BULLETIN OF MARINE SCIENCE, 79(3): 827–838, 2006

TRANSBOUNDARY MOVEMENT OF SAILFISH, *ISTIOPHORUS PLATYPTERUS*, OFF THE PACIFIC COAST OF CENTRAL AMERICA

Eric D. Prince, David B. Holts, Derke Snodgrass, Eric S. Orbesen, Jiangang Luo, Michael L. Domeier, and Joseph E. Serafy

ABSTRACT

The sailfish, *Istiophorus platypterus* (Shaw in Shaw and Nodder, 1792), is one of the most frequently caught istiophorids along the Pacific coast of Central America. Although conventional constituent-based tagging of sailfish in this region has been ongoing for several decades, little insight has emerged regarding their movements among multinational territorial waters. We used pop-up satellite archival tags (PSATs) to evaluate questions of management unit for sailfish in this region. A total of 41 PSATs were deployed on sailfish caught with recreational gear off Mexico, Guatemala, Costa Rica, and Panama. The 32 deployments that transmitted data yielded displacements (point of release to point of first pop-up transmission) that ranged from 21 to 572 nmi (39–1059 km). Monitoring durations ranged from 5 to 118 d, for a total aggregate of 1571 d. More than half of the deployments (22 of 32, or 68%) resulted in displacement vectors outside the EEZ or territorial waters of the country of tagging (lower bounds estimate). In addition, upper bounds estimates of tracks using two algorithms ranged from 57 to 65 transboundary crossings; average days to make a transboundary crossing ranged from 12 to 20 d, respectively. Given the relatively short residence time in the national waters of tagging, these movements strongly suggest that this resource requires management at the regional rather than national level.

Sailfish, *Istiophorus platypterus* (Shaw in Shaw and Nodder, 1792), have a circumtropical distribution and are known to be especially abundant along coastal equatorial regions of the Atlantic, Pacific, and Indian Oceans (Beardsley et al., 1975). Off Central America's coast, sailfish are the most abundant istiophorid and support viable recreational and artisanal fisheries for Mexico, Guatemala, Costa Rica, and Panama (Beardsley, et al., 1975; Prince et al., 2001; Ortiz et al., 2003). Although constituent-based conventional tagging programs for sailfish have been active in the Eastern Tropical Pacific (ETP) since 1963, sailfish recapture percentages in these waters (D. B. Holts, Southwest Fisheries Science Center, unpubl. data; E. Peel, The Billfish Foundation, unpubl. data) are generally two to three-fold lower than comparable sailfish tagging programs in other parts of the world (Ortiz et al., 2003).

There are numerous possible reasons for this poor recapture rate, including, but not limited to, the relative isolation of the region, the multi-national nature of the fisheries that exploit this species, and inadequate outreach efforts (Ortiz et al., 2003). In addition, oceanographic phenomena in the region, such as hypoxia-based habitat compression (Prince and Goodyear, 2006), may also potentially contribute to the low recapture rate. For example, fish in an oxygen deficit state after the capture and tagging event may not survive if they are unable to maintain forward movement (i.e., ram ventilate) and thereby sink into the hostile hypoxic environment below the thermocline (only 25 m below the surface). Under these circumstances, post release survival could be jeopardized. Prince et al. (2002) recommended resuscitative tech-

Bulletin of Marine Science

niques be applied prior to release, but it is unlikely that this procedure has been performed regularly on the majority of the tagged sailfish from the ETP over the last 40 yrs. Therefore, the apparent limited amount of movement data from conventional tagging of sailfish in the ETP prompted us to: (1) re-examine and analyze conventional tagging results from all sources for the ETP; and (2) use pop-up satellite archival tags to examine transboundary movements in this geographical region.

Methods

Study Area.—The present study was conducted in Pacific waters off Central America, from about 77°W to 110°W and from 25°N to 03°N. These coordinates include the territorial waters of Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, and Colombia. Coordinates for national territorial boundaries between countries and international EEZ offshore boundaries were developed from the Global Maritime Boundaries Database [Includes data supplied and copyrighted (1998) by Veridian Information Solutions, Inc., MRJ Engineering Group. These data or other information are provided on a best-efforts basis and MRJ does not guarantee their accuracy or warrant their fitness for any particular purpose. Such data or information has been reprinted with the permission of MRJ]. These boundary demarcations were used as the basis for determining transboundary movements. We chose sailfish captured in the waters of Mexico, Guatemala, Costa Rica, and Panama for electronic tag deployments as active recreational fisheries for this species exist at these locations.

Sources of Conventional Data.—Two sources of conventional tagging data for sailfish in the ETP include the Southwest Fisheries Science Center and The Billfish Foundation (Ortiz et al., 2003). Data extractions of sailfish tag and release files were made based on the coordinates of the ETP given above. Only displacements of recoveries that moved out of the general area of the original release locations (> 20 nmi or > 37 km) were analyzed for transboundary movements.

Deployment of Pop-up Satellite Archival Tags.—Deployment of pop-up satellite archival tags (PSATs) on sailfish was conducted from recreational fishing vessels using standard trolling gear with natural dead bait and non-offset circle hooks as terminal gear. All tag deployment activities were conducted within 50 nmi of land. Wildlife Computers Inc. (Redmond, WA) PAT 3 model tags were the primary tag used, although a few PAT 2 model tags were also used in 2000 and 2002. Tags were programmed following Prince and Goodyear (2006). Briefly, tag sampling parameters included sampling depth (pressure), temperature, and light once every 30 or 60 s and the depth and temperature records were compiled into histograms at 6-hr intervals for most deployments. A few of the early deployments summarized histograms at 3-hr intervals. The temperature bins were programmed for temperatures ≤ 12 °C, each successive 2 °C interval ending with 32 °C, and > 32 °C. The depth bins included depths < −1, and successive intervals of 25–250 m, and depths > 250 m.

Our plan was to deploy a total of 40 PSATs on sailfish in the area of interest; 10 each on fish captured off the coasts of Ixtapa, Mexico; Iztapa, Guatemala; Jaco (Los Sueños), Costa Rica, and Piñas Bay, Panama. PSATs were programmed for deployment durations of 30–120 d. A pressure-activated mechanical detachment device (RD 1500) was also used. This feature helps prevents data loss in the event of fish mortality. Release locations were obtained from global positioning systems onboard the tagging vessels and pop-up locations were obtained directly from the ARGOS transmissions of each tag. The data collected included the minimum and maximum temperature and depth, and amount of time spent in each of the specified depth and temperature bins for each 6 hr interval sampled. Billfish handling and tagging procedures and associated devices were as described by Prince et al. (2002). The body shape of sailfish is laterally compressed, particularly when compared to the more robust shape of the larger marlins. This body metric limits the depth of penetration for anchoring PSAT tags and likely contributes to premature release problems on this species (Prince and Goodyear, 2006). Anchoring problems on sailfish are further exacerbated by the fact that sailfish have a tendency to "free jump" more than the other istiphorids, which likely contributes to premature release of PSATs. In an effort to minimize premature release problems in this study, we conducted some preliminary tests on dead sailfish to identify the most desirable location for PSAT anchoring. We found that inserting the anchor about 4–5 cm ventral to the dorsal midline, through pterygiophores and connective tissue to a depth just short of exiting the opposite side of the fish, maximized the depth of anchor penetration. This approach was used on all deployments. In addition, a conventional streamer tag (series PS) was placed in the fish well posterior of the PSAT tag using standard procedures (Prince et al., 2002). Captured fish were resuscitated from 3 to 15 min, depending on their apparent state of exhaustion, by moving the vessel ahead at about two knots, while maintaining control of the fish with a "snooter" (Prince et al., 2002).

Data Presentation and Analysis.—We developed a dual approach to our analysis of transboundary crossings, defined here as movements that crossed international boundaries of countries neighboring the country of release, or that crossed offshore, international EEZ boundaries. First, we computed a lower bounds (minimum) estimate based on the displacement straight-line distance (in nmi) from the point of release to the point of first transmission. Second, we developed two upper bounds (maximum) estimates of transboundary crossings based on two algorithms that computed tracks: one that used a Kalman filter ("KF track"; Sibert et al., 2003) and another ("Domeier track") described by Domeier et al. (2004). The KF uses latitude and longitude derived from light-based estimates of geolocation, and time and distance between locations, but does not use sea surface temperature (SST). The current software (EASy) for the Domeier algorithm uses longitude, time, and distance between locations, and SST data. In addition, EASy has an option to incorporate an estimate of average movement speed between locations. The two upper bound estimators for transboundary movement, therefore, were based on slightly different input parameters. Their inclusion in this study was for the purpose of providing a range of estimated maximum transboundary movements and was not intended to test differences, performance metrics, or validity of tracking methodology.

We plotted the maximum number of international boundary crossings vs days at large and used simple linear regression (Steel and Torrie, 1960) to examine this relationship for each tracking method.

Results

Conventional Tagging.—Constituent-based tagging of sailfish in the ETP from the Southwest Fisheries Science Center's (SWFSC) billfish tagging program (1963–2005) showed a total of 7474 releases and 20 recoveries. The Billfish Foundation's (TBF) tagging program (1990–2004) had 23,629 releases and one recovery. The composite totals for both programs were 31,103 releases and 21 recoveries (0.07% recapture proportion); 12 recoveries were outside the original release locations (Fig. 1). Displacement vectors of the point of release and point of recovery indicate that only one out of the 12 conventional recoveries made a transboundary crossing.

Past Tagging.—Of the 41 deployments (10 off Guatemala, 11 off Panama, 11 off Costa Rica, and 9 off Mexico), 32 PSATs transmitted (22% non-transmission, Table 1). Deployment durations ranged from 5 to 118 d, with a total aggregate of 1572 monitoring days. PSAT displacement vectors ranged from 21 to 572 nmi (Table 1). In terms of a minimum lower bounds estimate of transboundary crossings, 22 of the transmitting PSATs (69%) from sailfish demonstrated at least one transboundary crossing, while only one conventionally tagged sailfish recovery made a transboundary crossing (4.8%).

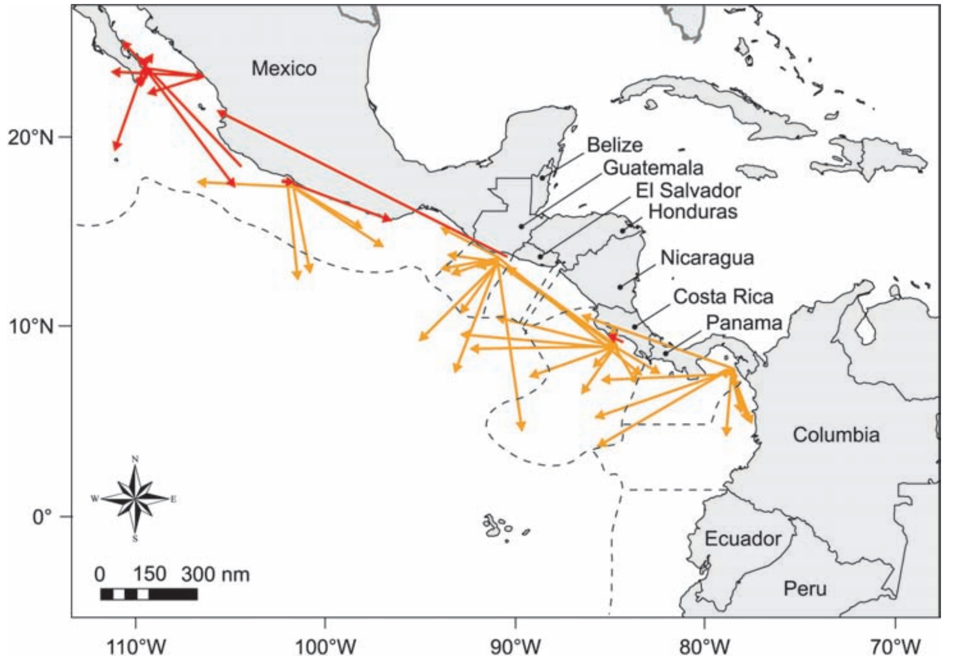

Figure 1. Sailfish displacement vectors from the 12 conventional tag recaptures (red) and 32 pop-up satellite archival tags (orange) off the eastern tropical Pacific (ETP).

Sixteen of the 32 PSATs that transmitted provided data of sufficient quality and quantity to allow reasonable track estimates (Table 2) for both of our upper bounds maximum estimation methods (i.e., the KF and Domeier tracking algorithms). These transmissions came from the release countries of Guatemala, Mexico, and Panama (Table 2, Figs. 2, 3). Although transmissions from Costa Rica deployments allowed determination of displacement vectors, transmissions from this country were corrupted to the point where estimates of upper bounds tracks could not be made. The totals for transboundary crossings for these 16 deployments for upper bound Domeier and Kalman tracks were 65 and 57, respectively (Table 2, Figs. 2, 3).

As the tracks resulting from our two upper bound methods were composed of a series of estimated geolocations, we also evaluated transboundary movement by examining the national distribution of geolocations resulting from both tracking methods for the release countries of Guatemala, Mexico, and Panama (Fig. 4). Overall, deployments from Guatemala and Panama resulted in estimated geolocations in multiple countries outside the country of origin, while estimated geolocations for Mexican deployments were either in Mexico or in international waters. The estimates of geolocations from both tracking algorithms for Guatemala releases showed comparable proportions within the confines of Guatemala (48% vs 39% for Domeier and KF algorithms, respectively, Fig. 4), and 32% of the geolocations were in international waters offshore of Guatemala for both methods. For deployments released off Mexico, 51% and 80% of the geolocations for the Domeier and KF methods, respectively, remained in Mexico, while all other geolocations were offshore in international waters. Geolocations from Panama deployments for both tracking methods showed comparable results, with a majority remaining in Panama and Costa Rica waters.

Table 1. Summary data for 32 sailfish tagged with PSAT tags off the Pacific coast of Central America.

Tag number and location	Weight (kgs)	Deployment date	Days at large	% of target deployment	Displacement (nm)
Panama_2002_03	38.6	8/9/02	28/28	100.0	21.0
Panama_2004_01	38.6	26/6/2004	43/45	97.8	165.0
Panama_2004_02	31.8	26/6/2004	59/60	100.0	199.0
Panama_2004_03	34.0	26/6/2004	65/90	72.2	460.0
Panama_2004_04	34.0	26/6/2004	45/45	100.0	131.0
Panama_2004_05	40.8	28/6/2004	53/60	88.3	568.0
Panama_2004_06	34.0	28/6/2004	88/90	98.9	487.0
Panama_2004_07	20.4	27/6/2004	5/45	11.1	43.0
Panama_2004_08	29.5	27/6/2004	56/90	62.2	432.0
Panama_2004_09	34.0	27/6/2004	120/120	100.0	61.0
Panama_2004_10	31.8	27/6/2004	26/120	21.7	53.0
Mean	33.4		53.4	77.4	236.2
Mexico_2004_01	24.9	15/1/2004	19/91	20.9	238.0
Mexico_2004_02	20.4	15/1/2004	25/61	41.0	286.0
Mexico_2004_03	18.1	15/1/2004	N/A		
Mexico_2004_04	15.9	15/1/2004	N/A		
Mexico_2004_05	18.1	16/1/2004	30/92	32.6	295.0
Mexico_2004_06	20.4	16/1/2004	56/120	46.7	279.0
Mexico_2004_07	13.6	18/1/2004	N/A		
Mexico_2004_08	15.9	18/1/2004	22/120	18.3	345.0
Mexico_2004_09	18.1	18/1/2004	N/A		
Mean	18.4		24.0	31.9	288.6
Guatemala_2000_01	38.6	11/8/00	31/31	100.0	155.0
Guatemala_2003_01	30.8	17/11/2003	61/61	100.0	178.0
Guatemala_2003_02	18.1	18/11/2003	29/59	49.2	198.0
Guatemala_2003_03	38.6	17/11/2003	48/90	53.3	572.0
Guatemala_2003_05	24.9	17/11/2003	53/92	57.6	197.0
Guatemala_2003_06	49.9	17/11/2003	54/92	58.7	140.0
Guatemala_2003_07	27.2	17/11/2003	90/92	98.9	385.0
Guatemala_2003_08	31.8	17/11/2003	72/121	59.5	470.0
Guatemala_2003_09	29.5	18/11/2003	22/94	23.4	341.0
Guatemala_2003_10	40.8	18/11/2004	106/121	87.6	73.0
Guatemala_2003_11	27.2	18/11/2004	118/124	95.2	537.0
Mean	32.5		62.2	71.2	295.0
Costa Rica_2003_01	36.3	11/3/03	17/34	50.0	64.0
Costa Rica_2003_02	29.5	11/3/03	29/34	85.3	376.0
Costa Rica_2003_04	24.9	10/3/03	30/30	100.0	87.0
Costa Rica_2003_05	29.5	10/3/03	21/40	52.5	128.0
Costa Rica_2003_06	34.0	10/3/03	40/40	100.0	450.0
Costa Rica_2003_07	29.5	11/3/03	60/59	100.0	422.0
Costa Rica_2003_08	27.2	11/3/03	39/39	100.0	482.0
Costa Rica_2003_09	31.8	11/3/03	29/29	100.0	157.0
Costa Rica_2003_10	27.2	11/3/03	29/29	100.0	281.0
Costa Rica_2003_11	24.9	12/3/03	29/28	100.0	179.0
Mean	29.5		32.3	94.0	262.6

Table 2. Summary data for the 16 PSAT tagged sailfish used to compute upper bound transboundary crossings. Tag designation and location of deployment, deployment date, deployment longitude, deployment latitude, scheduled pop-up date, pop-up longitude, pop-up latitude, and number of transboundary crossings (lower bound estimates, upper bound estimates from Domeier and Kalman Filter algorithms are given for each deployment).

Tag number and location	Deploy. date	Deploy. lon (°W)	Deploy. lat (°N)	Scheduled pop-up	Pop-up lon (°W)	Pop-up lat (°N)	Transboundary crossings (number)		
							Lower	Upper	
							Estimates	Domeier	Kalman
Guatemala_2003_01	17/11/2003	–90.85190	13.617200	17/1/2004	–93.831000	13.045000	1	3	3
Guatemala_2003_02	18/11/2003	–90.91667	13.366670	18/1/2004	–92.844000	10.733000	1	3	2
Guatemala_2003_05	17/11/2003	–90.85250	13.633610	17/2/2004	–93.826000	15.176000	1	11	2
Guatemala_2003_06	17/11/2003	–90.85083	13.650833	17/2/2004	–93.274000	12.781000	0	8	6
Guatemala_2003_07	17/11/2003	–90.83556	13.651940	18/2/2004	–93.151000	7.671000	1	8	9
Guatemala_2003_08	17/11/2003	–90.91660	13.351100	2/2/2004	–84.496100	8.765100	4	8	4
Guatemala_2003_09	18/11/2003	–90.91670	13.350000	20/2/2004	–94.987000	9.313000	1	1	1
Guatemala_2003_10	18/11/2004	–90.91667	13.366670	18/3/2004	–92.029000	13.174000	0	3	10
Mexico_2004_01	15/1/2004	–101.64167	17.368890	15/4/2004	–98.137000	15.223000	0	2	0
Mexico_2004_02	15/1/2004	–101.72670	17.625800	16/3/2004	–100.807000	12.916000	1	3	1
Mexico_2004_05	16/1/2004	–101.97110	17.480800	17/4/2004	–101.442000	12.545000	1	1	3
Mexico_2004_08	18/1/2004	–101.96550	17.523300	10/2/2004	–97.030000	14.250000	0	0	0
Panama_2004_03	26/6/2004	–78.59722	7.689440	24/9/2004	–85.802000	5.210000	1	3	1
Panama_2004_05	28/6/2004	–78.55750	7.798330	27/8/2004	–86.445000	10.566000	1	3	3
Panama_2004_06	28/6/2004	–78.76167	7.730000	26/9/2004	–85.695000	3.676000	2	3	3
Panama_2004_08	27/6/2004	–78.46722	7.501390	25/9/2004	–85.380000	7.196000	1	5	9
						Totals	16	65	57

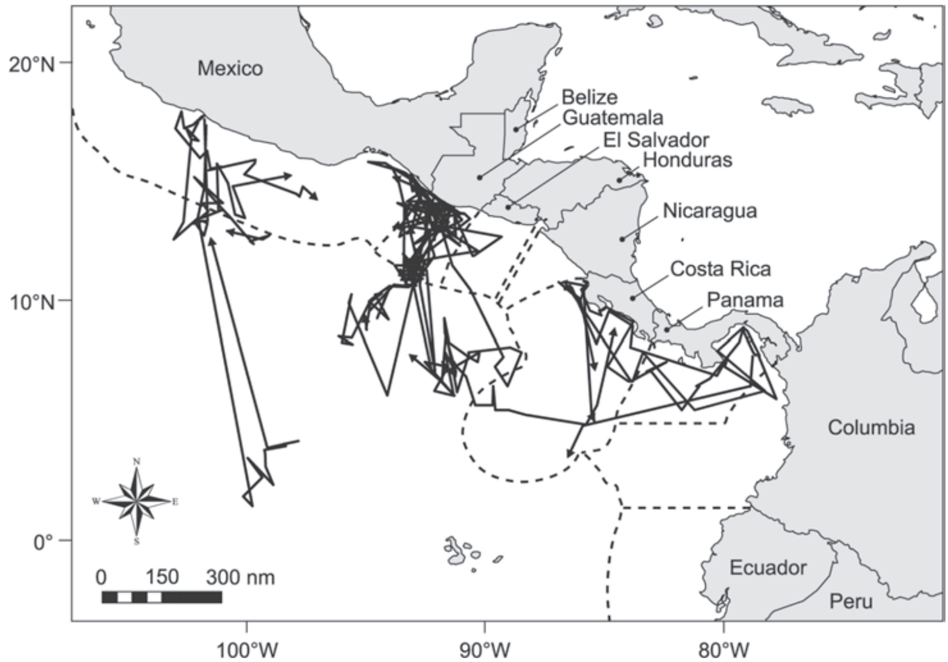

Figure 2. Tracks of 16 Pacific sailfish off Central America developed from pop-up satellite archival tagging data using the EASy algorithm (Domeier et al., 2003).

The number of upper bound international boundary crossings versus days at-large for the Domeier algorithm resulted in only a weak relationship ($r^2 = 0.249$, $P < 0.05$) equating to about one transboundary crossing every 20 d (Fig. 5A), while that for the KF track was stronger ($r^2 = 0.528$, $P < 0.01$) equating to about one transboundary crossing every 12 d (Fig. 5B).

Fate of Psat Tagged Sailfish.—Three of the 32 deployments that transmitted appeared to have mortality events that occurred after extensive periods at large: 65 d (Panama deployment), 50 d (Guatemala deployment), and 26 d (Panama deployment). All three mortality events occurred prior to the programmed release date of each tag and, in each case, the tags sank to depths exceeding 1000 m before the tag surfaced and transmitted. The temperature data collected by all three tags confirmed these vertical trajectories.

Discussion

Management Unit.—Research questions relative to unit stock, or management unit, are among the first issues addressed in any stock assessment (ICCAT, 2001). For billfishes, this issue is typically addressed with conventional tagging data, in combination with data from genetic studies, when available (Ortiz et al., 2003). The general area of study in the ETP examined here consists of coastlines of nine distinct political entities, including (north to south): Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, and Ecuador. Mexico has the longest shoreline, while Honduras has the smallest.

The amount of available conventional tagging data for sailfish in the ETP (21 recoveries in over 40 yrs, recovery percentage of 0.07%) is minute, even when compared

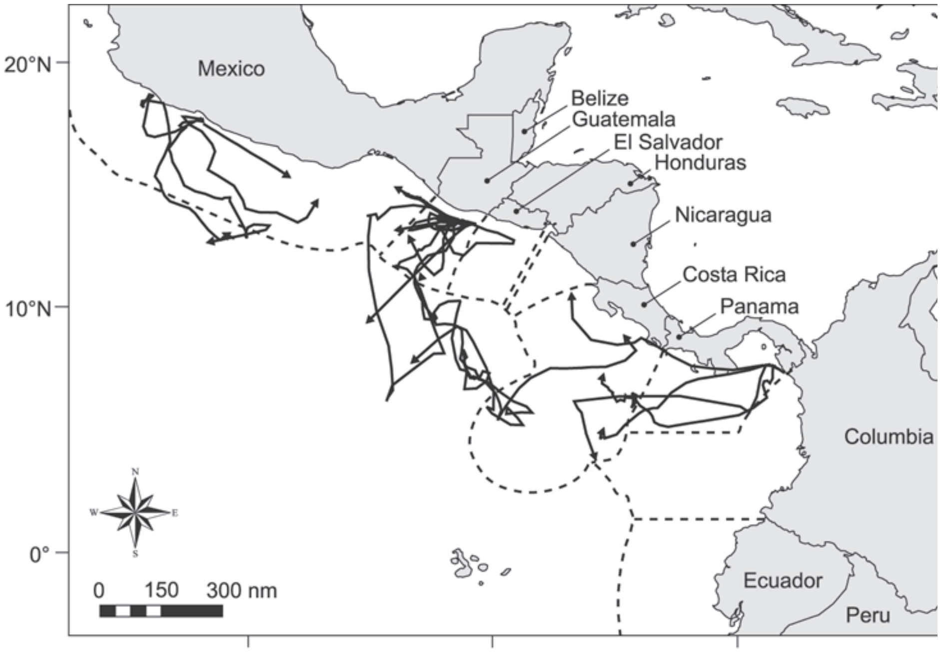

Figure 3. Tracks of 16 Pacific sailfish off Central America developed from pop-up satellite archival tagging data using the Kalman filter algorithm (Siebert et al., 2003).

to similar constituent-based programs for sailfish and other istiphorids in different parts of the world (Ortiz et al., 2003). These sparse tagging results do not appear to be related to the tag deployment effort, as 31,000 ETP releases are about half that of the leading sailfish tagging program (65,868, NMFS, Miami), but somewhat larger than sailfish tag release efforts in Australia (16,370) and substantially larger than those in New Zealand (55; Ortiz et al., 2003). However, within the ETP, the release data are restricted in geographical distribution primarily to Mexico, Guatemala, and Costa Rica. The ETP sailfish recapture proportions (0.07%) are exceedingly low by any standard, even for istiophorids, which are known to have very low recapture proportions world-wide (Ortiz et al., 2003). Thus, ETP conventional tagging results do not appear adequate for a comprehensive evaluation of transboundary movements.

Possible reasons for the typically low recovery rate for conventionally tagged billfish are reviewed by Ortiz et al. (2003) and others (Pepperell, 1990; Jones and Prince, 1998; Peel et al., 1998; Prince et al., 2002). These include: (1) inadequate outreach activities (communication issues) with fishers; (2) unknown tag shedding rates or use of tags with low retention rates; and (3) non-reporting of recovered tags. Appropriate outreach activities are particularly important in multinational fisheries, which exist for sailfish in the ETP.

The unique oceanographic features of the ETP (narrow mixed layer, shallow thermocline with a steep temperature gradient, and hypoxic environment below the thermocline, Prince and Goodyear, 2006) may also have affected conventional tagging results. Tagged sailfish may be subjected to a pelagic environment that works against survival after the initial catching and tagging event in the ETP. This situation could also contribute to disproportionately lower tag recovery proportions in the

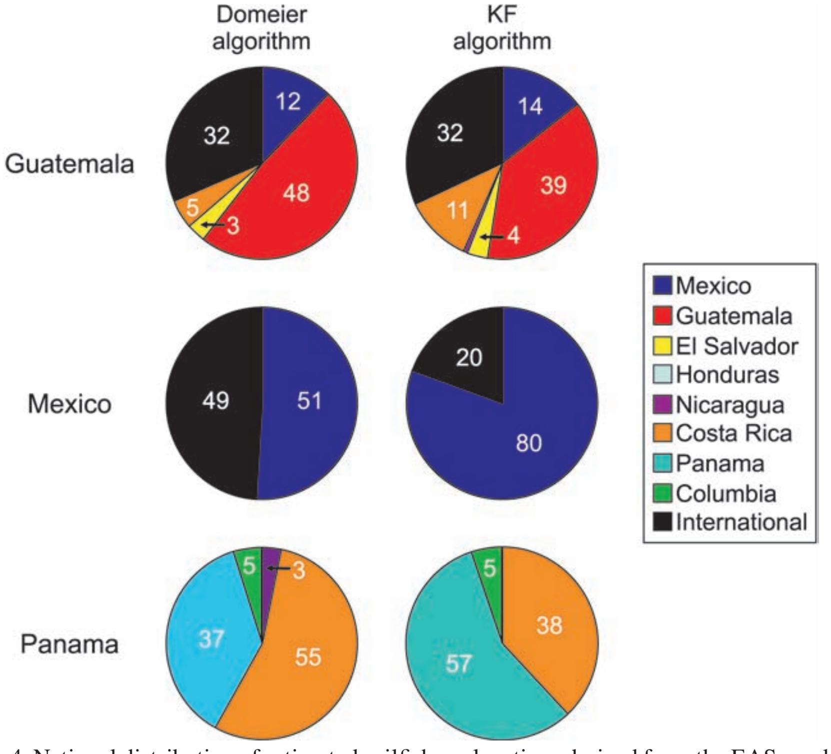

Figure 4. National distribution of estimated sailfish geolocations derived from the EASy and Kalman Filter algorithms using pop-up satellite archival data from 16 deployments from Guatemala (top), Mexico (middle), and Panama (bottom). Numbers indicate percentages.

ETP compared to other areas where conventional sailfish tagging activities occur (with the possible exception to the west coast of Africa).

Hoolihan (2004) evaluated transboundary migration using conventional tagging data for sailfish from the Arabian Gulf, which has a coastline covering a similar number of political entities (eight) as the ETP. Arabian Gulf conventional tag recapture proportions were uncharacteristically high (4.91%) and in this instance represent a valuable means of assessing transboundary movement patterns in this region (Hoolihan, 2003). However, the Arabian Gulf is a semi-enclosed body of water (distinctly different from the ETP) and this feature no doubt contributed to the higher tag recovery rate for sailfish.

If an assessment of transboundary movements were based only on conventional tagging results in the ETP, very little, if any transboundary behavior would be documented (1 of 21 recaptures). Thus, the lower bounds estimate from PSAT results (32 transmissions with displacement vectors, 22 of which made transboundary crossings) effectively increases by several fold the available data to address the issue of management unit in the ETP, resulting in quite different conclusions. Clearly, based only on lower bounds estimates of transboundary movements, sailfish in the ETP are a resource that is shared extensively with at least nine political entities in the region.

The upper bounds estimate for the 16 deployments used in the Domeier and Kalman filter algorithms ranged from 57 to 65 transboundary crossings, equating to one crossing every 12 d (KF algorithm) or one crossing every 20 d (Domeier algorithm).

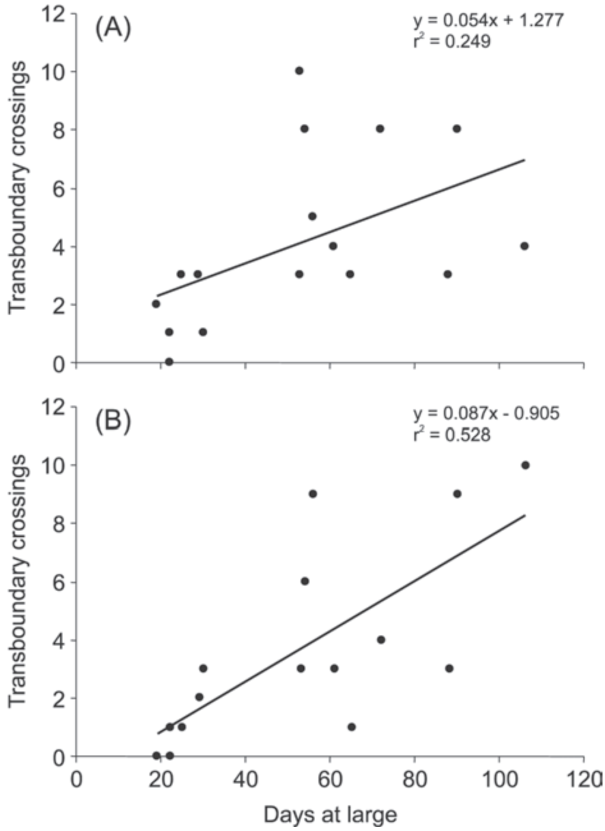

Figure 5. (A) Number of transboundary crossings vs days-at-large for sailfish from the Domeier EASy algorithm. These results equate to one transboundary crossing every 20 d ($r^2 = 0.249$, $P < 0.05$); and (B) Simple linear regression of the number of transboundary crossings for sailfish vs days-at-large for the Kalman Filter algorithm. These results equate to one transboundary crossing every 12 d ($r^2 = 0.528$, $P < 0.01$).

The national distribution of geolocations resulting from deployments off Panama and Guatemala were quite similar for both tracking methods, with a distribution of geolocations over 3–4 adjacent countries, as well as international offshore boundaries.

Geolocations outside the Mexican EEZ only involved crossings into offshore international waters. This disparity in the distribution of geolocations (compared to Panama and Guatemala), as well as transboundary crossings, likely reflects the length of shoreline and location of Mexico relative to the other release countries. Other factors influencing the degree of transboundary movements include the monitoring duration achieved for each fish, tag and release location within the release country relative to adjacent boundaries and offshore territorial boundaries, and size of fish monitored. For example, the average size of sailfish released off Mexico (40 lbs; 18 kg) was considerably smaller than the average release size (65–74 lbs; 29–33 kg) from other countries and we believe this may have impacted the monitoring duration (i.e., all Mexican releases were premature), number of geolocations distributed outside the release country, and subsequent number of transboundary crossings identified from Mexican deployments. In addition, only five of the nine PSAT deployments from Mexico transmitted, and this further limited the amount of transboundary information from this location. In contrast, Panama and Guatemala, with smaller shorelines, more adjacent countries, and larger sailfish that yielded longer monitoring durations, had many more transboundary crossings.

Extensive transboundary movements of sailfish in the ETP are evident from lower bound displacements (22) and upper bound transboundary crossings estimated by two tracking methods (57–65 crossings). In addition, as the relative frequency of these movements ranged from 12–20 d, it is evident that this resource requires management regionally, rather than by individual countries. Hoolihan (2004) similarly concluded that development of effective management of Arabian Gulf sailfish would require cooperation between all stakeholders in the region who share the resource. In only a few years, the use of pop-up satellite tag technology for sailfish in the ETP provided a sound basis for evaluation of transboundary movements, whereas in over four decades of conventional tagging, data were insufficient to address this issue.

The restricted PSAT deployment scheme (both in number of deployments and countries) and relatively short PSAT monitoring durations achieved in this study provide insight into, but not the final word on, the appropriate size and configuration of the ETP sailfish management unit. Further research, including a more comprehensive deployment strategy (i.e., increased number of PSAT deployments off Colombia, Ecuador, and possibly Peru), more deployments offshore from the Central American coastline, and catch data from the major fisheries (both directed and incidental) would be required to clarify the spatio-temporal dimensions of the ETP sailfish management unit.

Most of the political entities mentioned in this study that have directed recreational and artisanal fisheries for sailfish are member countries of the Inter-American Tropical Tuna Commission (IATTC). Thus, the IATTC has obvious jurisdiction for management of this species. Over the last several years, the IATTC has been attempting to conduct a stock assessment of Pacific sailfish (M. Hinton, IATTC, pers. comm.) and based on the available information, including genetic studies (McDowell, 2002), considers this species a single stock in the Eastern Pacific Ocean. The new results on sailfish movement presented here are consistent with this management unit designation.

Acknowledgments

Reference to commercial products does not imply endorsement by the National Marine Fisheries Service, University of Miami, or the authors. Funds used to purchase PSAT tags, transportation, and lodging was in large part donated through the Adopt-A-Billfish Program. We want to extend our thanks to J. Vernon, the Presidential Challenge Series of billfish tournaments, E. Peel of The Billfish Foundation, R. Cowen, and the University of Miami Rosenstiel School of Marine and Atmospheric Sciences who facilitated completion of this work.

Literature Cited

Beardsley, G. L. Jr., N. R. Merrett, and W. J. Richards. 1975. Synopsis of the biology of the sailfish, *Istiophorus platypterus* (Shaw and Nodder, 1971). Pages 95–120 *in* R. S. Shomura and F. Williams, eds. Proc. Int. Billfish Symp. Kailua-Kona, Hawaii, 9–12 August 1972, Part 3. Species Synopses. U.S. Dept. Commer. NOAA Tech. Rpt. NMFS SSRF-675. 159 p.

Domeier, M. L., D. Kiefer, N. Nasby-Lucas, A. Wagschal, and F. O'Brien. 2003. 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. Fish. Bull. 103: 233–306.

Fitchett, M. and N. M. Ehrhardt. 2005. On the abundance and decay of eastern Pacific billfish species. 4th Int. Billfish Symp., Catalina Island, California. [Abstract]

Hoolihan, J. P. 2004. Managing Arabian Gulf sailfish–issues of transboundary migration. Pages 339–347 *in* A. I. L. Payne, C. M. O'Brien, and S. I. Rogers, eds. Management of Shared Fish Stocks. Blackwell Publishing, Oxfordshire.

___________. 2003. Arabian Gulf sailfish movements—a summary of tagging efforts. Mar. Freshw. Res. 54: 509–514.

ICCAT. 2001. Proc. 4th ICCAT Billfish Workshop. Int. Commission for the Conservation of Atlantic Tunas, Madrid. Coll. Vol. of Sci. Papers 53: 1–375.

Jones, C. D. and E. D. Prince. 1998. The cooperative tagging center mark-release database for Istiophoridae (1954–1995) with an analysis of the west Atlantic ICCAT billfish tagging program. Int. Commission for Conservation of Atlantic Tunas, Madrid. Coll. Vol. of Sci. Papers 47: 311–322.

McDowell, J. R. 2002. Genetic stock structure of sailfish, *Istiophorus platypterus* based on nuclear and mitochondria DNA. Ph.D. Diss. College of William and Mary, Gloucester Point. 232 p.

Ortiz, M., E. D. Prince, J. E. Serafy, D. B. Holts, K. B. Davy, J. G. Pepperell, M. B. Lowry, and J. C. Holdsworth. 2003. Global overview of the major constituent-based billfish tagging programs and their results since 1954. Mar. Freshw. Res. 54: 489–507.

Peel, E. M., J. Rice, M. Ortiz, and C. D. Jones. 1998. A summary of the Billfish Foundation's tagging program (1990–1996). ICCAT, Madrid. Coll. Vol. Sci. Papers 47: 323–335.

Pepperell, J. G., 1990. Australian Cooperative Game-Fish Tagging Program, 1971–1987. Pages 765–774 *in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. G. Jester, E. D. Prince, and G. A. Winans, eds. Fish-Marking Techniques. Am. Fish Soc. Symp. 7.

Prince, E. D. and C. P. Goodyear. 2004. Hypoxia based habitat compression of tropical pelagic fishes. Fish. Oceanogr. 15: 451–464.

__________, M. Ortiz, A. Venizelos, and D. S. Rosenthal. 2002. In-water conventional tagging techniques developed by the Cooperative Tagging Center for large, highly migratory species. Pages 155–171 *in* J. A. Lucy and A. L. Studholme, eds. Catch and Release in Marine Recreational Fisheries. Amer. Fish. Soc. Symp. 30.

Sibert, J. R., J. K. Musyl, and R. W. Brill. 2003. Horizontal movements of bigeye tuna (*Thunnus obesus*) near Hawaii determined by Kalman filter analysis of archival tagging data. Fish. Oceanogr. 12: 141–151.

ADDRESSES: (E.D.P., D.S., E.S.O., J.E.S.) *NOAA Fisheries, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida 33149.* (D.B.H.) *NOAA Fisheries, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, California 92037.* (J.L.) *University of Miami, RSMAS, 4600 Rickenbacker Causeway, Miami, Florida 33149.* (M.L.D.) *Pfleger Institute of Environmental Research, 901-B Pier View Way, Oceanside, California 92054.* CORRESPONDING AUTHOR: (E.D.P.) *Telephone (305) 361-4248, Fax (305) 361-4562, E-mail: <eric.prince@noaa.gov>.*