals biting through the TBF-type monofilament tether. The absence of the conventional tags in all marlin recovered is consistent with historic conventional tag recoveries, indicating that the cause of very poor conventional tag returns in istiophorids is not because of underreporting, but instead due to a very high rate of tag shedding.

Some indirect but significant conclusions can be inferred from the results when comparing them to previously published studies of striped marlin. For example, all the fish were recaptured in the eastern Pacific after 1.1–7.7 years at liberty (Table 1). Satellite tagging results have never documented an individual to migrate between the eastern and western Pacific, but the DAL for these studies was months rather than years. The recovery of all our tags in the eastern Pacific supports the hypothesis that striped marlin rarely undergo ocean basin migrations, and supports the hypothesis that striped marlin in the Pacific are not a single stock.

Another interesting observation relates to the size of the individual marlin recovered. Striped marlin are thought to rarely attain an age of greater than 7 years (Kopf *et al.* 2011), and growth rates of striped marlin from different regions of the Pacific are very similar (Kopf *et al.* 2005). However, records kept by the International Game Fishing Association (2018) indicate that striped marlin off New Zealand can grow nearly twice as large as those found off Mexico. Although we do not have an accurate weight or length for any of the marlin that were recaptured for the present study, we were sent a picture of the specimen (Fig. 4) with the longest DAL (7.7 years). This fish was 174 cm LJFL (~18 months old) when tagged and at least 9 years old when recaptured; despite its advanced age, the fish is clearly a fraction of the size (for scale, the individuals standing next to the fish are children) of the largest specimens sampled by

Fig. 4. A recaptured striped marlin that was 174-cm lower jaw fork length at the time of tagging; very little growth occurred during the 7.7 years at liberty. If the conventional tags had remained on the fish, the archival tag recovery rate would likely been even higher, because, without the conventional tag, there was no external indication that a tag was inside the fish. The lack of conventional tags at the time of recovery also illustrates that tag shedding is the cause of low recovery rates of conventional tags on istiophorids.

Kopf *et al.* (2011). None of the estimated weights we received from those that recaptured the marlin for this study was more than 100 kg, indicating a large difference in maximum size in the striped marlin stocks of Mexico and New Zealand.

Future archival tagging studies of marlin will require modification to either the tag design or the location of tag implantation or placement. A tag from another manufacturer, which has a different stalk design, may produce better results or the stalk on the Mk9 could be redesigned to prevent the stalk from breaking. We implanted the tag in the distal region of the peritoneal cavity to avoid interacting with vital organs, but perhaps more anterior placement could reduce the movement of the light stalk and thereby prevent light stalk failure.

Striped marlin in the eastern Pacific are relatively small compared to blue and black marlin, making it possible to lift them from the water to conduct the surgical procedure necessary to implant an archival tag. However, larger billfish would require the design of a mechanical lift to properly handle them; such a lift would be very expensive and difficult to operate in even moderate sea conditions. A better solution would be the development of an archival tagging method that can be executed while the fish remains in the water. Istiophorids have a unique bony structure that could be suitable for long-term archival tag attachment: the bill. Developing a stalk-less archival tag that is affixed directly to the bill could rectify the stalk failure and improve tag recovery rates because the tag would be visible externally. The most challenging aspect of this idea is the development of an attachment method that would be quick and safe for both the researcher and the fish (i.e. anchored with bone screw).

Conflicts of interest

The authors declare that they have no conflicts of interest.

Declaration of funding

Funding for this research was provided by a grant from the Offield Family Foundation.

Acknowledgements

The authors dedicate this paper to Paxson Offield, who passed away in 2015. His passion for billfish went far beyond fishing; he also strongly believed in science-based fisheries management. In pursuit of answering research questions related to billfish, Paxson funded an unprecedented number of research projects, including this study. The authors also recognise the crew of the *Kelsey Lee*, Paxson Offield, Chase Offield, Calen Offield, Carl Schloderer and John Talsky, for capturing the striped marlin and deploying the archival tags. Additional support for S. Ortega-Garcia made possible through a Comision de Operación y Fomento de las Actividades Academicas (COFAA) Fellowship.

References

Cermeño, P., Tudela, S., Quílez-Badia, G., Sainz-Trápaga, S., and Graupera, E. (2012). New data on bluefin tuna migratory behavior in the western and central Mediterranean Sea. *ICCAT Collective Volume of Scientific Papers* **68**, 151–162.

Chiang, W.-C., Musy, M. K., Sun, C.-L., DiNardo, G., Hung, H.-M., Lin, H.-C., Chen, S.-C., Yeh, S.-Z., Chen, W.-Y., and Kuo, C.-L. (2015). Seasonal movements and diving behaviour of black marlin (*Istiompax indica*) in the northwestern Pacific Ocean. *Fisheries Research* **166**, 92–102. doi:10.1016/J.FISHRES.2014.10.023

Childers, J., Snyder, S., and Kohin, S. (2011). Migration and behavior of juvenile North Pacific albacore (*Thunnus alalunga*). *Fisheries Oceanography* **20**, 157–173. doi:10.1111/J.1365-2419.2011.00575.X

Domeier, M. L. (2006). An analysis of Pacific striped marlin (*Tetrapturus audax*) horizontal movement patterns using pop-up satellite archival tags. *Bulletin of Marine Science* **79**, 811–825.

Domeier, M. L., and Speare, P. (2012). Dispersal of adult black marlin (*Istiompax indica*) from a Great Barrier Reef spawning aggregation. *PLoS One* **7**, e31629. doi:10.1371/JOURNAL.PONE.0031629

Domeier, M. L., Kiefer, D., Nasby-Lucas, N., Wagschal, A., and O'Brien, F. (2005). Tracking Pacific bluefin tuna (*Thunnus thynnus orientalis*) in the northeastern Pacific with an automated algorithm that estimates latitude by matching sea-surface-temperature data from satellites with temperature data from tags on fish. *Fishery Bulletin* **103**, 292–306.

Graves, J. E., and McDowell, J. R. (1994). Genetic analysis of striped marlin (*Tetrapturus audax*) population structure in the Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences* **51**, 1762–1768. doi:10.1139/F94-177

Holland, K. N., Itano, D. G., and Domeier, M. (2006). First successful surgical internal implantation of electronic tags in marlin. *Bulletin of Marine Science* **79**, 871–874.

Hoolihan, J. P., Luo, J., and Prince, E. D. (2012). Preliminary analysis of time spent at temperature relative to the surface temperature for white marlin monitored with pop-up satellite archival tags. *ICCAT Collective Volume of Scientific Papers* **68**, 1585–1589.

International Game Fishing Association (2018) IGFA World Record Game Fishes. (IGFA: Dania, FL, USA.) Available at https://store.igfa.org/ProductDetails.asp?ProductCode=2018WRB [Verified 1 November 2018].

Jones, C. D., and Prince, E. D. (1997). Cooperative tagging center release and recapture activities for bluefin tuna: 1954–1996. *ICCAT Collective Volume of Scientific Papers* **46**, 363–367.

Kopf, R. K., Davie, P. S., and Holdsworth, J. C. (2005). Size trends and population characteristics of striped marlin, *Tetrapturus audax*, caught in the New Zealand recreational fishery. *New Zealand Journal of Marine and Freshwater Research* **39**(5), 1145–1156. doi:10.1080/00288330.2005.9517381

Kopf, R. K., Davie, P. S., Bromhead, D., and Pepperell, J. G. (2011). Age and growth of striped marlin (*Kajikia audax*) in the southwest Pacific Ocean. *ICES Journal of Marine Science* **68**, 1884–1895. doi:10.1093/ICESJMS/FSR110

Kraus, R. T., Wells, R. D., and Rooker, J. R. (2011). Horizontal movements of Atlantic blue marlin (*Makaira nigricans*) in the Gulf of Mexico. *Marine Biology* **158**, 699–713. doi:10.1007/S00227-010-1593-3

Lam, C. H., Kiefer, D. A., and Domeier, M. L. (2015). Habitat characterization for striped marlin in the Pacific Ocean. *Fisheries Research* **166**, 80–91. doi:10.1016/J.FISHRES.2015.01.010

Lam, C. H., Galuardi, B., Mendillo, A., Chandler, E., and Lutcavage, M. E. (2016). Sailfish migrations connect productive coastal areas in the West Atlantic Ocean. *Scientific Reports* **6**, 38163. doi:10.1038/SREP38163

McDowell, J. R., and Graves, J. E. (2008). Population structure of striped marlin (*Kajikia audax*) in the Pacific Ocean based on analysis of microsatellite and mitochondrial DNA. *Canadian Journal of Fisheries and Aquatic Sciences* **65**, 1307–1320. doi:10.1139/F08-054

Musyl, M. K., Domeier, M. L., Nasby-Lucas, N., Brill, R. W., McNaughton, L. M., Swimmer, J. Y., Lutcavage, M. S., Wilson, S. G., Galuardi, B., and Liddle, J. B. (2011). Performance of pop-up satellite archival tags. *Marine Ecology Progress Series* **433**, 1–28. doi:10.3354/MEPS09202

Ortiz, M., Prince, E. D., Serafy, J. E., Holts, D. B., Davy, K. B., Pepperell, J. G., Lowry, M. B., and Holdsworth, J. C. (2003). Global overview of the major constituent-based billfish tagging programs and their results since 1954. *Marine and Freshwater Research* **54**, 489–507. doi:10.1071/MF02028

Purcell, C. M., and 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. *Canadian Journal of Fisheries and Aquatic Sciences* **68**, 1861–1875. doi:10.1139/F2011-104

Schaefer, K. M., and Fuller, D. W. (2010). Vertical movements, behavior, and habitat of bigeye tuna (*Thunnus obesus*) in the equatorial eastern Pacific Ocean, ascertained from archival tag data. *Marine Biology* **157**, 2625–2642. doi:10.1007/S00227-010-1524-3

Seber, G. A. F. (1982). 'The Estimation of Animal Abundance and Related Parameters', 2nd edn. (Griffin: London, UK.)

Sippel, T. J., Davie, P. S., Holdsworth, J. C., and Block, B. A. (2007). Striped marlin (*Tetrapturus audax*) movements and habitat utilization during a summer and autumn in the southwest Pacific Ocean. *Fisheries Oceanography* **16**, 459–472. doi:10.1111/J.1365-2419.2007.00446.X

Waldman, J. R., Dunning, D. J., and Matson, M. T. (1991). Long term retention of anchor tags and internal anchor tags by striped bass. *North American Journal of Fisheries Management* **11**, 232–234. doi:10.1577/1548-8675(1991)011<0232:MBLTRO>2.3.CO;2

Handling Editor: Jenny Ovenden