Updates on the horizontal movements and stock affiliation of swordfish (*Xiphias gladius*) tagged in the eastern north Pacific (2002-2022). [1]

Chugey Sepulveda* and Scott Aalbers*
E-mail: Chugey@pier.org
www.pier.org

* Pfleger Institute of Environmental Research (PIER), 315 Harbor Dr. S. Oceanside, CA, USA

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Abstract

This work provides an updated overview of the horizontal movements of swordfish (*Xiphias gladius*) tagged in the Eastern North Pacific (ENP) from 2002 to 2022. Movement data are presented in relation to current stock boundaries used to manage the swordfish resources of the ENP. We summarized existing published data which has largely been collected off California (n=169) and Hawaii (n=12). We also incorporate findings from ongoing work off California, including archival tagging studies (~15% return rate; 212 deployed and 31 recaptured) and movements derived from fin-mounted Argos transmitters (n=46; 2017-2022). These data continue to suggest that: (1) swordfish movements do not directly align with current boundaries used to differentiate ENP stocks; (2) trans-equatorial movements are limited; and (3) movements are confined to the area east of the Hawaiian Islands (163°W). These data provide insight into the movement patterns of swordfish in the ENP and highlight the potential role that electronic tag data can play in elucidating regional stock boundaries.

Introduction

In the North Pacific Ocean (NPO), the swordfish is currently managed as two stocks, the Western and Central North Pacific Ocean stock (WCNPO) and the Eastern Pacific Ocean stock (EPO). Delineation of the two stocks is based on previous genetic, catch per unit effort (CPUE), and distributional data, but has not incorporated tagging or movement data (ISC, 2008; ISC, 2009). The western boundary of the EPO stock has been proposed as a diagonal line that extends from Baja California, Mexico (30°N) to the equator at 170°W (ISC, 2014; ISC, 2018). The southernmost boundary has been defined at the equator (ISC, 2018) or at 20°S (ISC, 2014). As noted in both the 2014 and 2018 WCNP assessments, stock structure continues to be a potential source of uncertainty for swordfish assessments in this region.

To date, movement and tagging data have not been formally included in the designation of stock boundaries for swordfish in the ENP (ISC, 2008). This is due to the lack of long-term movement studies in the region and the difficulty of estimating horizontal position using available light-based geolocation methodologies (Dewar et al., 2011). Given these difficulties, recent studies have focused on assessing swordfish horizontal movements using different tag technologies and geolocation methods (Sepulveda et al., 2019; Sepulveda et al., ongoing study). Specifically, the use of dorsal fin-mounted Argos transmitters has enabled real-time tracking of swordfish movements, including multi-year migration loops that span from tropical spawning grounds to temperate foraging areas (Sepulveda et al., 2019).

This paper collates the body of existing swordfish movement data collected from the ENP and presents the information within a management context.

Material and methods

Published tagging and movement data for swordfish within the ENP are detailed in Table 1. Additional data from active studies deploying fin-mounted Argos transmitters as well as depth and temperature-sensitive data storage tags (DST) were also incorporated into the analyses (Sepulveda et al., ongoing studies; Table 1). Data were plotted over existing ENP stock boundaries used by the ISC in both the 2014 and 2018 assessments of the WCNP stock using ArcGIS Pro version 2.4.0.

Estimated positions of tagged swordfish were either obtained directly from peer-reviewed publications (Sepulveda et al., 2018; Sepulveda et al., 2019; Abecassis et al., 2012) or estimated from published maps (Dewar et al., 2011). Data from Argos transmitters were analyzed based on protocols described in Sepulveda et al. (2019). Tags were not included into the present analysis if: (1) there was any major

uncertainty with geolocation estimates, or (2) minimal horizontal movements were reported for a tagged individual.

Point to point movement data were obtained from either the pop-up locations of satellite-based tags or the recapture location of DSTs (Cefas G5; Lowestoft, UK; n=31) deployed from 2011-2022 off the California coast (Sepulveda et al., 2019; Sepulveda et al., ongoing).

Results and discussion

The data used to describe swordfish horizontal movements and distribution in the ENP were derived from 181 swordfish tagged in six studies spanning from 2002 to 2022 (Table 1). Movement data showed that swordfish tagged off southern California entered into, and spent significant time within, both the EPO and WCNP management units (Figure 1). More than half of the swordfish tagged within the Southern California Bight (SCB) exhibited movements into the EPO stock boundary area, while the more northern and western tag deployments (central California and Hawaii) largely resulted in WCNP affiliation.

Data obtained from dorsal-fin-mounted Argos transmitters (Figure 2) support results from published studies, and offer increased resolution on the movement paths of swordfish throughout the north Pacific. Of particular significance is the presence of multi-year (>900 d), round-trip tracks that have greatly improved our understanding of the western and southern extent of swordfish movements within this region. Because previous swordfish tag deployments provided only point-specific pop-up or recapture data, it has been difficult to infer the overall extent of annual migration patterns or regional affiliations. Collectively, Figures 1 and 2 exhibit a lack of movements west of the Hawaiian Islands (~163°W) and south of the equator. The increased resolution and duration of tracks with fin-mounted Argos transmitters revealed that some swordfish transverse both management units over their active tracks and routinely exhibit seasonally site fidelity to their SCB release locations. Most of the swordfish tagged in the SCB exhibited periods of directed movements either to the south and east along Baja California, Mexico, or to the west and southwest towards Hawaii (Figure 2), followed by periods of reduced horizontal movement (i.e., milling). Based on the time of year, reports from fishers on gonadal size and stage, and changes in depth distribution; we hypothesize the milling areas to be probable spawning locations.

To date, 212 data storage tags have been deployed off California with 31 individuals recaptured (max. duration 1,343 d, average duration 388 d). Of the 31 recovered DSTs, ~60% of the tagged swordfish were recaptured near the original deployment locations during subsequent seasons, further supporting the importance of the SCB foraging area and the prevalence of seasonal site fidelity.

In summary, existing and ongoing tagging studies suggest that swordfish in the ENP do not exclusively adhere to the current WCNP and EPO stock boundaries used in ISC stock assessments. However, it is acknowledged that additional data may be needed to better delineate such boundaries. The presented data do, however, suggest that there may be a potential east-west boundary as previously proposed by others (reviewed by Hinton and Bremer, 2007) and that the west coast of the United States is an important foraging ground for north Pacific swordfish. Although these data represent significant advancements towards understanding swordfish movement patterns and stock delineation in the Pacific, we feel that seasonal movement patterns will become more apparent as we continue to collect longer-term movement data from ongoing deployments of both fin-mounted Argos transmitters and DSTs (Sepulveda et al., unpublished data). Complimentary research efforts are also underway to better characterize and evaluate the genetic population structure of tagged individuals with a documented track history (Alvarado-Bremer et al., in preparation). Collectively, these data will improve our understanding of stock structure boundaries in the north Pacific.

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Table 1. Details for seven published tagging studies conducted in the central and eastern north Pacific from 1993–2019 along with two ongoing tagging studies (Sepulveda et al., in Prep.). * Tracks included in movement analyses are from individual swordfish and exclude duplicate tracks that have been reported in more than one study. All tagged swordfish from Carey and Robison (1981), Holts et al. (1984) and Sepulveda et al. (2010) exhibited minimal horizontal movements during the study period and were not included. SCB=Southern California Bight; BCS=Baja California Sur; HI=Hawaii; PLCA=Pacific Leatherback Conservation Area off central California. WC=Wildlife Computers, PSAT=Pop-up satellite archival transmitter, mrPAT=Mark-report pop-up archival transmitter, DST=Cefas data storage tag.

Study	Study Period	No. of individuals tagged	No. of individuals included	Pacific Deployment Region	Tag type	Max. Track Duration
Abecassis et al., 2012	2002-2008	28	28*	SCB;HI	WC MK-10 PSAT	180 d
Carey & Robison, 1981	1977	5	0	BCS	Acoustic transmitter	5 d
Dewar et al., 2011	2001-2006	24	16*	SCB; HI	WC MK-10 PSAT	150 d
Holts et al., 1994	1993	1	0	SCB	Acoustic transmitter	1 d
Sepulveda et al., 2010	2005-2006	9	0	SCB	WC MK-10 PSAT	89 d
Sepulveda et al., 2018	2012-2014	11	11	PLCA	WC MK-10 PSAT	150 d
Sepulveda et al., 2019	2012-2019	71	49*	SCB; PLCA	WC MK-10, mrPAT, DST	703 d
Sepulveda et al., ongoing study[1]	2011-2022	212	31*	SCB	DST	730 d
Sepulveda et al., ongoing study[2]	2017-v. 2022	57	46*	SCB	Argos transmitters	904 d

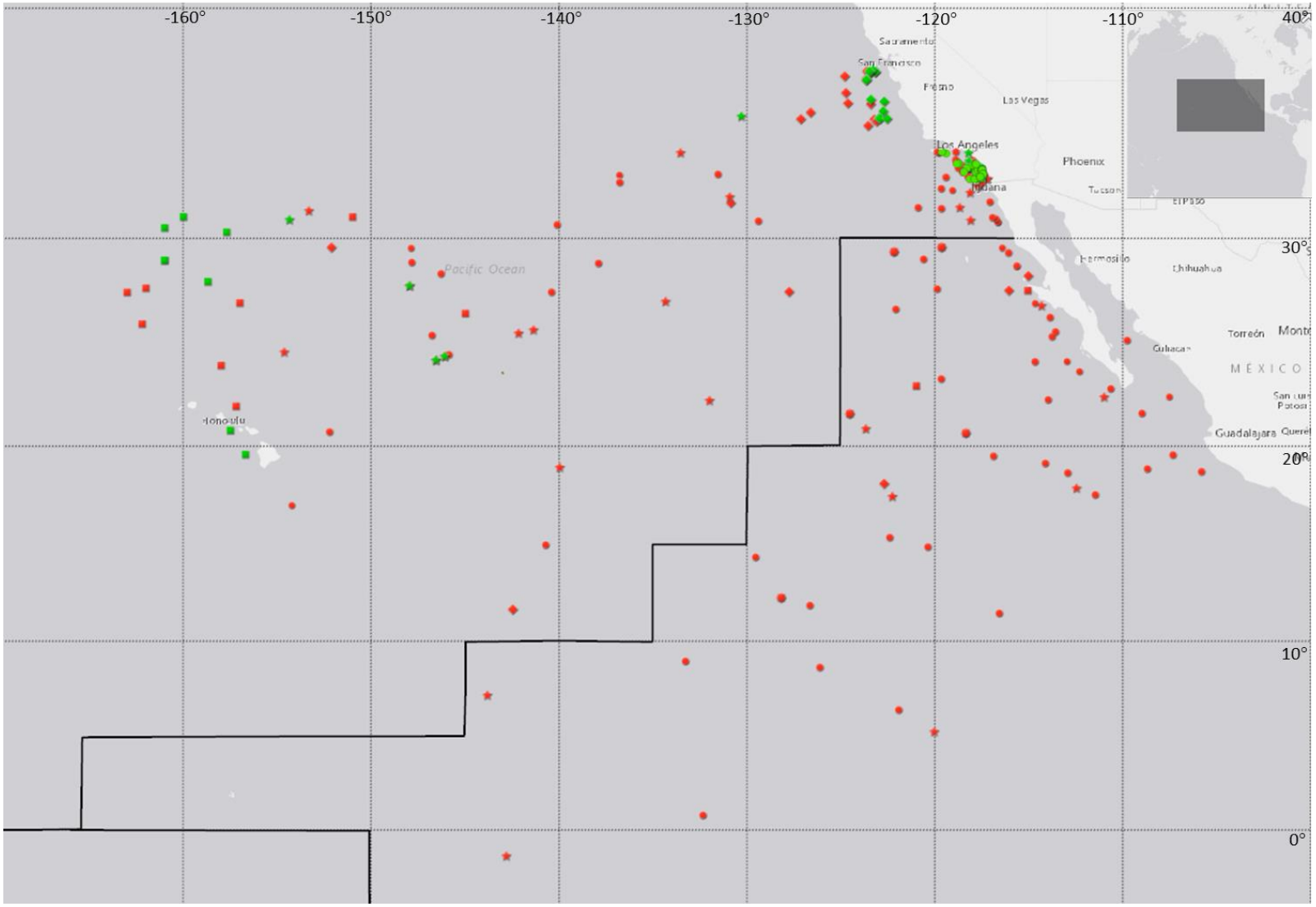

Figure 1: Electronic tag deployments (green symbols) and pop-up or recapture positions (red symbols) for 135 tagged swordfish—in relation to ISC swordfish stock boundaries —from tagging studies conducted in the eastern and central north Pacific (Dewar et al., 2011 [Squares]; Abecassis et al., 2012 [Stars]; Sepulveda et al., 2018 [Diamonds]; Sepulveda et al., 2019 [Circles] and Sepulveda et al., ongoing study[1][Circles]).

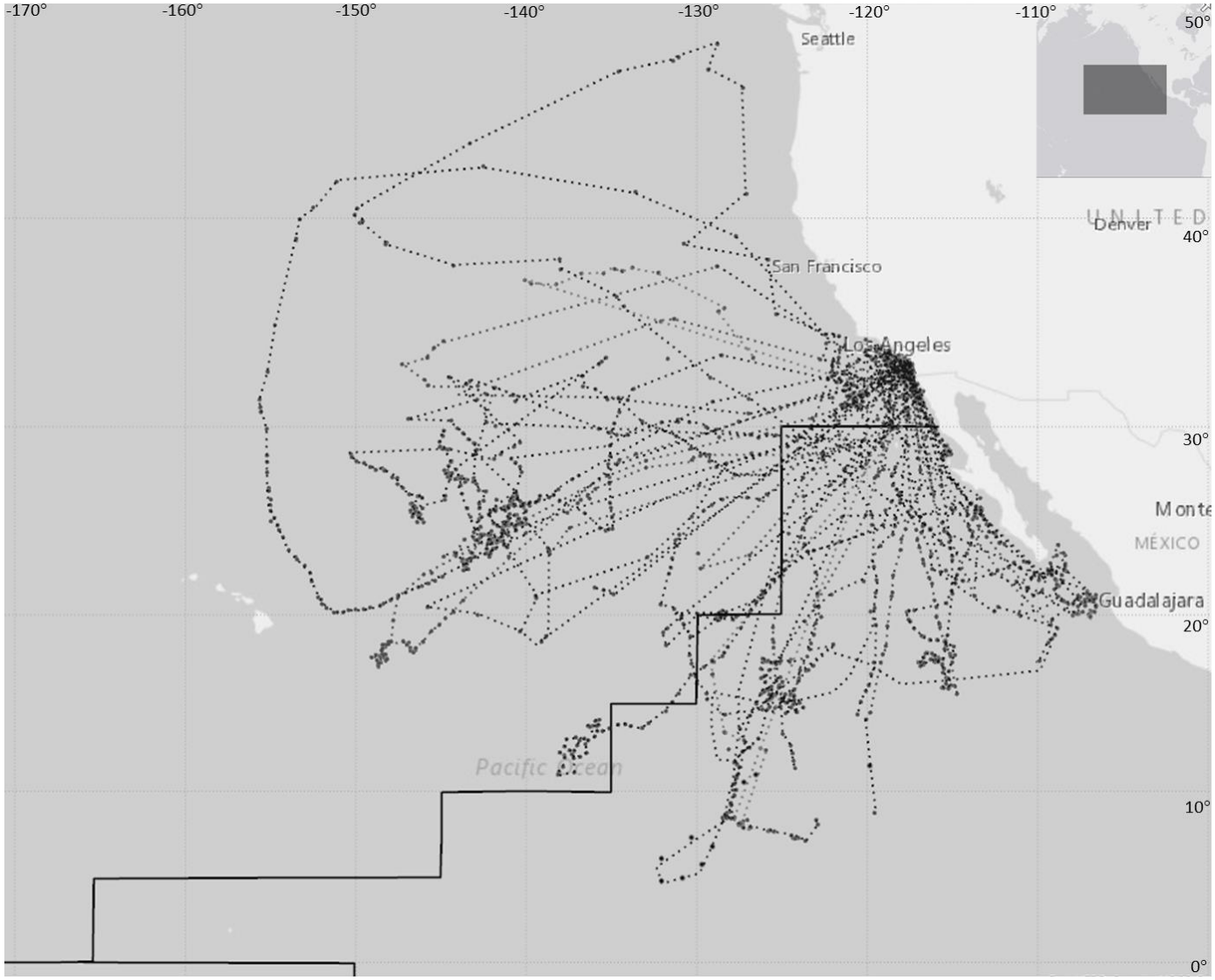

Figure 2: Horizontal movement data from 46 swordfish affixed with dorsal-fin mounted Argos transmitters for up to 904 days between November, 2017 and November, 2022, with estimated individual tracks (dotted lines) relative to ISC swordfish stock boundaries (black lines).