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Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California

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Doctorado en Ciencias en Ecología Marina

Insights into the transboundary stock structure of white seabass, *Atractoscion nobilis*, along the coast of California and Baja California

Tesis
para cubrir parcialmente los requisitos necesarios para obtener el grado de
Doctor en Ciencias

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Resumen de la tesis que presenta **Arturo Fajardo Yamamoto** como requisito parcial para la obtención del grado de Doctor en Ciencias en Ecología Marina

Perspectivas sobre la estructura del stock transfronterizo de la corvina blanca, *Atractoscion nobilis,* a lo largo de la costa de California y de Baja California

Resumen aprobado por:

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La corvina blanca (*Atractoscion nobilis*) es un recurso pesquero transfronterizo que se extiende desde California, EE. UU., hasta Baja California Sur, México, y dentro del norte del Golfo de California. Se han propuesto dos hipótesis que describen la estructura del stock de la corvina blanca a lo largo de su área de distribución en el Pacífico oriental. Sin embargo, aún quedan vacíos en la información biológica-pesquera que nos permita comprender de una manera más robusta la estructura del stock. El objetivo de este estudio fue el desarrollar más información que nos permita comprender la estructura del stock de la corvina blanca que habita el Pacífico mediante (1) la reconstrucción de los desembarques de la pesquería mexicana, (2) la estimación del tamaño de madurez y (3) la descripción de los patrones de movimiento horizontal y el uso de hábitat de la corvina blanca adulta. Los resultados sugieren que los desembarques de la pesquería mexicana de corvina blanca mostraron un aumento en los últimos 70 años. Durante los últimos 20 años, la mayor parte de la captura proviene de Baja California Sur, concentrándose los desembarques en las oficinas pesqueras de Ciudad Constitución, Punta Abreojos y San Carlos. Las hembras de corvina blanca del sur de la Península de Baja California Sur maduran a una talla de 72,7 cm, mientras que los machos lo hacen a una talla de 58 cm. Además, se estimaron diferencias regionales de madurez, siendo que las corvinas blancas de California maduran a una talla mayor que las del sur de la Península de Baja California. Se estimó un cierto grado de conectividad de la corvina blanca adulta entre la costa de California y la costa oeste de la península de Baja California. En general, las áreas alrededor de las islas y las zonas costeras son zonas de alto uso para la corvina blanca adulta. Las islas del Canal, la región frente a las islas Coronado-Ensenada, la región de San Quintín y la región de la bahía Vizcaíno son zonas esenciales para la corvina blanca, ya que se han registrado diferentes fases ontogénicas en dichas zonas. El uso del hábitat de las corvinas blancas adultas durante la temporada de desove (marzo-septiembre) y la no desove (octubre-febrero) fue diferente. Se estimaron dos rutas migratorias: una, con movimientos de dispersión donde la corvina blanca adulta se desplazó hacia el norte alcanzando el área alrededor de las Islas del Canal en California, y un movimiento hacia el sur, a lo largo de la costa del litoral oeste de la Península de Baja California ocupando múltiples áreas de alto uso y, segundo tipo de movimiento que fue de retorno desde las áreas norte y sur hacia un área restringida y limitada frente a la costa de Tijuana y San Quintín. Los resultados de esta tesis cubren algunos vacíos en la información de este recurso pesquero transfronterizo, que permitirán el desarrollo medidas de manejo binacionales y comprender de una mejor manera la estructura del stock.

Palabras clave: Corvina blanca, estructura del stock, reconstrucción de desembarques, talla de madurez sexual, uso de hábitat.

Abstract of the thesis presented **by Arturo Fajardo Yamamoto** as a partial requirement to obtain the Doctor of Science degree in Marine Ecology.

Insights into the transboundary stock structure of white seabass, *Atractoscion nobilis*, along the coast of California and Baja California

Abstract approved by:

Dr. Oscar Sosa Nishizaki	Dr. Chugey A. Sepulveda
Codirector de tesis	**Codirector de tesis**

The white seabass (*Atractoscion nobilis*) is a transboundary fishery resource that ranges from California, U.S., to Baja California Sur, Mexico, and within the north of the Gulf of California. It has been proposed two stock structure hypotheses that exist across their range in the eastern Pacific. However, still there are important data gaps to fill to understand the stock structure of this species. The aim of this study was to develop more information to understand the Pacific stock structure of the white seabass by (1) enhancing the baseline (catch-effort) information for the Mexican WSB fishery, (2) estimating the size-at-maturity and (3) describe the horizontal movement patterns and habitat utilization of adult WSB. Results suggest that the landings of the Mexican white seabass fishery showed an overall increase over the past 70 years. Landing fluctuations were associated with shifts in contextual factors, such as market changes and geopolitical events. For the past 20 years, the majority of harvest has come from Baja California Sur, with landings concentrated primarily in the fishery offices of Ciudad Constitución, Punta Abreojos, and San Carlos. White seabass females from southern Baja California mature at a size of 72.7 cm, while the males mature at a size of 58 cm. Moreover, regional differences of maturity were estimated where WSB from California matures larger than those from southern Baja California. A connectivity degree of white seabass adult was estimated between the coast of California and the west coast of the Baja California Peninsula. Overall, areas around islands and coastal areas are high-use areas for adult WSB. The Channel Islands, the region off Coronado Islands-Ensenada, the San Quintin region, and the Vizcaino Bay region are essential areas for WSB since different WSB ontogenic stages have been recorded. The spawning (March-September) and none spawning (October-February) seasons for adult WSB have marked differences in habitat utilization. Two migration pathways were estimated: one, a dispersal movement where adult white seabass moved northward to an area around the Channel Islands in California and a southward movement along the coast of the west coast of the Baja California Peninsula where multiple high-use areas were occupied and, second a return movement from north and south areas to a constrained and restricted area off the coast of Tijuana and San Quintin. Considering the information generated in this thesis, we have attempted to fill several data gaps that continued to preclude effective bi-national management of this important transboundary resource and generated more information to understand the stock structure of the WSB along its Pacific distribution.

Keywords: White seabass, stock structure, landings reconstruction, size-at-maturity, habitat utilization.

Dedication

A Tí, Abbá.

A mi esposa Naty y a nuestro hijo Matías Masao.

A la familia y amigos.

"FIDES ET RATIO son como las dos alas con las cuales el espíritu humano se eleva hacia la contemplación de la verdad. Dios ha puesto en el corazón del hombre el deseo de conocer la verdad y, en definitiva, de conocerle a Él para que, conociéndolo y amándolo, pueda alcanzar también la plena verdad sobre sí mismo".

"El científico es muy consciente de que la búsqueda de la verdad, incluso cuando atañe a una realidad limitada del mundo o del hombre, no termina nunca, remite siempre a algo que está por encima del objeto inmediato de los estudios, a los interrogantes que abren el acceso al Misterio".

IOANNES PAULUS PP. II

"Desventurado el hombre que sabe todas las cosas y no te conoce a Tí; y dichoso el hombre que te conoce aunque ignore todas las cosas. Y el que te conoce junto a todas las demás cosas, no es más feliz porque conozca estas cosas, sino únicamente porque te conoce a Tí**"**

2 Cf. San Agustín. Confesiones, I, 1

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Chapter 1. General introduction

The white seabass, Atractoscion nobilis (WSB), is a member of the Sciaenidae family and is distributed from northern California in the U.S. to the southern Baja California Peninsula region and part of the Gulf of California, Mexico. In warmer conditions, it has been caught up to Alaska (Ayres, 1860; Love, 2011; Thomas, 1968). The maximum size reported for this species is 166 cm in total length, and the maximum reported weight is 42.3 kg (Love, 2011). Due to its wide distribution, the size it can reach, and the quality of its meat, the WSB has been considered an important fishery resource for commercial, artisanal, and sport fishing (Rámirez-Rodríguez et al. 2010; Thomas 1968).

In the U.S., the California WSB fishery (commercial and recreational) had harvested WSB since the late 19th century in both U.S. and Mexican waters until 1982, when the Mexican authorities prohibited foreign commercial fleets from fishing within national waters (Young, 1973; Vojkovich and Reed, 1983). California WSB landings have fluctuated over time, reaching their highest level in the late 1950s and their lowest in the late 1990s (Valero & Waterhouse, 2016). Due to a decreasing trend in catch volumes, in the 1930s the U.S. established several regulations for managing the WSB resource, including the establishment of a minimum size limit for retained fish, closed seasons, limited fishing areas, and restrictions on the use of purse seines and bottom nets (CDFG, 2002; Valero & Waterhouse, 2016; Vojkovich and Reed, 1983). The first integrated stock assessment was conducted for WSB in 2016, which estimated the stock status and spawning biomass trends, and showed a steady decline in California landings since 2008 (Valero and Waterhouse, 2016). However, this assessment did not incorporate any landings data from fisheries in Mexico, given the spatial scope of the assessment and data availability.

In Mexico, WSB landings record information remains unavailable for commercial and recreational fisheries for WSB and there us no species-specific WSB management (SADER, 2018). Therefore, baseline information on catch and effort is necessary to assess harvest trends and develop effective management regulations for the Mexican WSB fishery. Several approaches have been used to infer the WSB stock structure along its Pacific distribution and past work has shown that those WSB inhabiting the upper Gulf of California are genetically different and likely comprise a different functional stock (Franklin et al., 2016). Initial studies indicated that individuals from the Southern California Bight (SCB) and the western coast of the Baja California Peninsula have a common breeding population (Ríos-Medina, 2008). Most recently, differences in growth rates of the first year of life (Romo-Curiel et al., 2015), otolith microchemistry (Romo-Curiel et al., 2016), and genetic analysis (Franklin et al., 2016) have been the basis for a two-stock hypothesis along the WSB Pacific distribution. The stock separation has been proposed to be at Punta Eugenia, B.C.S., which is considered a transitional area in the California Current System and, due to seasonal shifts in upwelling intensity and variation in the direction and intensity of coastal currents, forms a seasonal oceanographic barrier that divides two biogeographical regions (Durazo, 2015).

Based on WSB growth rates, Romo-Curiel et al. (2015) showed differences between individuals from the SCB and those from the southern Baja California Peninsula (SBCP) region, with the latter having higher growth rates in the first year of life. They associated the higher growth rate in SBCP individuals with the the higher environmental temperatures of the region. Subsequently, Romo-Curiel et al. (2016) also showed that the isotopic composition of the otolith was also different between samples from the SCB and SCBP, suggesting that the juveniles were reared under different environmental conditions. In addition, Franklin et al. (2016) used microsatellite DNA analyses to propose that WSB along the Pacific were structured in two subpopulations, one in the SCB and the other in the SBCP. Franklin et al. (2016) also noted that their results may be preliminary due to the low number of samples obtained in the SBPC compared to those in the SCB.

Other approaches used to determine the stock structure of fishery resources include assessing the size-at-maturity and analyzing the movement patterns. The size at which an organism reaches maturity represents an evolutionary trade-off between the advantages and drawbacks of reproducing early or late in life (Hutchings and Baum, 2005; Swain et al., 2005). Benefits of early maturation include an increased probability of surviving to reproduce and an enhancement of the gene rate flow into the population and reducing generation time. By contrast, early maturation can result in lower fecundity and/or low recruitment associated with decreased post-reproductive survival due to a trade-off between smaller body size and early maturation (Swain et al., 2005). The WSB is an iteroparous and batch spawner species that spawns in groups; the spawning season lasts from March to September, with a peak in late spring to early summer (Albers and Drawbridge, 2008). Based on a preliminary study that macroscopically examined the gonads of WSB females and males, Clark (1930) estimated the sexual maturity of the WSB off the coast of California, estimating that 50% of the females were mature at 70 cm in total length (TL) and that 50% of the males matured at 60 cm in TL. It is worth mentioning that the author recognized the study to have a high degree of uncertainty.

Movement patterns have been used to determine stock boundaries, identify mixing rates and confirm that variations in populations across distinct habitats stem from local environmental factors rather than genetic ones (Bain, 2005; Cooke et al., 2022). Using electronic tags to understand and define individual behaviors controlling stock distribution and habitat utilization offers a valuable tool for fisheries management (Bain, 2005; Cooke et al., 2022). Based on studies that used electronic tags (Aalbers and Sepulveda, 2015; Aalbers et al., 2021), it has been shown that WSB display a marked seasonal distribution. The WSB shifts to shallower and warmer waters during the spring and summer which coincide with the spawning season. Meanwhile, movements to deeper and colder waters is evident during the fall and winter. The WSB has a preferred temperature range between 13 and 16 ◦C. Moreover, it has been proposed that the WSB might exhibit site fidelity since individuals were recaptured within a ratio less than 30 km from tag deployment sites. However, from the points of deployment and recapture, it has been recorded that the WSB could travel long distances (> 500km), and northward and southward movements across the border of the U.S. and Mexico have also been reported. Nevertheless, movements across the Punta Eugenia region, B.C.S., have not been recorded. To date the published data for WSB only provide snapshot information (deployment and recapture information) and do not offer information on long-term fish behavior, horizontal movement patterns, spatial use, or migration pathways.

Considering that the WSB is an important transboundary fishery resource for Mexico and the U.S. and that there are significant data to support a two-stock hypothesis for this species along its Pacific distribution, the present thesis focuses on better understanding WSB stock structure in the Pacific. This work offers new baseline (catch-effort) information for the Mexican WSB fishery, it estimates the size-at-maturity and presents horizontal movement and habitat utilization for this species along the Baja California coast.

1.1 Objectives

1.1.1 General objective

This study used a comprehensive approach to better understand white seabass (*Atractoscion nobilis*) stock structure and habitat utilization along the coast of California (U.S.) and the west coast of the Baja California Peninsula (Mexico). The work couples fisheries information from the U.S. and Mexico with size-at-maturity data and information from electronic tag deployments.

1.1.2 Specific objectives

- Landings reconstruction of the white seabass fishery along the west coast of the Baja California Peninsula based upon an exhaustive literature review.
- Analyze the official catch landings reports for 2000-2019 to assess seasonal variations, regional landings and estimate an abundance index.
- Estimate the size-at-maturity of white seabass captured in the southern Baja California Peninsula region of its Pacific distribution.
- Compare size-at-maturity estimates of white seabass between California and the southern Baja California Peninsula region.
- Update the white seabass larvae distribution estimate in Mexican waters.
- Describe the horizontal movement patterns and habitat utilization of adult white seabass using geolocating archival tags.
- Describe the migratory pathways and seasonal spatial use of adult white seabass along the west coast of the Baja California Peninsula.

Chapter 2. Balancing the asymmetry of knowledge of the transboundary white seabass (*Atractoscion nobilis*) fishery resource: landings reconstruction along the west coast of the Baja California Peninsula

2.1 Introduction

Catch data play a critical role in fisheries management as they are used to inform stock assessments and determine the harvest volume that may be sustainably extracted from a system (Pauly, 1998; Pauly et al., 2013). Moreover, historical catch data contribute to a better understanding of the current fishery status and how it has changed over time (Mcclenachan et al., 2012a; Pauly et al., 2005). In many developing countries, catch time-series data are either unavailable or unreliable. For species with a geographic distribution that extends across international boundaries, data asymmetry (i.e., bias in the availability of information over the full range of a fishery) between countries may complicate national or international management, bias stock assessment results, and impact the effectiveness of management policies (Cisneros-Montemayor et al., 2020; Ishimura et al., 2013; Ramírez-Valdez et al., 2021).

White seabass (WSB, *Atractoscion nobilis*) ranges from the Gulf of California (Mexico) to Alaska (U.S.) in the northeastern Pacific, where it is considered a transboundary fishery resource exploited by both Mexico and the U.S. (Cartamil et al., 2011; Cota-Nieto et al., 2015; Ojeda-Ruiz et al., 2018; Thomas, 1968; Valero and Waterhouse, 2016). Nearly all of the U.S. landings are from California, harvested by hook and line, drift net, and set net gear types, in addition to the presence of a large recreational fleet (CDFG, 2002; Valero and Waterhouse, 2016). The California commercial fishery has harvested WSB for over 100 years, both in U.S. and Mexican waters until 1982, when the Mexican government prohibited foreign commercial fleets from fishing within national waters (Vojkovich and Reed, 1983). California WSB landings have fluctuated over time, reaching their highest level in 1959 with almost 1,600 metric tons (mt) and their lowest in 1997 with less than 30 mt (Valero and Waterhouse, 2016). Since 1931, California state managers have enacted several fishery regulations to counteract declining harvest trends, including a minimum size limit of 71 cm in total length, bag limit reductions, gear restrictions, and a fishing seasonal ban for commercial purposes (March 15-June 15) during a portion of the spawning season (CDFG, 2002; Valero and Waterhouse, 2016; Vojkovich and Reed, 1983). In 2016, the first modern statistically integrated stock assessment was conducted for California WSB, which estimated the stock status and spawning biomass trends (Valero and Waterhouse, 2016). The 2016 assessment showed a steady decline in California landings since 2008, from ~300 mt to ~70 mt in 2014. However, according to the California State guidelines, the WSB stock is not experiencing overfishing (CDFG, 2020). This assessment did not incorporate landings data from neighboring fisheries in Mexico, given that data was not available at the time and the focus of the assessment was on U.S. waters.

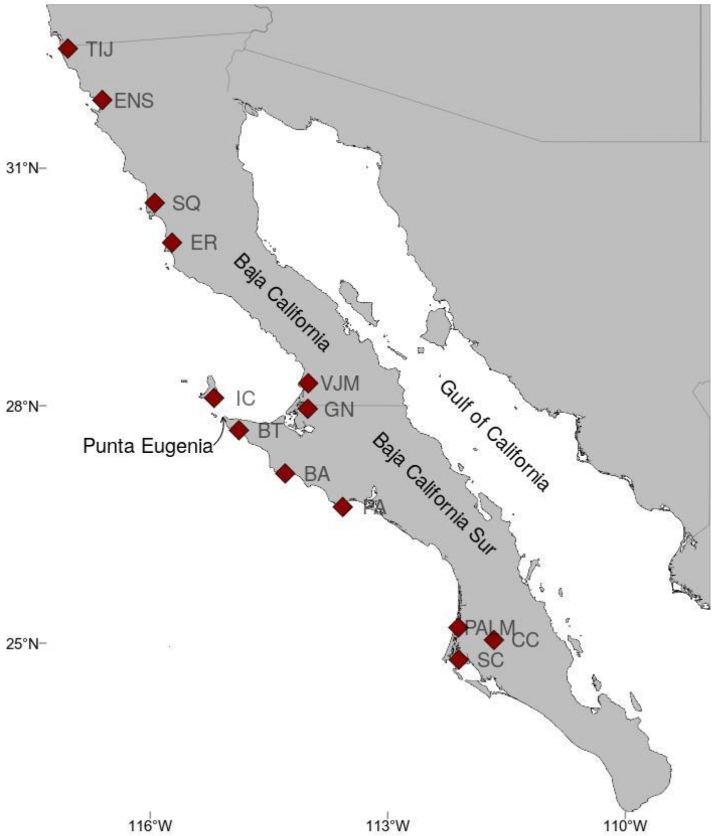

Figure 1. The 13 local fisheries offices of the West Coast of the Baja California Peninsula referenced in the study. TIJ=Tijuana, ENS = Ensenada, SQ = San Quintín, ER = El Rosario, VJM = Villa Jesús María, IC = Isla de Cedros, GN = Guerrero Negro, BT = Bahía Tortugas, BA = Bahía Asunción, PA = Punta Abreojos, PALM = Puerto Adolfo López Mateos, CC = Ciudad Constitución and SC = San Carlos.

In Mexico, the WSB is considered a seasonal target species along the west coast of the Baja California Peninsula and within the upper Gulf of California (Cartamil et al., 2011; Cota-Nieto et al., 2018; Escobedo-Olvera, 2009; Ojeda-Ruiz et al., 2018). Although fisheries exist within the northern Gulf of California, there is limited information on the effort and catches of WSB in this region, and genetically, it is thought to be distinct from the Pacific coast stock(s) (Franklin et al., 2016). White seabass population connectivity along the Pacific coast remains uncertain, and there is debate over whether there are one or two stocks in the region. Early studies suggested that California and the west coast of the Baja California Peninsula share the same breeding stock (Ríos-Medina, 2008). Other studies have proposed a two-stock hypothesis across the west coast distribution, based on genetic analyses (Franklin et al., 2016), otolith microchemistry (Romo-Curiel et al., 2016), and distinct growth rates (Romo-Curiel et al., 2015) between WSB within northern (California and Baja California) and southern regions (Baja California Sur). In support of the two-stock hypothesis, tagging studies have documented northerly and southerly movements across the U.S. and Mexico border, with limited movement from the northern range into the southern fishing areas below Punta Eugenia (Aalbers and Sepulveda, 2015; Aalbers et al., 2021).

In further support of the two-stock hypothesis, the Baja California Peninsula (BCP) encompasses the southern portion of the California Current System (McClatchie, 2014; Durazo, 2015), which has a geographic break around Punta Eugenia (Ibarra-Obando et al., 2001, Fig. 1). This break occurs near the middle of the BCP, proximal to the border between Baja California (BC) and Baja California Sur (BCS), the two Mexican states with the largest WSB production in the country (Escobedo-Olvera, 2009; Ojeda-Ruiz et al., 2018). The prominent landmass around Punta Eugenia produces two distinct biogeographic provinces characterized by differences in seasonal oceanographic features and represents the distribution boundary for several fish taxa common to the San Diegan and the tropical Panamic provinces (Quast 1968; Durazo et al., 2010; Durazo 2015; Ramirez-Valdez et al., 2015). In summer and autumn, the separation of these two biogeographic provinces is evident due to differences in the sea surface layer. The influence of subarctic waters characterizes the northern region, where high oxygen content, lower salinity, and upwellings are persistent (Durazo et al., 2010). The southern region has two climatic regimes, characterized by the presence of subtropical and tropical surface waters during the summer and fall months (warm regime) and the strengthening in the intensity of seasonal winds and coastal upwelling events during the winter and springtime (cold regime) (Durazo et al., 2010). Seasonal differences in oceanographic conditions have been suggested to explain the distinctions in early life growth rates and otolith isotopic composition among WSB sampled from north and south of Punta Eugenia (Romo-Curiel et al., 2015) as well as a boundary among WSB populations studied in the region (Franklin et al., 2016).

In addition to uncertainties in the WSB stock structure, catch records from the commercial fishery remain unavailable throughout Mexico. Currently, catches of WSB are aggregated into a sciaenid-species complex called 'Corvina,' which includes other croakers such as *Cynoscion parvipinnis, Cynoscion xanthalus,* and *Cynoscion othonoptherus* (SADER, 2018). In Mexico, the Corvina fishery does not have any species-specific management regulations such as size, effort limits, or landing quotas, and it is regulated only through non-species-specific fishing permits (SADER, 2018). Therefore, baseline information on effort and catch is necessary, including species-specific trends of landings over time, to develop effective management regulations for the WSB fishery in Mexico. These data are critical for better understanding the trends and current stock status and how it has changed in response to exploitation (Mcclenachan et al., 2012).

Considering the importance of the WSB resource and the lack of available fishery information, the objective of this study was to compile and analyze historical WSB landings in Mexico. We incorporated methods modified from a general procedure used to reconstruct historical landings for other data-limited fisheries (Pauly and Zeller, 2016a). Based on a thorough literature search and the use of alternative data sources (i.e., official reports, and fisher interviews), we reconstructed WSB landing estimates for Mexican fisheries from 1949 through 2019. White seabass landings reconstruction trends were associated with historical and contextual factors. This study also incorporates more recent (2000-2019) and detailed fishery statistics from Official Catch Landings Reports (OCLRs) to assess seasonal and state-wide landings (BC and BCS), as well as preliminary estimates of catch per unit effort (CPUE). Based on the potential for more than a single WSB stock along the Pacific coast, analyses were also performed to compare regional differences between the two Mexican states.

2.2 Methods

2.2.1 Reconstruction of the total white seabass Mexican landings:1949-2019`

To reconstruct WSB landings on the BCP west coast, we utilized a combination of reconstruction methods developed by Pauly (1998), Zeller and Pauly (2007), and Pauly and Zeller (2016a) for 273 regional fisheries around the world. Although the reconstruction approach described by Pauly and Zeller (2016b) typically consists of a seven-step process, we did not need to interpolate values between years (the typical step 5) because our time-series data did not have missing baseline catch records. Therefore, we utilized a modified six-step process to reconstruct WSB landings in the Mexican fishery:

1. *Identification of existing baseline catch time series:* As a baseline of catch time series, we used the Mexican official landings statistics compiled annually by several agencies of the Mexican Federal Government and published as the Fisheries Statistics Year Books (FSYB) from 1949 to 2018 (Arreguín-Sánchez and Arcos-Huitrón, 2007). At the time this manuscript was written, the 2019 FSYB had not been published. Since 2001, the agency in charge of the FSYB has been the Mexican

National Commission of Fisheries and Aquaculture (CONAPESCA). Within the FSYB, WSB catch data have been pooled with landing records from eleven other regionally important sciaenid species into aggregate catch records reported under the category ‘Corvina’ (Escobar-Fernandez, 1989), creating the need to differentiate landings at the species level to reconstruct the time series for the BCP west coast. Disaggregation of the ‘Corvina’ category to WSB species-specific is addressed in step 3.

2. *Identification of fishing operations, locations, sectors, and periods with missing data.* From the baseline data (FSYB), we reconstructed the ‘Corvina’ category landings in each of the two states (BC and BCS) and considered only landings on the BCP west coast from 1949 to 2019 (Table 1). In some years of the time series, the FSYB separated the 'Corvina' category geographically for the BCP west coast. In years were it was not reported geographically, we separated the national landings of the `Corvina` category based on proportions published in the grey literature, firstly for the Pacific coast (including the Gulf of California), then for the states of BC and BCS, and finally for the BCP west coast. Meanwhile, from 2000 to 2019, and based on alternative data sources, landing data were segregated between two sectors of the Mexican fishery that harvested WSB along the BCP west coast: the small-scale fishery and the medium-scale fishery. We found that the medium-scale fishery started harvesting WSB across the BCP west coast in the early 2000s (Escobedo-Olvera, 2009). In contrast, only the small-scale fishery landed WSB before to 2000.

3. *Using alternative information sources to estimate missing data*. To estimate the proportion of white seabass in the aggregated ‘Corvina’ records for the BCP west coast from 1949 to 2019, we carried out an extensive literature review (peer-reviewed and grey literature) and consultations with local fishermen and fishery experts. Proportions estimated for a region were used when no detailed information on WSB landing was found, which allowed us to reconstruct the quantity of WSB landed for several periods (Tables 1 and 2). Additionally, to estimate the proportions of WSB in the landings from 2000 to 2019, we used the Official Catch Landings Reports (OCLR) that CONAPESCA started to produce in 2001 and was made available through official channels upon direct request. The OCLR is an electronic database that contains compiled landing-slip records from small-scale and medium-scale fisheries and contains specific information such as, catch in dressed weight (i.e., eviscerated) by species or group of species, landing site, permit holder code, and name of the fishery office where the slips were submitted. The OCLR database allowed for the extraction of landings records by common fish name as reported at the 13 fishery offices along the west coast of the Baja California Peninsula from 2000 to 2019 (Fig. 1). After interviewing local

fishermen and using the guide compiled by Ramírez-Rodríguez (2013), we extracted all catch records from the database that included common names associated with WSB. For the State of Baja California, all catch records with the common names of "Corvina Blanca" and "cabaicucho" records were selected. However, because the common name "cabaicucho" was used for a different serranid species (Diplectrum pacificum) within the state of Baja California Sur (BCS), records using this common name were not included into our landing estimates for BCS (Holguin-Quiñones, 1976; Pellowe and Leslie, 2017; Ramírez-Rodríguez, 2013). The OCLR time series was used to estimate the total WSB landings for the BCP west coast and estimate the proportion of WSB to be applied to the baseline time series of the FSYB.

4. *Determination of anchor points for periods with limited catch data.* When detailed catch records of WSB were found during our literature review, specific information was used to define anchor points at specific years to reconstruct landings data across periods with less precise details (see Table 1 for anchor points and Table 2 for references).

5. *Estimation of final total catch time series.* Reconstruction of estimated landings for discrete-time periods was completed after time-series data derived from steps 2-4 were applied to the documented Corvina aggregate yearly landing records in the FSYB described in step 1 (Pauly and Zeller, 2016b). Depending on the year, the Corvina aggregated records were reported in the FSYB as nationwide, Pacific-wide, or for each Baja California or Baja California Sur state landing, making it necessary to estimate the proportions of WSB for the BCP west coast for each yearly total from 1949 to 2019.

6. Q*uantifying the uncertainty associated with each reconstructed period.* The uncertainty associated with the historical reconstruction of the Mexican white seabass landings was evaluated using a scoring process developed by Zeller et al. (2015), which incorporated uncertainty criteria modified from the methodology used by the Intergovernmental Panel on Climate Change (Mastrandrea et al., 2011). We applied the results from a workshop with experienced scientists who individually reviewed the assumptions and scored the survey based on each time period and sector (Table 3). Survey scores were averaged for each period, and confidence intervals were obtained with the catch-weighted average (Table 3). The scoring periods evaluated were: 1949-1952, 1953-1961, 1962-1973, 1974-1976, 1977-1982, 1983-1989, 1990-1994, 1995-1999 and 2000-2019.

2.2.1.1 Fishery characterization

The FSYB and the OCLR do not report the fishing gears used to target WSB. Therefore, we carried out an extensive literature review (peer-reviewed and grey literature) and consultations with local fishermen and experts to describe the fishing gears used by the small-scale and medium-scale fisheries on the BCP west coast.

2.2.2 Analysis of the Official Catch Landings Reports 2000-2019

Between 2000 and 2019, OCLRs provided additional information that allowed us to establish yearly regional (BC and BCS) landing estimates by type of commercial fishery. Total catch was pooled across this period for each fishery office to estimate average (± SE) and maximum landing statistics for each region. Because assumptions of normality and homogeneity were not met, we performed non-parametric Kruskal-Wallis statistical analyses to test for differences by region (BC and BCS) and by type of commercial fishery (small-scale and medium-scale).

Furthermore, OCLRs provided additional information related to the number of fishing days for the medium-scale fishery and the number of small-scale vessels participating in the commercial fishing for each region (CONAPESCA, 2015a; 2015b). With this information, we estimated the catch per unit of effort (CPUE), where fishing days were used as a unit of effort for the medium-scale fishery, and the number of vessels was used as a unit of effort for the small-scale fishery. CPUE estimates for the medium-scale fishery were reported as average monthly catch per fishing days, while CPUE estimates for the small-scale fishery were reported as average monthly catch per number of vessels. Due to a lack of effort information from 2000 to 2005, CPUE analyses were only conducted for the 2006 and 2019 period.

Table 1. Synthesis of the methodologies used in each reconstruction period.

Period	Anchor period (white seabass species-specific landings)	Anchor periods mean proportion of white seabass	Corvina aggregate region data	Confidence interval (%)	Description reconstruction period	References
1949-1952	1949-1952	NA	Specific landings of white seabass	10	Almost all fishery resources landed on the west coast of the Baja California Peninsula were exported to the U. S. and, assuming that all the white seabass landed in Mexico were exported to the U.S., we considered that the records reported in 1949-1952 were the first species-specific landings for white seabass.	Berdegué (1956) Hool (1949) Hernández-Fujigaki (1988) Samaniego-López (1999)
1953-1961	1949-1952	~4% Berdegué (1956)	West coast of the Baja California Peninsula corvina aggregate	20	We estimated the mean proportion of white seabass for 1953-1961, and assuming similar fishing practices, we applied this proportion to the Corvina aggregate for 1953-1961.	Secretaría de Industria y Comercio (1964)
1962-1973	1962-1973	NA	Specific landings of white seabass	20	Species-specific landings for white seabass were reported for the west coast of the Baja California Peninsula for 1962-1971.	McCall et al. (1976)
1974-1976	1962-1973	~8% McCall et al. (1976)	West coast of the Baja California Peninsula of corvina aggregate	50	Corvina group landings of the west coast Baja California Peninsula for 1974, 1975, and 1976. To estimate white seabass landings, we used the mean ratio of ~8% from the last period.	Secretaría de Industria y Comercio (1974) Departamento de Pesca (1979) INAPESCA (1976)
1977-1981	1962-1973	~8% McCall et al. (1976)	West coast of the Baja California Peninsula of corvina aggregate	30	From 1977-1981, LFOs reported Corvinas group landings for the west coast of the Baja California Peninsula. Therefore, we estimated the landings for white seabass using the mean ratio of ~8%.	Departamento de Pesca (1979-1981)
1982-1989	1962-1973	~8% McCall et al. (1976)	BC and BCS of corvina aggregate	50	We estimated the proportion of corvina aggregate for the west coast of the Baja California Peninsula using the ratio of landings estimated for the corvina aggregate from the last	SEPESCA (1982-1994)

					period. And applied the mean ratio of ~8% to estimated landings for the white seabass.	
1990-1994	1990-1994	~97% Gobierno del Estado de Baja California (1995)	Specific landings of white seabass	30	On the west coast of Baja California, species-specific landings for white seabass were reported for 1990-1994, and a mean proportion was estimated for this period. Meanwhile, for Baja California Sur, determined Corvina aggregate was made for the west coast and estimated white seabass landings using the mean proportion estimated for Baja California.	Gobierno de Baja California (1995) SEPESCA (1982-1994) SEMARNAP (1994-1999)
1995-1999	1990-1994	~97% Gobierno del Estado de Baja California (1995)	BC and BCS of corvina aggregate	50	We estimated the mean ratio of white seabass landings from the Corvina aggregate of 1990-1994 to determine the 1995-1999.	SEMARNAP (1994-1999)
2000-2019	2000-2019	NA	West coast of the Baja California Peninsula corvina aggregate	20	White seabass landings were estimated from Corvina aggregate landings reported by 13 Local Fishery Office of the west coast of Baja California Peninsula. Moreover, this period comprises information for the small-scale and the middle-size vessel fishery. Likewise, specific white seabass landings published in peer-reviewed journals were also incorporated.	CONAPESCA (2000-2018;2015b,2015c) Ramirez-Rodriguez (2013) Pellowe and Leslie (2017) Cota-Nieto et al. (2018) Ojeda-Ruiz et al. (2018) Escobedo-Olvera (2009)

2.3 Results

2.3.1 Fishery characterization

Table 2. Main sources used for the historical reconstruction landings of white seabass in the West Coast of Baja California Peninsula.

Type of information	Period	Reference	Catch description
Mexican official landings statistics	1950-1956	SEMAR (1950-1969)	Corvina aggregate
	1952 and 1954	SEMAR (1950-1969)	Corvina aggregate by Fishery office BC and BCS
	1956-1961	Secretaria Industria y Comercio (1964)	Corvina aggregate by Fishery office BC and BCS
	1962-1969	SEMAR (1950-1969)	Corvina aggregate
	1972-1974	Secretaría de Industria y Comercio (1974)	Corvina aggregate
	1975-1976	Departamento de Pesca (1975-1981)	Corvina aggregate
	1977-1980	Departamento de Pesca (1975-1981)	Corvina aggregate by Fishery office BC and BCS
	1981-1982	SEPESCA (1982-1994)	Corvina aggregate by Fishery office for BC and BCS
	1983-1993	SEPESCA (1982-1994)	Corvina aggregate for BC and BCS
	1994-1999	SEMARNAP (AEP 1994-1999)	Corvina aggregate for BC and BCS
	2000-2018	CONAPESCA (2000-2018)	Corvinas aggregate for BC and BCS
	2000-2019	OCLR (200-2019)	Corvinas aggregate delimitated by common name and Fishery office BC and BCS
Quantitative descriptions of white seabass landings	1949-1952	Berdegué (1956)	Quantitative white seabass descriptions for West Coast of Baja California Peninsula
	1962-1973	MacCall et al., (1976)	Quantitative white seabass descriptions for the West Coast of Baja California Peninsula
	1990-1994	Gobierno de Baja California (1995)	Quantitative white seabass descriptions (specific landings in BC)

	2000-2006	Escobedo-Olvera (2009)	Quantitative white seabass descriptions for middle-sized vessels
	2000-2007	Cota-Nieto (2010)	Quantitative white seabass descriptions by Cooperativa Punta Abreojos
	2001-2015	Cota-Nieto et al., (2018)	Quantitative white seabass descriptions by Cooperativa Punta Abreojos
	2018	Ojeda-Ruíz et al., (2018)	Quantitative white seabass descriptions in Bahia Magdalena
Diverse literature	1949	Hool (1949)	Mexican fishery industry
	1968	Roedel and Frey (1968)	California based fisheries of the west coast of Mexico
	1976	Holguin-Quiñones (1976)	Catalogue of fishes from Baja California Sur
	1988	Hernández-Fuijigaki (1988)	Mexican fishery history
	1994	Soberanes-Fernández (1994)	Historic description of the Mexican fishery
	1996	Ramírez-Rodríguez, M (1996)	% of total catches for the Pacific and the GC coast of BCS
	1999	Samaniego-Lopez (1999)	Fisheries in Baja California
	2013	Ramirez-Rodriguez (2013)	Catalogue of fishes from the Mexican Pacific
	2015	Romo-Curiel et al., (2015)	Von Bertalanffy growth parameters for white seabass
	2016	Romo-Curiel et al., (2016)	Otolith isotope composition for white seabass
	2017	Pellowe and Leslie (2017)	Artisanal fishery species description BCS
	2020	García-Rodríguez and Sosa-Nishizaki (2020)	Artisanal fishing activities in Bahia Vizcaino Bay, B.C.S.

The WSB is a seasonal target species harvested along the BCP west coast, by a commercial gillnet fishery comprised of both medium-scale and small-scale vessels. The medium-scale fishery consists of boats between 10 to 27 m in length, equipped with hydraulic systems, inboard engines, and cold storage systems. The medium-scale fishery primarily harvest white seabass using either drift or set gillnets composed of 17 cm (6.5 in) nylon mesh, which are up to 2000 m in length. Following a national ban on drift-gillnet fishing for the medium-scale fishery in 2009, gillnets were primarily set along the bottom at depths between 1.8 to 18 m using anchors and a lead line along the base of the net and a floating line along the top. The average reported gillnet soak time was 9 hrs onboard medium-scale vessels targeting

WSB. Although WSB is a primary target of the gillnet fishery, they are also caught incidentally during gillnet sets targeting yellowtail *(Seriola lalandi*) and have also been reported as bycatch in the trawl fishery for shrimp (Table 4).

Table 3. Scores for the evaluation of the uncertainty associated with the Mexican white seabass landings reconstruction.

Score		Confidence interval +/-%	Corresponding IPCC criteria*	Historical species composition estimation criteria
4	Very high	10	High agreement and robust evidence	Quantitative white seabass descriptions
3	High	20	High agreement and medium evidence or medium agreement and robust evidence	Studies or surveys describing the white seabass fishery
2	Low	30	High agreement and limited evidence or medium agreement and medium evidence or low agreement and robust evidence	Studies only for one region along the west coast of the Baja California Peninsula
1	Very low	50	Low agreement and low evidence	Studies without a description of a specific region (i.e., National corvinas species group in Mexico)

*Mastrandrea et al., (2010) noted that "confidence increases" (and hence confidence intervals are reduced) "when there are multiple, consistent independent lines of high-quality evidence".

The small-scale fishery consists of boats between 7 to 10 m long, equipped with outboard engines and no cold storage systems. The WSB is a seasonal target species for small-scale fisheries, although it is caught year-round. The main fishing gear used to harvest WSB is the monofilament gillnet, with a mesh size ranging between 13 to 25 cm (5-10 in), set depths between 5 to 30 m, and lengths between 100 to 6000 m (when multiple gillnets are strung together). The average soak time for the gillnet is 24 hrs., but soak times can range between 4 to 48 hrs. (Table 4). In the small-scale fishery, different gillnet configurations are tailored based on seasonal depth distribution and ocean conditions (i.e., set gillnet, bottom gillnet, drift gillnet, and seine gillnet; Aalbers et al., 2021). Outside of the spawning season (during winter months), bottom and set gillnets are most common, and the fishery switches to surface-based gear during the spawning season (late spring and summer months; May and June) when the WSB occur at shallower depths. When using the drift-gillnet configuration (typically deployed when WSB are in the upper water column), commonly referred to as "garetear," fishermen deploy gear late in the day and drift with the boat attached to the net all night. During the 12-hr soak time, the net is consistently checked and any WSB catch is immediately hauled to ensure better meat quality and to reduce predation by sea lions (Pers. Comm. Ignacio Romero, fisherman from San Juanico, BCS). During most small-scale fishery operations, fishermen hand-pull gillnets manually; however, hydraulic spools have been reported to be used recently, especially in the fishing camps of San Juanico, BCS, and Vizcaino Bay, BCS (Pers. Obs. AFY).

2.3.2 Regional fleet dynamics

Although the BCP has two well-established fleets that target WSB (i.e., small-scale, and medium scale), the small-scale operations in both BC and BCS make up the bulk of the overall effort. Based on the OCLR records, the small-scale fishery makes up ~97% of the total WSB landings, while the medium-scale fishery comprised the remaining ~3%. The landings of the small-scale fleet increased from 409 mt in 2000 to 928 mt in 2019, while the medium-scale fishery showed landings fluctuations between 7 to 40 mt (Figure 2). Most of the landings for the medium-scale fishery fleet (mean 14±8 mt y-1) were recorded in BC, while BCS had the highest landings for the small-scale fleet (mean 599±179 mt y-1).

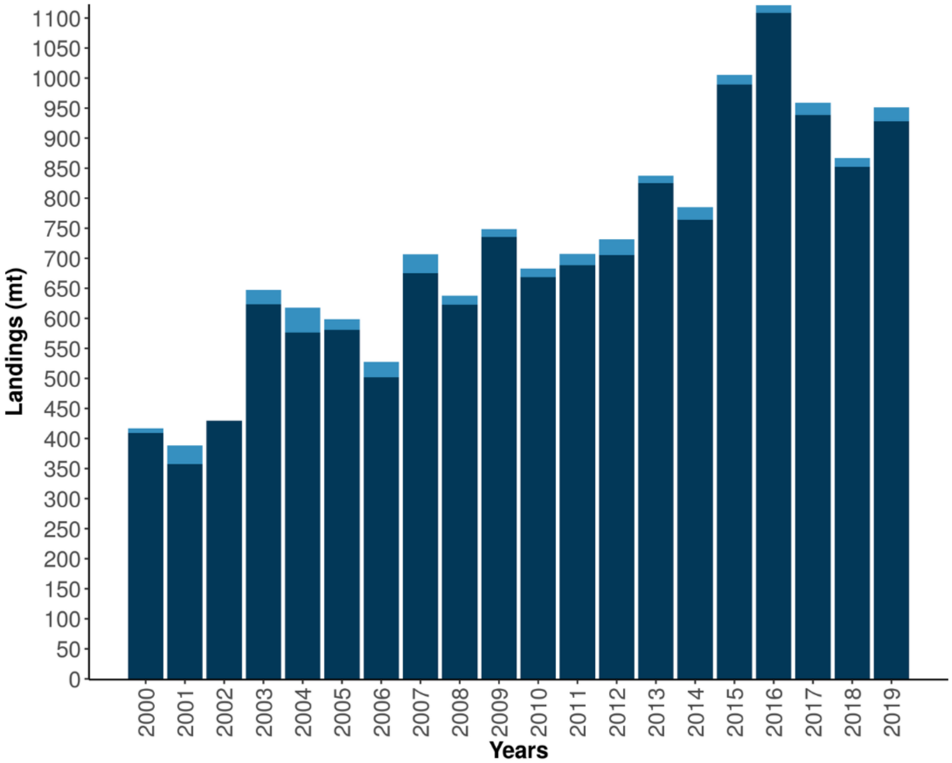

Figure 2. Total annual landings of the Mexican white seabass fishery from 2000 to 2019 using the OCLR data. The dark blue color indicates the landings of the small-scale fishery, and the light blue color indicates the landings of the medium-scale fishery

Table 4. Mexican white seabass commercial fishery characteristics along the west coast of the Baja California Peninsula

Fishery	**Locality**	**Type of fishing**	**Description**	**Reference**
Small scale	Pacific Coast of BC	Target and Incidental	Bottom gillnet with mesh size between 2 – 5 in.	Cartamil et al., (2011)
	Bahía Tortugas and Punta Abreojos, BCS	Target	Set gillnet and drift gillnet with lengths up to 1,400 m.	Shester and Micheli (2011)
	Punta Abreojos, BCS	Target	Set gillnet with mesh size of 6.5 or 8 in and lengths from 100 to 500m.	Cota-Nieto et al.,, (2018)
	Magdalena-Almejas Bay, BCS	Target	Set gillnet with mesh size of 6, 8 and 12 in. With length ranging 100 to 250 m	Ojeda-Ruiz et al., (2019)
	Bahía Sebastián Vizcaíno, BCS	Target and Incidental	Set gillnet, bottom gillnet, and seine net with mesh size of 5, 6, 8 and 10 in. With lengths between 200 to 6000 m. Some boats used hydraulic spools.	García-Rodríguez and Sosa-Nishizaki (2020)
	San Ignacio region, BCS	Target	Bottom and surface nets.	Mendoza-Portillo et al., (2020)
	San Juanico, BCS	Target and Incidental	Set gillnet, bottom gillnet, and drift gillnet with a mesh size of 5.5 to 6 in and length of 100 to 200 m. Use of hydraulic spools in a single boat.	Interviews with local fishermen
Medium-scale	Esenada, BC	Target and Incidental	Until 2009, drift net gillnet with mesh size of 6.5 in and length of 2000m. Incidental when targeting yellowtail (*Seriola lalandi*)	Escobedo-Olvera (2009)
	Bahia Magdalena Bay, BCS	Incidental	Incidental by the shrimp fishery	De la Rosa-Meza (2005)

The medium-scale fishery reported the highest pooled landings in the Ensenada fishery office with 261 mt and the lowest in the Ciudad Constitución fishery office with less than 1 mt (Fig. 3). Meanwhile, BC had the highest estimated nominal effort of 300 days (average monthly effort of 27 days) compared to the effort estimated for BCS with 200 days (average monthly effort of 16 days). However, there are no significant differences between effort estimates in both states (Fig. 4a), and the CPUE estimates for both states show similar trends (Fig. 4b). The months with the highest average landings for both states were June and July (Fig. 4c). Because the small-scale fishery makes up most of the WSB landings, the description of regional efforts is mainly focused on the efforts of the small-scale fishery.

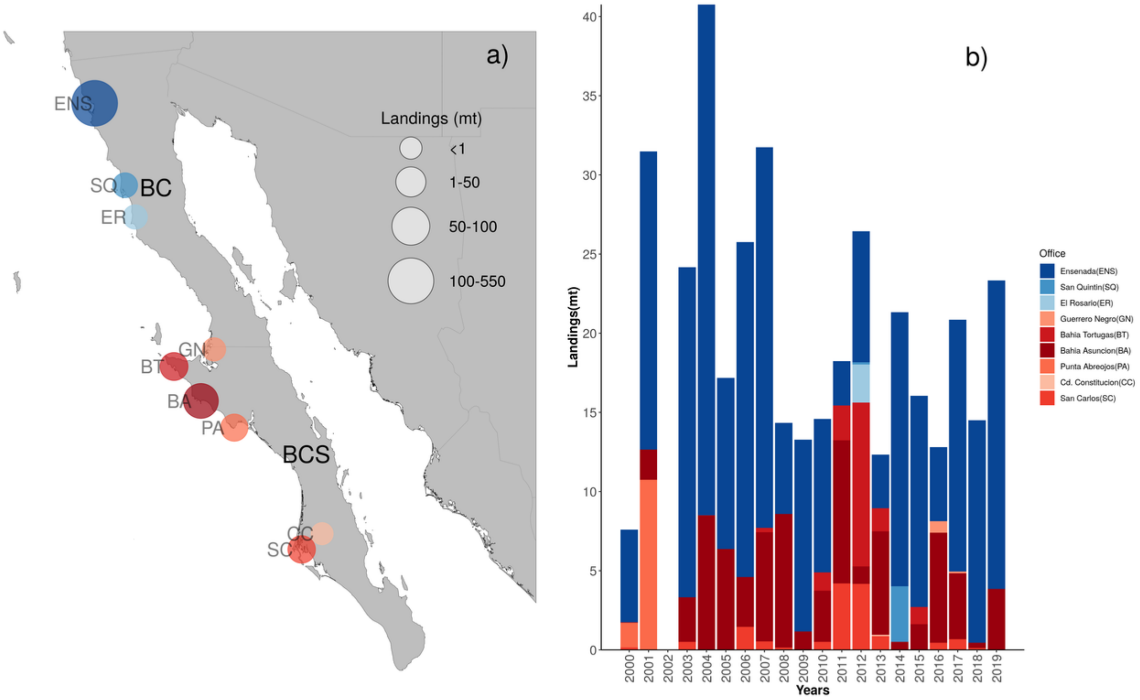

Figure 3. 2000–2019 Fishery Offices landings for the medium-scale fishery. (a) Pooled landings for 2000–2019. (b) Landings by year for each Fishery Office. Only landings from 9 Fishery Offices are shown because the OCLRs only recorded those volumes for the medium-scale fishery.

2.3.3 Baja California

Within the state of BC, the Villa Jesus Maria fishery office reported the highest pooled landings from 2000 to 2019 for the small-scale fishery with 415 mt (Fig. 5). Conversely, the lowest pooled landed volume for the same period was estimated for the Tijuana fishery office at approximately 1 mt (Fig. 5). The average nominal effort from 2006 to 2019 for the BC small-scale fishery was estimated at 1,597 vessels and increased from 1,122 vessels in 2006 to a maximum nominal effort of 2,233 vessels in 2016 (Fig. 6a). The lowest CPUE estimated was 0.02 monthly catch (mt) per vessel in 2012 and the highest in 2007 with 0.09 monthly catch (mt) per vessel (Fig. 6b).

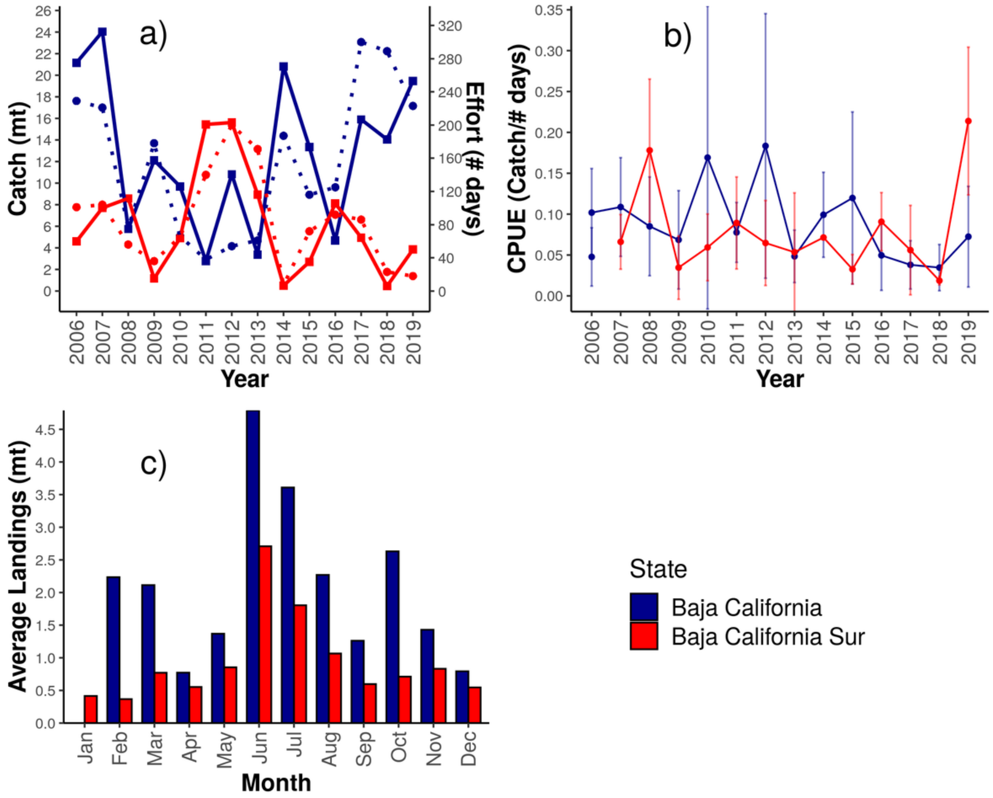

Figure 4. Medium-scale fishery. (a) Nominal catch (mt) in solid lines and effort (#days) in dotted lines. (b) CPUE is estimated as the average monthly catch per day. (c) Average monthly landings.

The highest average monthly WSB landings along BC occurred during the spring and summer seasons with a peak in June and July. Meanwhile, the lowest average monthly landings were recorded during the autumn and winter seasons, with the lowest average monthly landings in November (Fig. 6c).

2.3.4 Baja California Sur

In BCS, the fishery office with the highest pooled landing volume from 2000 to 2019 was Ciudad Constitución with 4,830 mt (Fig. 5). Because the fishery office of Puerto Adolfo López Mateos closed in 2006, there was a subsequent increase in landings slips recorded at the surrounding fishery offices from Ciudad Constitución and San Carlos (Erauskin-Extramiana et al., 2017). All fishery offices across BCS registered more than 500 mt of WSB captured by the small-scale fishery (2000-2019), with the lowest pooled landing estimate recorded in the Bahía Asunción fishery office (525 mt).

A steady increase in the fishing nominal effort was reported from 2006 (1,708 vessels) to 2019 (5,222 vessels), with an average of 3,773 vessels fishing during this period (Fig. 6a). The CPUE showed an increasing trend over time, with the highest estimated CPUE of 0.12 mean monthly catch (mt) per vessel in 2019 (Fig. 6b). The highest average monthly landings were recorded during the spring and summer seasons, with three notable peaks in June, July, and August (Fig. 7c). The lowest average monthly landings occurred during the transition between winter-spring and autumn-winter seasons, with the lowest landings in September (Fig. 6c).

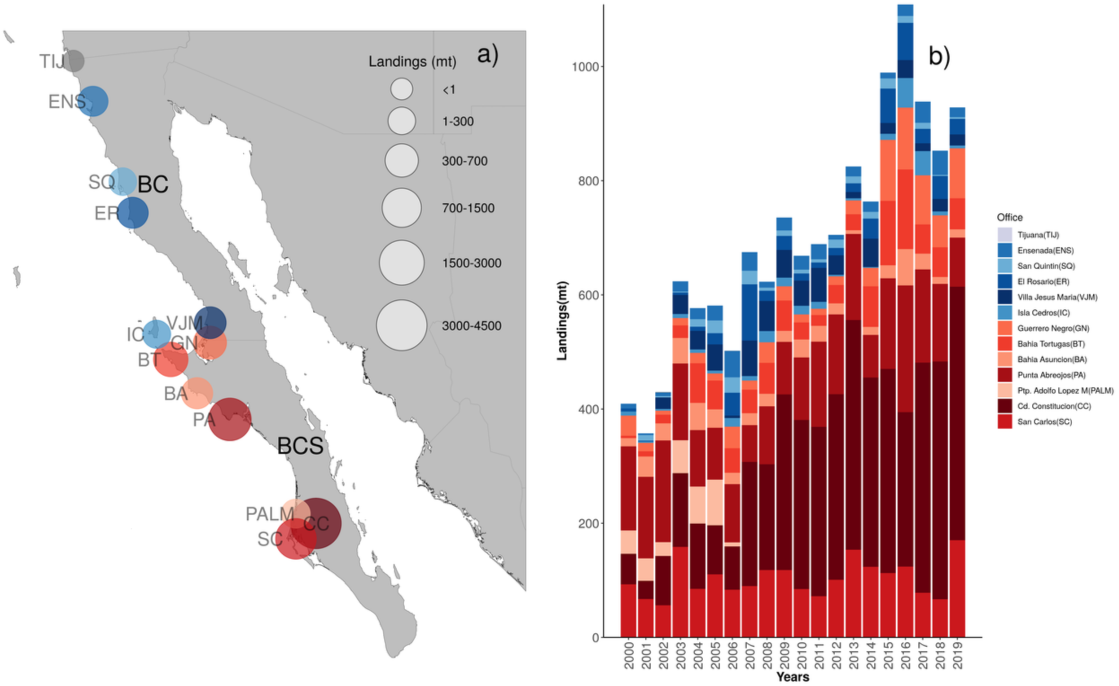

Figure 5. 2000–2019 Fishery Offices landings for the small-scale fishery. (a) Pooled landings for 2000–2019. (b) Landings by year for each Fishery Office.

2.3.5 Reconstruction of the total white seabass landings on the Baja California Peninsula west coast

In summary, the reconstruction efforts revealed only FSYB landings data for the period from 1949 to 2000, with both FSYB and OCLR data sources available for the later periods (2000-2019). Although similar trends were evident in both data sources, notable differences were identified between the two data sources. The reconstruction efforts revealed five distinct periods marked by the volume of landed product (Fig. 7). Based on FSYB records, initial landings fluctuated from 0.21 mt to 9 mt between 1949 and 1961. From 1962 to 1989, landing estimates fluctuated from 8 mt to 72 mt, showing a high increase up to 481 mt in 1990. During the 1991 to 2002 period, estimated landings fluctuated from 374 mt to 638 mt and from

2003 to 2014, landings estimates fluctuated between 467 mt to 966 mt. During the most recent time period (2015-2018) reconstructed catch estimates from FSYB data sources increased to a peak of nearly 2000 mt in 2016 before declining to approximately 1,402 mt in 2018 (Fig. 7). The OCLR records for this same overlapping period show landings to fluctuate between 300 mt and 1,150 mt with an average of 718 mt from 2000 to 2019. The OCLR data show that annual landings increased from 417 mt yr-1 in 2000 to 952 mt yr-1 in 2019, revealing an overall increase of ~228% (Fig. 7).

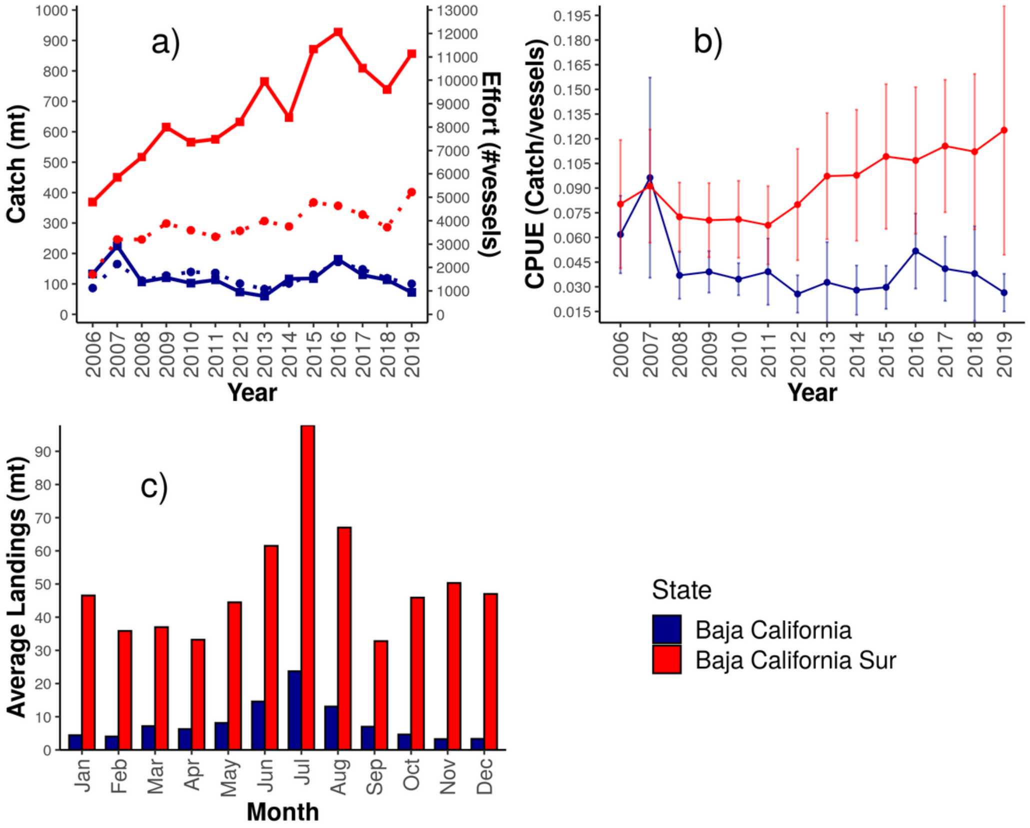

Figure 6. Small-scale fishery. (a) Nominal catch (mt) in solid lines and effort (#vessels) in dotted lines. (b) CPUE is estimated as the average monthly catch per vessel. (c) Average monthly landings

2.3.6 Discrepancies and uncertainties associated with the landing's reconstruction

As shown in Fig. 7, this study found large discrepancies in the FSYB estimations (a combined croaker index compiled by resource managers for federal reporting purposes; see methods, section 2.2) and the WSB landings estimates between the OCLR records (catch data obtained from fishermen landings receipts; see methods, section 2.2). The estimated landings from the FSYB reached a peak of 2,000 mt in 2016, while landing estimates based on OCLR records were much lower (~1,121 mt), resulting in a 74% discrepancy (Fig. 7; Table 5). For other years, differences between estimates based on FSYB and OCLR records fluctuated between -4.0% and 94% (Table 5). The rationale behind the apparent discrepancies is provided in section 2.4.2

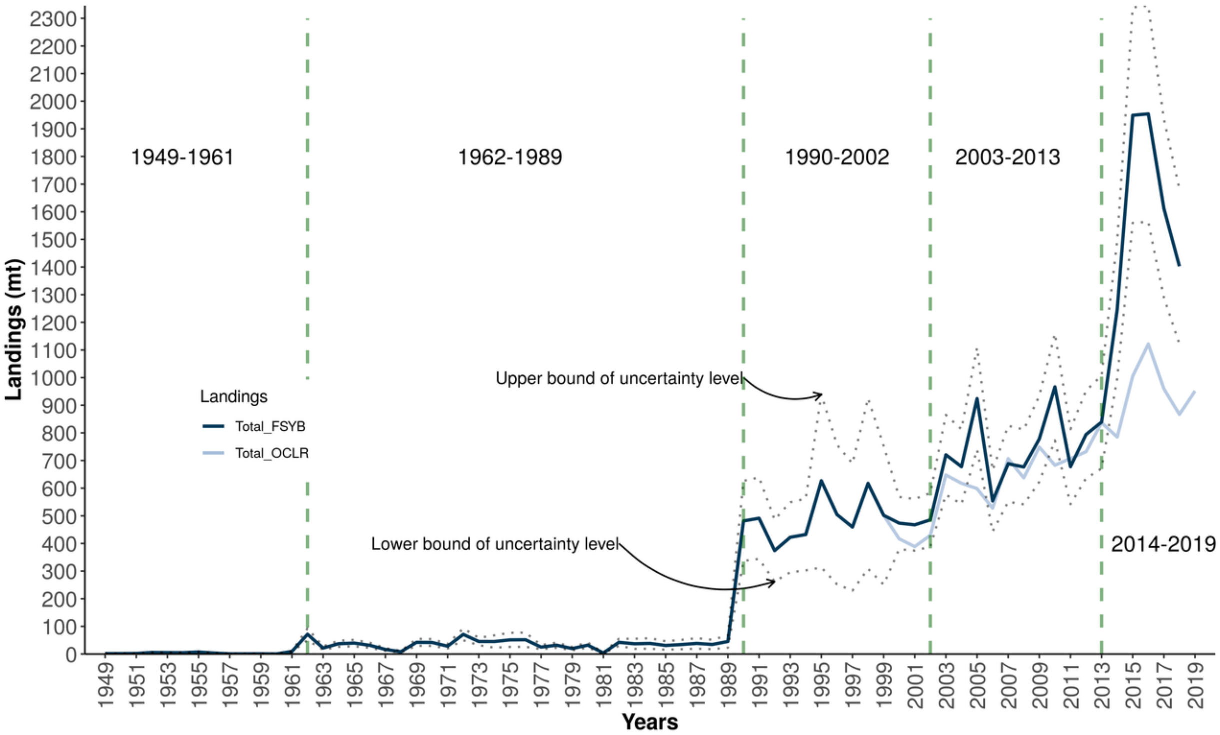

Figure 7. Historical reconstruction of WSB Mexican fishery landings from 1949 to 2019. The dark blue line indicates total WSB landings from 1949-to 2019 using the FSYB as a baseline, and the light blue line indicates total WSB from 2000-to 2019 using the OCLR data.

The mean weighted percentage uncertainty of the reconstructed WSB landings based on FSYB is shown in Fig. 7. The uncertainty estimated for the reconstructed landings of WSB has narrower confidence intervals for the periods 1949-1952 (10%), followed by a 20% uncertainty estimate for the periods of 1953-1961, 1962-1973, and 2000-2019. Meanwhile, the periods with the broadest confidence intervals were 1977-1982, 1990-1994 with 30% and 1974-1976, 1983-1989, and 1995-1999 with 50%.

2.4 Discussion

2.4.1 Summary of reconstruction efforts along the Baja California Peninsula

The main objectives of this work were to collate and reconstruct Mexican WSB landings from the start of the commercial fishery, which we estimate originated in 1949. When coupled with the documented harvest from California-based vessels (1916-1982), it is evident that the white seabass stocks along the Pacific coast of North America have now been exploited for over a century (Coleman, 1923; Radcliffe, 1922; Skogsberg, 1939, 1925). Although the reconstructed landings records show an overall increase in WSB landings over the past 70 years (Fig. 7), this work highlights the complexity of this fishery and reveals regional differences that are likely related to regional abundance and population dynamics (Valero and Waterhouse, 2016). This study has also identified fluctuations in WSB landings that are likely in response to other factors such as international market dynamics, environmental conditions, and the political context of the period (Caddy and Gulland, 1983; Mcclenachan et al., 2012).

Table 5. Reconstructed landings from OCLR and FSYB their differences (Diff) and Diff%. Also, the size of the US WSB market in metric tons, California (CA) landings, Mexican estimated imports to cover the 75% of the US market (Mex75), mean USD/Kg WSB value, and US total market value (CDFW, 2022).

Year	OCLR	FSYB	Diff	Diff %	CA mt	Mex75 mt	US Market mt	US Market USD/kg	US Market USD$ Value
2000	417	474	57	13.6	99	296	395	4.4	1,746,508.36
2001	389	467	79	20.2	118	355	473	4.1	1,933,904.24
2002	430	486	56	13.0	189	567	756	4.0	3,029,484.17
2003	648	721	73	11.3	203	608	811	3.8	3,084,995.13
2004	617	678	60	9.8	135	404	539	4.5	2,426,690.55
2005	598	924	326	54.4	133	399	532	5.7	3,040,838.03
2006	528	554	26	5.0	174	522	697	4.6	3,186,922.60
2007	707	688	-18	-2.6	209	627	836	5.5	4,619,881.87
2008	637	677	39	6.2	293	880	1174	5.1	6,025,850.78
2009	749	778	29	3.9	176	528	705	4.9	3,457,900.59
2010	683	966	283	41.5	249	746	995	6.2	6,194,729.75
2011	707	678	-29	-4.1	248	743	990	6.6	6,538,622.33
2012	732	794	62	8.5	176	528	705	7.9	5,602,309.47
2013	837	840	2	0.3	114	343	458	8.8	4,028,875.05
2014	785	1247	462	58.8	119	358	477	9.5	4,533,133.76
2015	1005	1949	944	93.9	93	280	373	9.6	3,595,545.77
2016	1121	1954	833	74.3	105	316	421	8.1	3,408,669.55
2017	959	1612	652	68.0	104	311	415	8.9	3,696,655.08
2018	867	1403	536	61.8	108	325	434	9.2	3,980,104.11
2019	952	NA	NA	NA	70	209	279	10.5	2,935,597.69

Because it is often difficult to quantify how environmental changes impact landings or fishery dynamics, this study focused primarily on describing trends relative to contextual factors and geopolitical events (i.e., fishery management policies, market development, transportation) (Espinoza-Tenorio et al., 2011; Cisneros-Montemayor et al., 2013; Saldaña-Ruiz et al., 2017; Sosa-Nishizaki et al., 2020). Landings data were summarized and compared over a geopolitical timeline that considered administration priorities at the time, regional changes in infrastructure, and any events that may have influenced effort or trade. Based on these historical accounts this work was able to divide the history of the landings into five development periods that range from the beginning of the commercial fishery in 1949 to the present day. In the following sections, we described the five periods.

2.4.1.1 1949-1961 Beginning of the western coast of Baja California Peninsula local fishery

Fishing along Baja California was initiated through pressures from the Mexican government to develop a regional fishing industry in the 1920s, that included small catches of WSB. This was coupled with support from Japanese and American investors that reinforced fishery development efforts focused on high-value species (i.e., abalone, lobster, and tuna) (Chenaut, 1985; Crespo-Guerrero and Jiménez-Pelcastre, 2017; Velázquez-Morales, 2007). In the 1930s the BCP began to see the development of its first fishing cooperatives, community fishing groups that were established to increase and expand local fish production (Aguilar-Ibarra et al., 2000; McCay et al., 2014; Samaniego-López, 1999).

Following management policies of the 1940s that promoted expansion and growth, the Baja California fishing industry became one of the largest national fisheries of the time (Berdegué, 1956; Hool, 1949). During this period the Mexican government fostered technological developments, industrial fisheries regulations, and the renovation of communication ports, electrical networks, and roads to strengthen the international market trade between Mexico and the U.S. (Espinoza-Tenorio et al., 2011; Hool, 1949). It was during this era (1949) that the exportation of WSB from Mexico to the U.S. was first documented (Berdegué, 1956). Although we can assume that WSB harvest predated this era, this was the first period for which there were any records or landings data for this species in Mexico. During this initial period (1949 and 1961), WSB landings fluctuated from 0.21 mt to 9 mt (Fig. 7).

2.4.1.2 1962-1989 Growth of the Baja California white seabass fishery

During this period the BCP saw several large changes that directly affected the WSB fishery. For one, in 1976 the Mexican government established its Exclusive Economic Zone (EEZ), which led to the official closure of its waters to foreign fishermen in 1982 (Cicin-Sain et al., 1986). This change prohibited U.S. fishermen from seasonally fishing for WSB in Mexican waters and led to a rapid decline in WSB landings off California (Cicin-Sain et al., 1986; Vojkovich and Reed, 1983). During this period, WSB landings fluctuated from 8 mt to 72 mt (Fig. 2), with products consumed locally and also exported to U.S. markets (MacCall et al., 1976). In addition to the establishment of a national EEZ, the Mexican government also enacted new federal laws to help develop and promote local fisheries (Aguilar-Ibarra, et al., 2000; Cicin-Sain et al., 1986; Soberanes-Fernández, 1994). This era also saw the establishment of parastatal agencies, the promotion of fishery loans as well as increased marketing and processing of marine fishery resources (BANPESCA, 1980; PROPEMEX,1972; Ocean Garden, 1975; Espinoza-Tenorio et al., 2011; OECD, 2006). Additionally, the completion of the Transpeninsular Federal Highway in 1973 increased market connectivity and trading between the U.S. and Mexico (Crespo-Guerrero and Jiménez-Pelcastre, 2017). Collectively, fishery development efforts and changes to local infrastructure resulted in nearly twice the total WSB landings by Mexican fishermen during this period compared with the previous fishing period (Fig. 7).

As with other eras, Mexico also reported periods of fluctuating WSB harvest affected by different factors including a period in the early 1980s when the international oil market led to a country-wide economic crisis that impacted parastatal agencies and resulted in a fall in the local fisheries production (Aguilar-Ibarra et al., 2000; Espinoza-Tenorio et al., 2011; Martinez de la Torre, 1994). These historical factors likely explain the abrupt fall of WSB production to 3.49 mt in 1981 (Fig. 2).

Similarly, other marine resources that domestic fishing cooperatives had exploited (i.e., abalone, sea turtle) showed similar decreases in landings during this period. It was also during this period that local fishing cooperatives, which formerly focused primarily on lobster, began to diversify, and to harvest finfish to offset declines in production. Species like WSB were targeted, mainly because their large size provided high-quality fillets that were readily marketable (Cota-Nieto et al., 2015; Early-Capistrán et al., 2018; Prince and Guzmán del Próo, 1993). Despite periods of reduced harvest, fishery landings increased dramatically from a low of 3.49 mt in 1981 to 45.32 mt in 1989 (Fig. 7).

2.4.1.3 1990-2002 Establishment of the Mexican white seabass fishery

This period started with a large increase in WSB landings which went from 45 mt in 1989 to 480 mt in 1990 and later fluctuated between 374 mt to 486 mt, suggesting that the local WSB fishery had reached a period of stabilization along the western coast of the Baja California Peninsula. Two main factors that contributed to the increase observed during this period were improvements in fishing gear, such as the widespread use of fiberglass boats and monofilament gillnets (Álvarez et al., 2018), along with an increase in the number of small-scale vessels participating in the directed fishery (Martinez de la Torre, 1998; OECD, 2006; Young, 2001).

Increased participation in the directed WSB fishery may have also been influenced by the total ban of traditional sea turtle fisheries in 1990, which forced fishermen to target other resources (Acuerdo, 1990; Early-Capistrán et al., 2018). The development of a new Federal Law that established a system of permits and removed exclusive fishing rights from the cooperatives also allowed fishers to participate in different fisheries more readily (McCay et al., 2014; OECD, 2006). A strong export market for WSB was developed in California and trade between Mexico and the U.S. was further complemented with the establishment of the North American Free Trade Agreement in 1994 (Young, 2001).

2.4.1.4 2014-2019 Boosting fish consumption and international markets

This period was characterized by an increasing trend in Mexican WSB landings that fluctuated between 600 to 900 mt and peaked in 2010 at 966 mt (Data from OCLR, Fig. 2). Heightened landings during this period (Fig. 7) suggest that the WSB role in local fisheries was further solidified along the entire BCP (Cartamil et al., 2011; Rosales-Casián and Gonzalez-Camacho, 2003), with increased targeting by Fishing Cooperatives of the North Pacific (Shester and Micheli, 2011), both within the Ulloa gulf (Cota-Nieto et al., 2018) and Magdalena-Almejas Bay (Ojeda-Ruiz et al., 2019; 2018). During this period the WSB had also become an important fishery resource of the medium-scale fishery fleet which mainly fished out off Ensenada (BC) and the Port of San Carlos (BCS). The Mexican government banned the use of drift gillnet gear for sharks and swordfish in 2009 (Norma, 2007; Escobedo-Olvera, 2009), which may have been responsible for the decline in landings observed at the end of the period (Fig. 7).

Moreover, the period from 2014 to 2019 coincides with an administrative term during which the Fishery and Food Development Program of Mexico was actively promoting the consumption of fishery and aquaculture products (Acuerdo, 2017). To enhance fishery operations, subsidies for both small and larger-scale fisheries were offered to promote harvest and regional production (Cisneros-Montemayor et al., 2016). Given the basis for federal subsidies, there may have been an incentive to report higher levels of the catch than what was actually harvested (Cisneros-Montemayor et al., 2016). The economic incentives during this period allowed small-scale fishermen to enhance the efficiency of their operations by purchasing better equipment and upgrading platforms to increase efficiency (i.e., larger gillnets, newer motors). Consistent demand and increased exports to U.S. markets also helped support increased landings during this period. Moreover, it is estimated that Mexico (principally the BCP) continues to supply 75% of the U.S. WSB market volume, with an estimated 400 mt imported annually at a mean value of $3.7 million dollars (data from 2014 to 2019, Table 5; CDFG, 2020).

2.4.2 Discrepancies and uncertainties associated with the landing's reconstruction

2.4.2.1 Discrepancies associated with the landing's reconstruction

Although it is difficult to identify the exact cause for discrepancies between data sources, similar inconsistencies have been described for other fisheries around the world (i.e., Chinese marine fisheries catch) based on changes in administrative reporting policies (Watson and Pauly, 2001). Additionally, it may be possible that FSYB statistics represent aggregate landings comprised of both WSB and other croakers (corvinas) that were marketed under the same label in response to the growing market demand for WSB during this period.

Because the OCLRs are comprised of the "raw" catch data obtained directly from landings slips, we consider the OCLR estimates to be more reliable than the FSYBs. Moreover, the OCLRs have recently been used to characterize other local fisheries in Mexico, such as the finfish fishery (Ojeda-Ruiz et al., 2018) and the serranid fisheries in Magdalena-Almejas Bay, BCS (Erauskin-Extramiana et al., 2017). In contrast, FSYB estimates are calculated based on other variables that may influence data quality such as the transfer of fishery information between management levels (i.e., from fishermen to fishery offices, from fishery offices to state offices, and from state offices to central offices) (Arreguín-Sanchez and Arcos Huitrón, 2007).

2.4.2.2 Uncertainty associated with each reconstructed period

The periods with the highest associated uncertainty (i.e., larger confidence intervals) primarily occurred when fishery office data were absent and only Corvina aggregate data were available. Meanwhile, the periods with reduced uncertainty (i.e., tighter confidence intervals) were mainly related to the presence of specific landing reports for WSB, detailed descriptions of WSB harvest in peer-reviewed, grey, and historical literature, and the existence of fishery office data (Berdegué, 1956; Cota-Nieto et al., 2018; Escobedo-Olvera, 2009; McCall et al., 1976). The rationale supporting reduced uncertainty in the early years of the reconstruction is based on studies by Berdegué (1956) which detailed species-specific catch information for the northwest coast of Mexico. This level of species-specific detail contrasts with subsequent years which reported on general aggregate landings data, which often lacked species-level information (FSYB).

Although this study used the best available information to reconstruct the historic landings of the WSB in Mexico, the methodology we used has been shown to be associated with the inconsistency and uncertainty of non-standardized data sources (Zeller et al., 2015). We evaluated the uncertainty of our reconstruction based on a scoring process to evaluate the quality of our time-series data and the methods used in each period (Zeller et al., 2016). Although Cisneros-Montemayor et al. (2013) highlighted a decrease in unreported Mexico landings, we did not standardize our data because a non-reporting ratio was unavailable for each period. Additionally, even though some studies have highlighted the importance of WSB in the recreational fisheries of Mexico (García-Rodríguez et al., 2013; Rodrigues-Medrano, 1993), landings data are not available for this sector of the fishery.

2.4.3 Official Catch Landings Data 2000-2019

The reconstruction efforts have identified the OCLR database to be the most accurate and useful for understanding regional trends in both effort as well as the volume of WSB landed. Although not perfect, these data do provide managers with baseline information that can be used to gauge economic importance and assess changes in relative volume landed by region and season. Our results are consistent with previous studies that also discuss the importance of the WSB as a fishery resource for local communities in BC and BCS (Romo-Curiel et al., 2015, 2016; Rosales-Casián et al,. 2003). From similar analyses of OCLR data, Ojeda-Ruiz et al. (2019) documented the continued reliance upon the WSB by fishers of the Magdalena-Almejas Bay region, and its importance in mitigating the social impacts of recent fishery closures to the Catarina clam *(Argopecten ventricosus)* fishery in 2012. They considered barred sand bass (*Paralabrax nebulifer*), ocean whitefish (*Caulolatilus princeps*), and WSB as the main species in the finfish fisheries along the BCP. Cota-Nieto et al. (2018) also reported the WSB to be a resource of great importance to the Punta Abreojos Fishing Cooperative, as it represents the fourth highest revenue source, just below the spiny lobster (*Panulirus interruptus*), abalone (Haliotis spp.), and verdillo (*P. nebulifer*).

With the information estimated in this study and the lack of any formal stock assessment, it is not possible to determine the current status of the WSB fishery in Mexico. Continuous monitoring of landings and additional fishery information (e.g., comprehensive effort information, length-frequency data) are needed to better understand predictors of stock status.

2.4.4 Regional trends

From a total harvest perspective, it is notable that the Mexican fishery has shown a steady increase in landings over the past 20 years, reaching its peak in 2016 (Fig. 7). The majority of WSB harvest has come from BCS (~84% mean from 2000 to 2019), with landings concentrated primarily in the regions of Ciudad Constitución, Punta Abreojos and San Carlos (OCLR data, Fig. 5). Meanwhile, fisheries from BC more closely resemble those off California, with a peak in 2007 and relatively suppressed landings and effort since 2008 (Fig. 6a). California WSB landings have also been shown to be in decline since 2008 with spawning stock biomass estimated at just 24% of the historical level (Valero and Waterhouse, 2016). Although the lack of information for Mexican fisheries precludes our understanding of the current regional status, several factors may contribute to the differences observed in landings volume and effort trends between BC and BCS. It is possible that the fisheries across BC and BCS target different WSB stocks that vary in terms of their current population status. Based on historic landings data from California (CA) gillnet vessels fishing along the BCP prior to the closure of Mexican waters to U.S. vessels in 1982, fishers would travel to the waters of BCS to capitalize on the abundant WSB resource during periods of reduced WSB availability along CA (Vojkavich and Reed, 1983; Valero and Waterhouse, 2016). It has been suggested through tagging, genetics, and age-growth studies that more than one putative stock may exist along the BCP (Romo-Curiel et al., 2015; Franklin et al., 2016; Aalbers et al., 2021). Based on electronic tagging data, it has been proposed that California WSB seasonally extend into northern Baja with limited movements below Punta Eugenia (the border between BC and BCS).

It must also be considered that BCS has a larger fishing community than BC (60 fishing communities vs. 44; Ramírez-Amaro et al., 2013), which could also partially explain the higher estimated effort (greater number of vessels) and landings within the BCS region (Fig. 6a). Estimates in the level of effort and CPUE may also be functionally different between regions given the use of hydraulic-powered net spools by some of the small-scale vessels within the larger BCS fishing communities (San Juanico and Vizcaíno Bay; Table 4). Moreover, the highest BCS landings were concentrated in traditionally productive fishing grounds (such as Magdalena-Almejas Bay, Ulloa gulf, and Vizcaíno Bay), which have also been associated with higher landings of the giant sea bass (*Stereolepis gigas*; Rámirez Valdez et al., 2021). Productive inshore areas of Vizcaíno Bay and San Juanico Bay, BCS were also identified to have the highest concentrations of WSB larvae during the months of May-August (Moser et al., 1983). Nonetheless, further investigation on the differences between the two regions is needed to better understand the fishery dynamics and management needs of the Mexican WSB fishery.

2.4.5 Seasonal trends

Our study estimated that the highest seasonal landings occurred in the summer months of June and July, matching the spawning season described for WSB (Aalbers, 2008; Aalbers and Sepulveda, 2012). Similar seasonal patterns have also been reported for WSB along CA, suggesting that the resource is most vulnerable to exploitation during the spawning season across its entire range. Given that the seasonality of peak harvest is similar in CA, BC and BCS, it may be that regional fisheries rely upon different segments of the spawning stock rather than the same population being harvested across all three regions. Elevated landings are commonly observed for various serranid species in Magdalena-Almejas Bay, BCS, during the spawning season (Erauskin-Extramiana et al., 2017) and groupers in the Gulf of California (Erisman et al., 2007). Although fish spawning aggregations have been identified as highly vulnerable to overfishing, certain species may be harvested sustainably when managed properly (Erisman et al., 2014).

Similar to the CA fishery, commercial operations along the BCP target WSB at different depths depending on the season, using gillnets either suspended from the surface or set along the bottom. Electronic tag data has shown that WSB occurred shallower during the spring and summer spawning season and at deeper depths between October and March (Aalbers et al., 2021). Commercial fishers along BC and BCS seasonally adapt their gear to either drift near the surface at night or to target fish along the ocean floor using demersal gillnets (Cartamil et al., 2011; García-Rodríguez and Sosa-Nishizaki, 2020). Unlike CA, which has implemented a seasonal ban on WSB, Mexican fisheries can target this species year-round. However, the WSB could be incidentally favored in its protection along the west coast of the BCP during the winter and spring months from an umbrella effect due to more valuable fishery resources being harvested in this season, such as the lobster and abalone, decreasing the fishing effort for finfish resources (Briones-Fourzán and Lozano-Álvarez, 2000; Cota-Nieto et al., 2018).

Nonetheless, given recent increases in effort and advancements in gear along BCS (i.e., hydraulics and larger nets), additional resources and monitoring efforts may be needed to estimate the stock status and prevent the decline in WSB landings previously observed off CA. Because the small-scale fishery registers the highest landings of WSB, it is necessary to enhance the importance of the communities associated with this fishery in managing the species (McCay et al., 2014). Several studies have demonstrated that co-management and participatory management of those communities are key components to achieving economic and ecological sustainability (Gutierrez et al., 2011; Finkbeiner and Basurto, 2015).

2.4.6 Trends in CPUE

The CPUE estimates generated in this study offer insight into the fishery dynamics of the region, but should also be viewed with caution, as several relevant factors (i.e., fleet efficiency and environmental factors) were not accounted for (Maunder et al., 2006). Moreover, the landing slips that constituted the primary tool for developing OCLRs were compiled on a weekly or monthly basis and did not reflect daily effort or catch, and the unit of effort may not be directly associated with the fishing operation (i.e., number of vessels or days fished). Other limitations and inconsistencies, such as the aggregation of taxa under a single common name (i.e., corvina complex) and missing information in required data fields often presented constraints to generating accurate CPUE estimates. Discrepancies in vessel operations and fishing gear, such as the number and size of the nets deployed, the size of the gillnet mesh and whether the gillnet was hand-pulled or mechanized may also influence CPUE estimates.

In a previous study, Cota-Nieto et al. (2008) proposed a decreasing trend in the CPUE for the white seabass for the Punta Abreojos Fishing Cooperative between 2001-2007 contrasted by an increasing trend from 2007 to 2013. Although Cota-Nieto et al. (2008) also reported a large decline in effort (less than 500 trips) for WSB in 2007, this period was also characterized by increased effort and landings of lobster and abalone, two species with higher market value than the WSB. The effort shift reported by Cota-Nieto et al. (2008) is likely responsible for some of the changes in effort and landings reported for WSB in different areas along the BCP. From interviews and through the efforts data, it has become evident that most WSB fishers are portfolio fishermen that often change target depending upon availability and market price. Cota-Nieto et al. (2008) reported similar harvest trends during this period for other fin-fish resources [i.e., yellowtail (*Seriola lalandi*), whitefish (*Caulolatilus princeps*), California halibut (*Paralichthys californicus*) and speckled flounder (*Paralichthys woolmani*)]. Thus, the CPUE fluctuations observed in this study likely include regional variation and should be viewed from a general perspective rather than a year-to-year basis.

More detailed information is needed to address the lack of information in the OCLR and estimate a more reliable CPUE to be used in a stock assessment. The reliability of fishery-dependent CPUE estimates depends on the descriptions of fishing gear (i.e., mesh size of nets, length of nets), fishing power (i.e., size of boats, type of net retrieval, whether manual or mechanical), and effective fishing effort (i.e., soak times) associated with catches. A fraction of the catches related to accurate fishing effort helps estimate relative abundance indices that can be compared between regions, boats, and cooperatives. More accurate information on fishing efforts may result from conducting fishery-independent data collections or more thorough examinations of select logbooks obtained from Fishing Cooperatives. For example, the study conducted by Cota-Nieto et al. (2018) used information from the Punta Abreojos Fishing Cooperative to estimate a WSB CPUE based on the catch and the number of boat trips. In addition to more reliable CPUE estimates, information related to the length composition of the catches, coupled with additional biological information (i.e., size at maturity), may allow for a better determination of appropriate size limits and fishing gear restrictions. Future work aimed at filling critical data gaps may allow for improved species-specific management strategies as well as co-management efforts with the U.S.

2.4.7 Management implications

Several studies have discussed the importance of bi-national management for ensuring the sustainability of transboundary resources (Sumaila et al., 2020; Palacios-Abrantes et al., 2020; Ramírez-Valdez et al., 2021). However, it is important to reduce data inconsistencies across borders to better achieve this goal.

Indices of relative abundance, such as CPUE, size, and age composition data, coupled with life-history parameters, could be helpful to define spatial distributions and delineate stock boundaries (Begg, 2005; McBride, 2014). Furthermore, specific information from fishery reporting areas could be used indirectly to better define putative stocks (Cadrin, 2020; Halliday and Pinhorn, 1990), or at least reveal the spatial structure of the population based on fishery dynamics. For example, three stocks of silver kob, *Argyrosomus inodorus*, were identified by regional differences in catch records, life history parameters, and CPUE estimates along the South African coastline (Griffiths, 1997). Likewise, Ames (2004) used an interdisciplinary approach to define the stock structure of Atlantic cod by combining fishing records and fishermen interviews. Although variations in fishing effort could mask landings volumes, there is a significant difference between landings volumes of BC and BCS from 2000 to 2019. Differences in the volume of WSB landings between the northern and the southern regions, along with differences in life-history traits (Romo-Curiel et al., 2015), environmental conditions (Romo-Curiel et al., 2016), genetic analysis (Franklin et al., 2016), and tagging data (Aalbers et al., 2021), all suggest limited movements between BC and BCS.

Also, several studies indicate the importance of bi-national management for transboundary resources to maximize fishery sustainability (Sumaila et al., 2020; Palacios-Abrantes et al., 2020; Ramirez-Valdez et al., 2021). However, it is important to reduce data inconsistencies across borders to achieve this goal better, especially if it is necessary to assess the stock by pooling the data. For example, Ramirez-Valdez et al. (2021) highlighted the asymmetry in management and the research information between the U.S and Mexico for the giant seabass (*Stereolepis gigas*) that resulted in a biased view of the population status. Moreover, it emphasized the importance of a continually developing process of new information to comprehend transboundary marine resource connectivity, distribution, and stock structure for effective management in both countries.

Chapter 3. Size-at-maturity estimation of white seabass, *Atractoscion nobilis*, in southern Baja California Peninsula region with updates on its larvae distribution in Mexican waters

3.1 Introduction

Understanding the reproductive life history parameters (i.e., reproduction, spawning, and size-at-maturity) of fishes provides fundamental information necessary for effective management (Begg, 2005). Collectively, these data help us understand the biological mechanisms that contribute to maintaining stock dynamics of a species (Begg, 2005; Begg and Waldman, 1999). Biologically, the definition of a fish stock is that they are self-reproducing or reproductively isolated units; members of each putative stock exhibit similar life history parameters (Begg, 2005; Hilborn and Walters, 1992). The size at first maturity is an important life history metric for stock identification since it is heritable, responsive to selection, and closely corresponds with the population growth rate (Swain et al., 2005). Moreover, early life stages and their distribution can also help differentiate among stocks as they can be used to indicate the spatial distribution of spawning. Spawning represents the beginning of larval dispersal and places offspring within a particular advective and dispersive flow field, which is crucial in determining the transport outcome and ensuring the arrival of offspring to appropriate juvenile habitats (Hare and Richardson, 2014).

The white seabass (*Atractoscion nobilis*, WSB) is the largest member of the family Scianidae in the Northeastern Pacific, reaching 160 cm in total length (TL) and more than 40 kg. Its distribution ranges from central California, U.S., to southern Baja California Peninsula region (SBCP) and within the north of the Gulf of California, Mexico. In warmer periods, it has been harvested up to Alaska, U.S. (Thomas, 1968). The WSB is an important transboundary fishery resource exploited in both countries (Fajardo-Yamamoto et al., 2022; Vojkovich & Reed, 1983). The California commercial fishery has relied upon this resource since the early 1900s, both in U.S. and Mexican waters, until 1982, when the Economic Exclusive Zone was enacted (Vojkovich & Reed, 1983). Based on the landing's fluctuations, California state managers have enacted several fishery regulations that started in the 1930s', which include bag limits, gears restrictions, a minimum size limit of 71 cm in TL, and a seasonal fishing ban on commercial harvest (Valero & Waterhouse, 2016; Vojkovich & Reed, 1983). The Mexican commercial fishery has been harvesting the WSB since the late 1940s', and in the past 20 years, regional differences in landings volumes between Baja California and Baja California Sur states have been pronounced (Fajardo-Yamamoto et al., 2022).

Several biological studies have contributed to our understanding of WSB stock structure along its Pacific distribution and a study in the Gulf of California has proposed that there is a different genetic population within the Sea of Cortez (Franklin et al., 2016). Based on otolith growth rate parameters, Romo-Curiel et al. (2015) found regional differences in the first year of life between individuals from California and SBCP region, likely due to the distinct oceanographic conditions of the two regions. Furthermore, the isotopic analysis of the first otolith growth ring also confirmed that the WSB collected off California experienced different environmental conditions than those reared in southern Baja California (Romo-Curiel et al., 2016). Both studies suggested a two-stock hypothesis along the Pacific WSB distribution; with a stock boundary around Punta Eugenia, which is considered a transitional area in the California Current System and forms two biogeographical regions due to seasonal shifts in upwelling intensity and variation in the direction and intensity of coastal currents (Durazo, 2015).

Reproductive studies on WSB have determined that the spawning season is from March to September, with a peak in late spring and early summer when seasonal spawning aggregations form along nearshore islands and shallow coastal waters (Aalbers, 2008; Aalbers & Sepulveda, 2012; Moser et al., 1983). Based on the macroscopic classification of gonads, two studies have provided data on the size-at-maturity of WSB (Clark, 1930; Valero & Waterhouse, 2016). Clark (1930) estimated the sexual maturity of WSB from individuals collected in the local fish market of San Pedro, California and determined that 50% of the females mature at less than 70 cm in TL and that 50% of the males mature at 60 cm in TL. It is worth mentioning that the author recognized a high degree of uncertainty in his data and that these data were obtained as a reference point for legislative purposes. Valero & Waterhouse (2016) reported newer parameters based on an ongoing study performed at the Pfleger Institute of Environmental Research (PIER). The PIER study examined 77 females and 20 males that were collected in California between 2007 and 2015 to determine size-at-maturity. They found that 50% of the females mature at 86 cm TL, while 50% of the males matured at 68 cm TL, findings that do not directly align with the Clark work (1930). Although these past studies offer important insight, additional histological analyses are needed to provide a more accurate estimation of the gonad developmental stages and avoid misinterpretation of maturity stages (Domínguez-Petit et al., 2017).

In addition to gonadal development work, studies on WSB larval and juvenile distributions are needed to better understand reproductive dynamics. Based on an ichthyoplankton collection study performed by the

California Cooperative Oceanic Fisheries Investigation (CalCOFI), Moser et al. (1983) identified the presence of different larval stages of WSB in 104 ichthyoplankton samples from tows made during 1950-1978. They found that 15% of the larvae occurred in the samples from southern California, while the remaining 85% occurred along the west coast of the Baja California Peninsula, with 50% north and 35% south of Punta Eugenia. The highest WSB larval abundances was reported in the coastal areas of Sebastian Vizcaino Bay and San Juanico Bay. WSB's nursery areas for young-of-the-year (YOY) have been suggested in different locations, including the Channel Islands, coastal areas of the Southern California Bight and within San Diego Bay (Allen & Franklin, 1988; Donohoe, 1997).

Since former WSB size-at-maturity estimates lack microscopically classification, no information of size-at-maturity has been estimated for the SBCP region and from 1983 there is no recent reported information in WSB larvae distribution in Mexican waters. This study aims to estimate macroscopically and microscopically the size-at-maturity of WSB SBCP region and compare it with maturity estimates from California. Moreover, we update the WSB larvae distribution in Mexican waters to determine if changes occurred from previous studies.

3.2 Methods

3.2.1 Study area and samples collection

This study was conducted at the fishing camp of San Juanico, belonging to the Baja California Sur Mexican state (Fig. 1), which is part of the SBCP region. All fish were obtained from the local small-scale commercial fishery, which is composed of small (5-10m) outboard fishing vessels, using set gillnets within 5 to 20 km offshore.

White seabass samples were collected in 2018, 2019, and 2021. Collection occurred on the first days of June of each year when directed commercial fishing commonly starts and when the white seabass is known to be aggregating for reproductive purposes (Aalbers and Drawbridge, 2008; Aalbers and Sepulveda, 2015). The date, total length (TL), total weight (TW), and dressed weight (DW) of each fish were recorded to the nearest centimeter and 0.1 kilograms, respectively. Gonad samples were removed from individuals and weighted on a digital weighting balance to the nearest gram.

3.2.2 Classification of maturity phases and histology process

All gonads were macroscopically classified according to Brown-Peterson et al. (2011) and the previous length-at-first maturity study for WSB (Clark, 1930; Valero and Waterhouse, 2016). A subsample of individuals ranging in size between 55 to 90 cm were also microscopically classified. A mid-transverse slide (~4 cm) of each ovary and testis were preserved in 10% buffered formalin and sent to an independent laboratory for histological preparation. These samples were dehydrated, embedded in paraffin wax, thin-sectioned, stained with hematoxylin-eosin (HE), and mounted on microscope slides for analysis. Examination of the gonad slides was carried out using a compound microscope at 40-100x. Brown-Peterson et al. (2011) criteria for classifying maturity phases were used to identify the gonadal maturation and oocyte and spermatocyte development phases.

Female and male histological slides were examined to identify the most advanced oocyte and spermatocyte development phases. We examined the oocyte development phases as chromatin nuclear (CN), perinucleolar (PN), cortical alveolar (CA), primary growth (PG), primary vitellogenic (Vtg1) secondary vitellogenic (Vtg2), tertiary vitellogenic (Vtg3) and Postovulatory follicle complex (POF). Furthermore, for male histological slides, we examined the following spermatocyte development: Spermatogonia (Sg), Spermatocyte (Sc), Spermatid (St), and Spermatozoa (Sz).

Based on the macroscopic and microscopic classification, we labeled female and male individuals as immature, developing, and spawning capable. Therefore, we considered mature samples classified as developing and spawning capable phases.

3.2.3 Maturity estimation

A macroscopic and microscopic female and male maturity were estimated for the SBCP region white seabass. We estimated the maturity at size using a logistic regression model:

$$P_L = \frac{1}{(1 + e^{-(\beta_0 + \beta_1 L)})} \tag{1}$$

Where PL is the proportion of mature individuals at size, L. β_0 and β_1 are the intercept and slope of the logistic regression model. The size at 50% maturity (L) was calculated as follows:

$$L_{50} = -\frac{\beta_0}{\beta_1} \tag{2}$$

All models fitted a logistic regression using the GLM function with a binomial distribution and a logit link function. Models were programmed using the R software (version 4.2.1).

3.2.4 Regional comparisons

The size at maturity by region was analyzed by comparing the maturity ogives. For California, we used data provided by PIER (unpublished data and based on macroscopic classification) and parameters of the maturity estimates published by Clark (1930). Moreover, following Ogle (2015), we performed an analysis of deviance to test if the slopes of the logistic regression models differ by region. We used the *ANOVA* function from the *car* (version 3.0.13) R library.

3.2.5 Larvae distribution in Mexican waters

White seabass larvae distribution in Mexican waters was obtained from the Mexican Monitoring Program of the California Current (IMECOCAL, for its Spanish acronym) ichthyoplankton collection from 1998, 2000, 2002, 2005, 2010, 2011, and 2014. Following Jimenez-Rosenberg et al. (2007), fish larvae were standardized to 10 m^2. For a more detailed description of the IMECOCAL ichthyoplankton collection, refer to Jiménez-Rosenberg et al. (2007); Jiménez-Rosenberg et al. (2010); and Aceves-Medina et al. (2019).

3.3 Results

3.3.1 Samples collection

A total of 132 WSB were collected, of which 37% (n=49) were females and 63% (n=83) males (Fig. 2). The overall size distribution was composed of individuals between 49 cm and 128 cm in TL (Females range: 49.5-128 cm in TL, males' range: from 49-117.9 cm in TL). The most abundant size groups were between 81 and 90 cm LT (Fig. 8). A subsample of 50 individuals were microscopically classified, of which 27 were females and 23 were males.

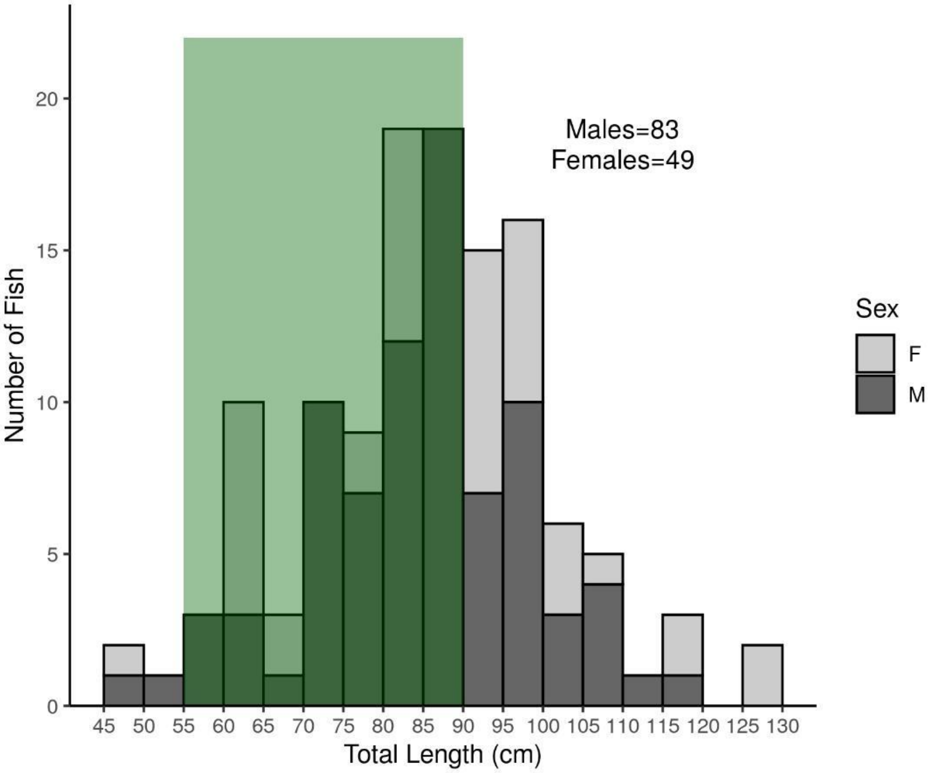

Figure 8. Length frequency distribution for white seabass collected in San Juanico, B.C.S. Grey bars denote the number of females, and black bars indicate the number of males. The green shaded box shows the lengths of the subsamples that were histologically classified.

3.3.2 Maturity phases classification

Based on macroscopic and microscopic classifications, white seabass females were classified in two maturity phases: immature (n=10) and mature (developing, n=3; spawning capable, n=36). Meanwhile, we distinguished for white seabass males: immature (n=2) and mature (developing n=5; spawning capable, n=76) phases.

For female histological slides, we distinguished an immature phase by the presence of only CN, CA, and PG (Fig. 9a). Meanwhile, we microscopically characterized as mature the developing (Fig. 9b) and spawning capable (Fig. 9c) phases. Both phases have the presence of CN, CA, PG, Vtg1, and Vtg2. However, the main difference between the developing and spawning capable stages is the presence of Vtg3 and POFs in the latter phase (Fig. 9b and 9c). Moreover, for the male histological slides, we only distinguished developing (Fig. 9d) and spawning capable (Fig. 9e) phases, which were considered mature. Sg, Sc, and Sz determine the developing stage in white seabass males. Meanwhile, the presence of Sz in the lumen distinguished the spawning capable from the developing phase.

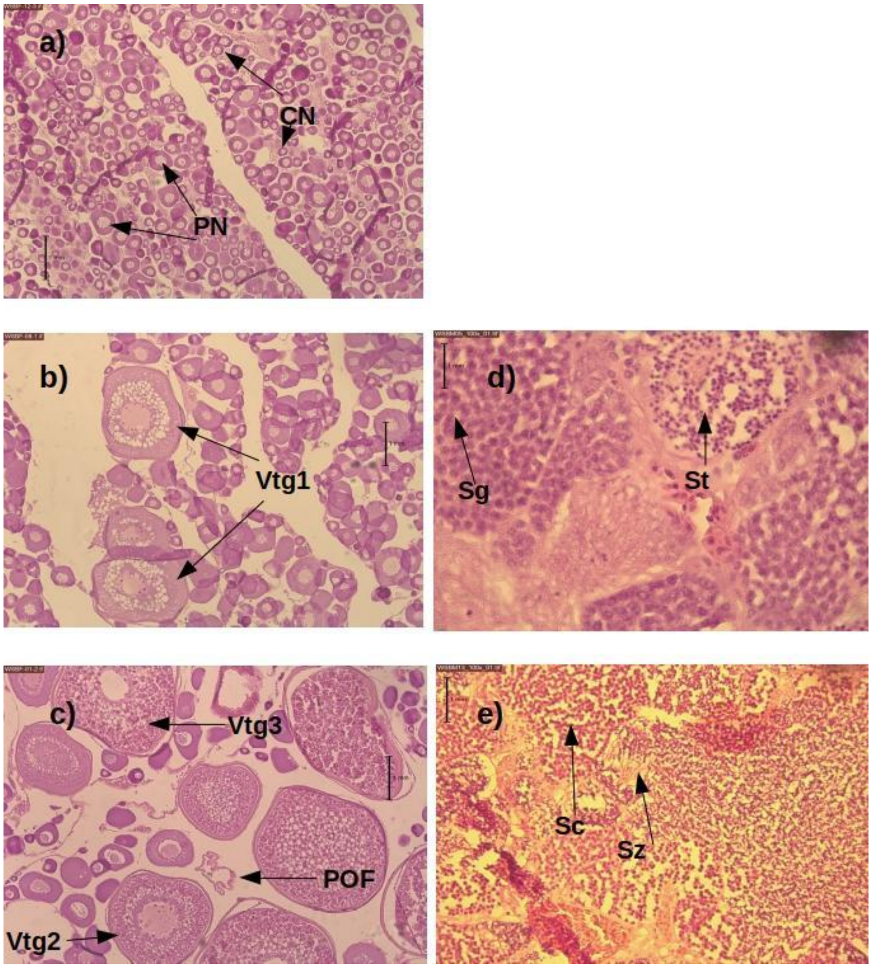

Figure 9. Images of histological slides (40x and 100x) depicting the most advanced oocyte (a, b, c) and spermatocyte (d, e) stages. Phases are identified based on the presence of distinct oocyte or spermatocyte development: a) Immature phase (CN=chromatin nuclear, PN=Perinucleolar), b) Developing phase (Vtg1=Early vitellogenic), c) Spawning capable (Vtg2=Late vitellogenic, Vtg3=Full grown vitellogenic, POF=Post-Ovulatory Follicle), d) Developing phase (Sg=Spermatogonia, St=Spermatocyte) and, e) Spawning capable (Sc=spermatocyte, Sz=Spermatozoa).

3.3.3 Maturity estimation

The size (TL, cm) at which 50% of females reached maturity was 72.71 cm (Fig. 10). All females reached maturity at 73.45 cm.

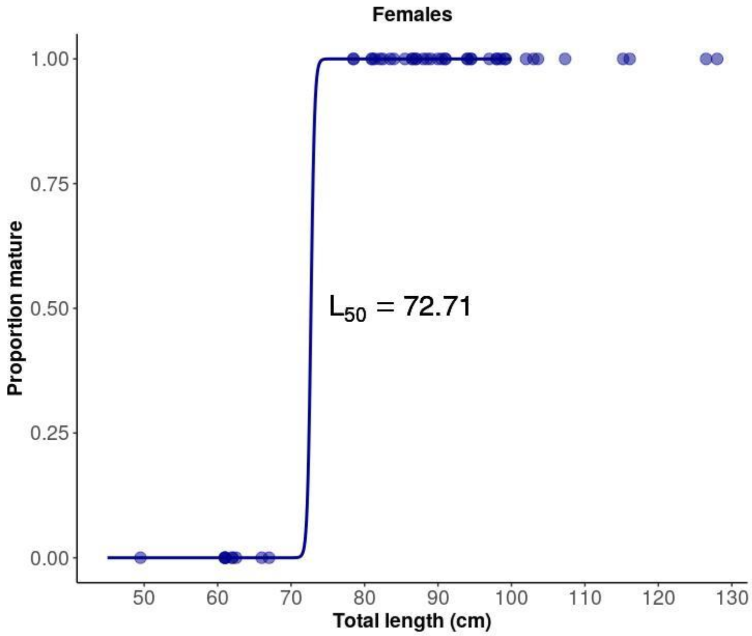

Figure 10. Ogive for size of maturity for white seabass females. Size at first maturity by total length (cm).

Meanwhile, the size (TL, cm) of the males at which 50% of samples reached maturity was estimated as 58 cm (Fig.11). All males reached maturity at 58.35 cm.

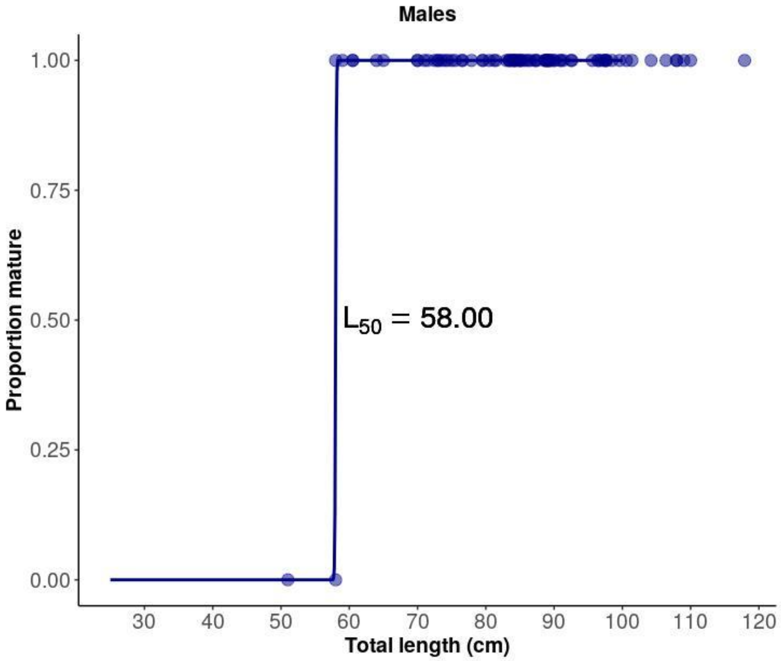

Figure 11 Ogive for size of maturity for white seabass males. Size at first maturity by total length (cm).

White seabass females from the SBCP region mature at a smaller size (L_{50}=72.71 cm) than the females from the California (L_{50}=75.65) (Fig. 12). Furthermore, the results from the deviance analysis suggested that the slopes from the SBCP region and California have significantly different slope values (χ^2=43.06, p<0.001). However, when we compared our maturity results against Clark's (1930) estimates, the females from the SBCP region matured at a larger size than those from Clark (1930) (L_{50}=69.33 cm, Fig. 12). Nonetheless, when we compare the maturity estimate slopes from the SBCP region and Clark (1930), the deviance analysis suggested no significant difference (χ^2 =3.52, p=0.06).

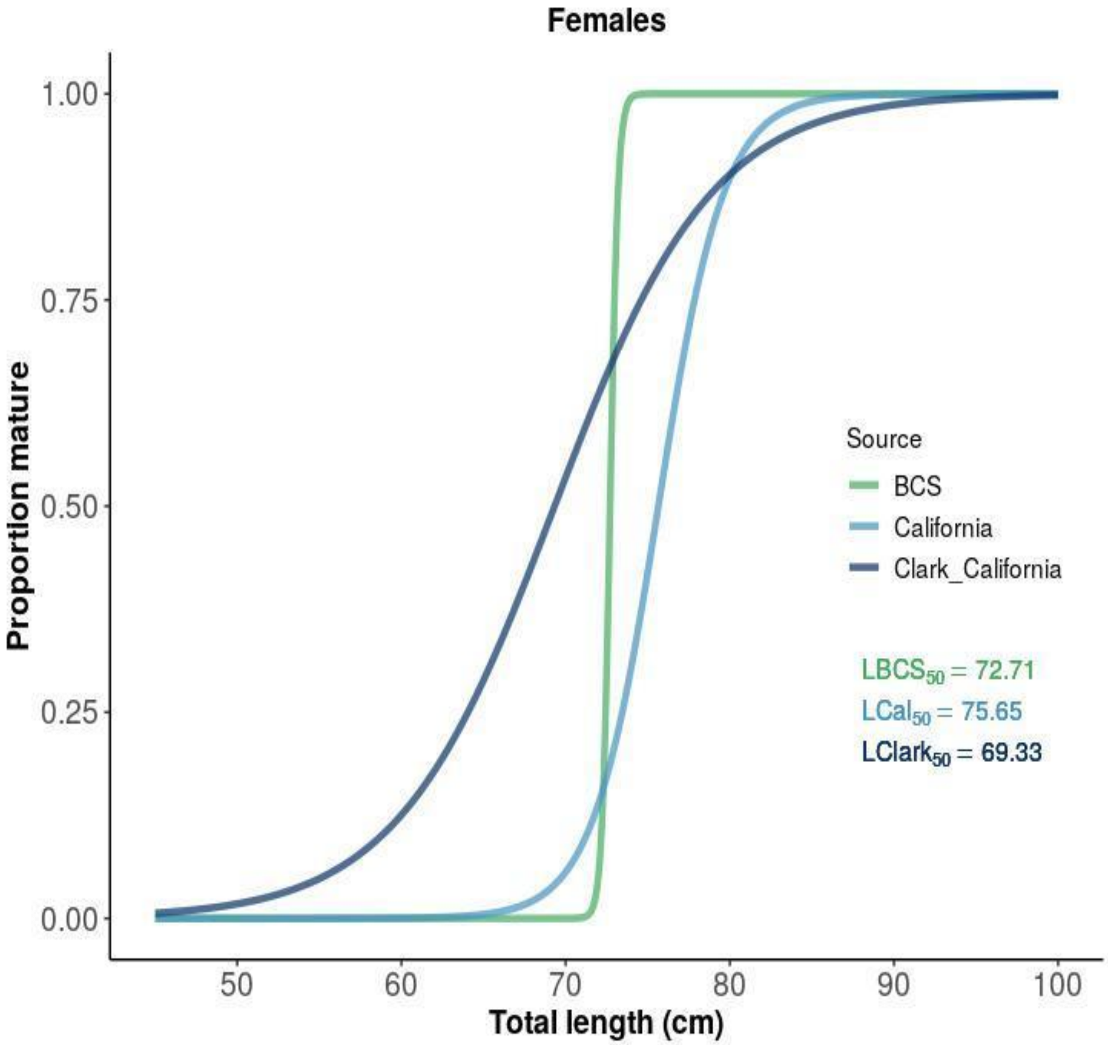

Figure 12. Maturity ogives for northern (California and Clark) and southern (BCS) white seabass females**.**

White seabass males from the SBCP region mature at a smaller size (L_{50}=58 cm) than the males from the north (California, L_{50}=75.01) (Fig. 13). Furthermore, the results from the deviance analysis suggested that the slopes from the SBCP region and the north have significantly different slope values (χ^2 =12.67, p<0.001).

Likewise, when we compared our maturity results against Clark's (1930) estimates, the males from the SBCP region matured at a smaller size than those from Clark (1930) (L_{50} =58.57 cm, Fig. 13). Nonetheless, when we compare the maturity estimate slopes from the SBCP region and Clark (1930), the deviance analysis suggested no significant difference (χ^2 =3.59, p=0.06).

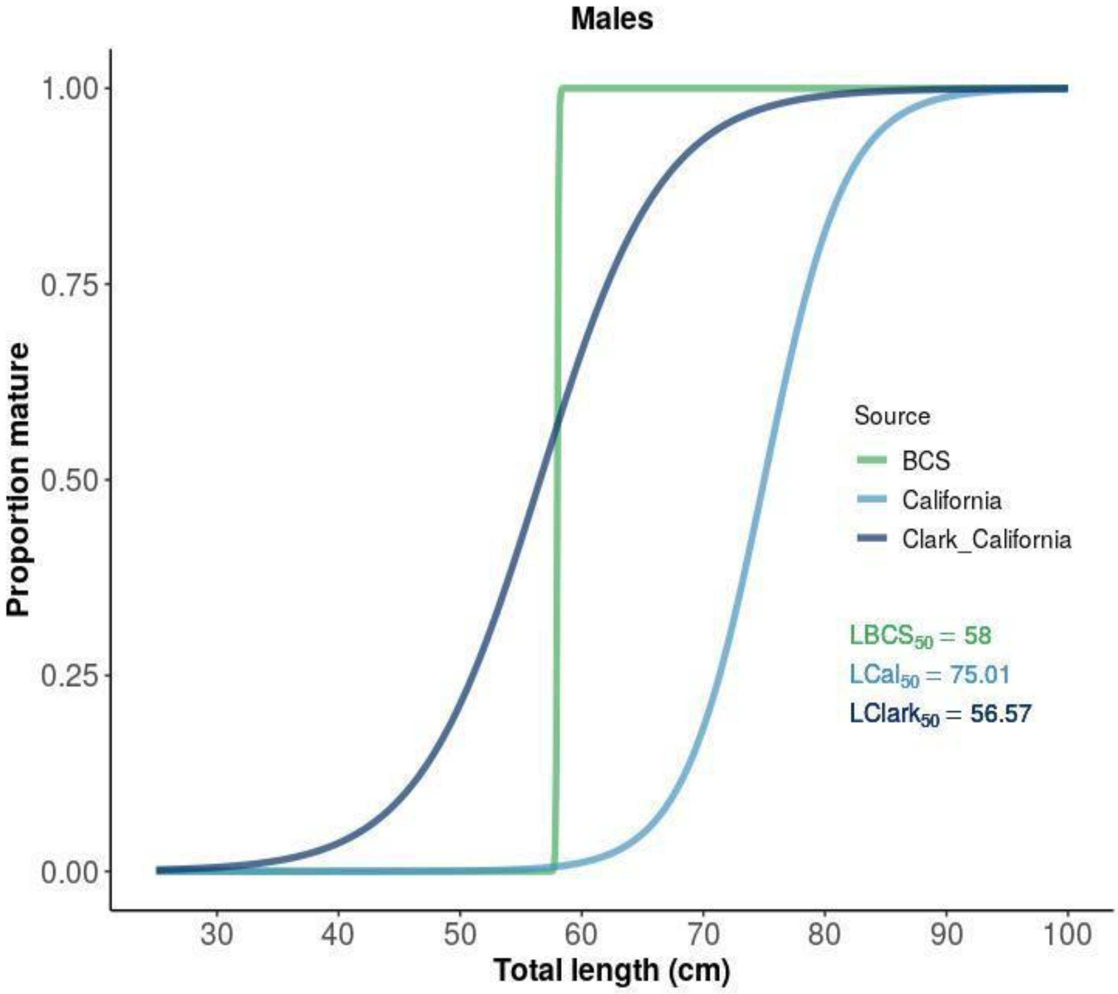

Figure 13. Maturity ogives for northern (California and Clark) and southern (BCS) white seabass females.

3.3.4 White seabass larvae distribution in Mexican waters

Of the eight records of white seabass larvae distribution recorded in the IMECOCAL ichthyoplankton collection, six were recorded in July, with the remaining two recorded in January and April. High concentrations of white seabass larvae were found in the adjacent waters of the Baja California state (Fig. 14). The regions between Ensenada and San Quintin and Sebastian Vizcaino Bay area concentrated the highest abundances for WSB larvae with ~50% and ~35%, respectively. The highest abundance of WSB larvae estimation was ~10 larvae/m^{2,} and the lowest was ~3 larvae/m^2.

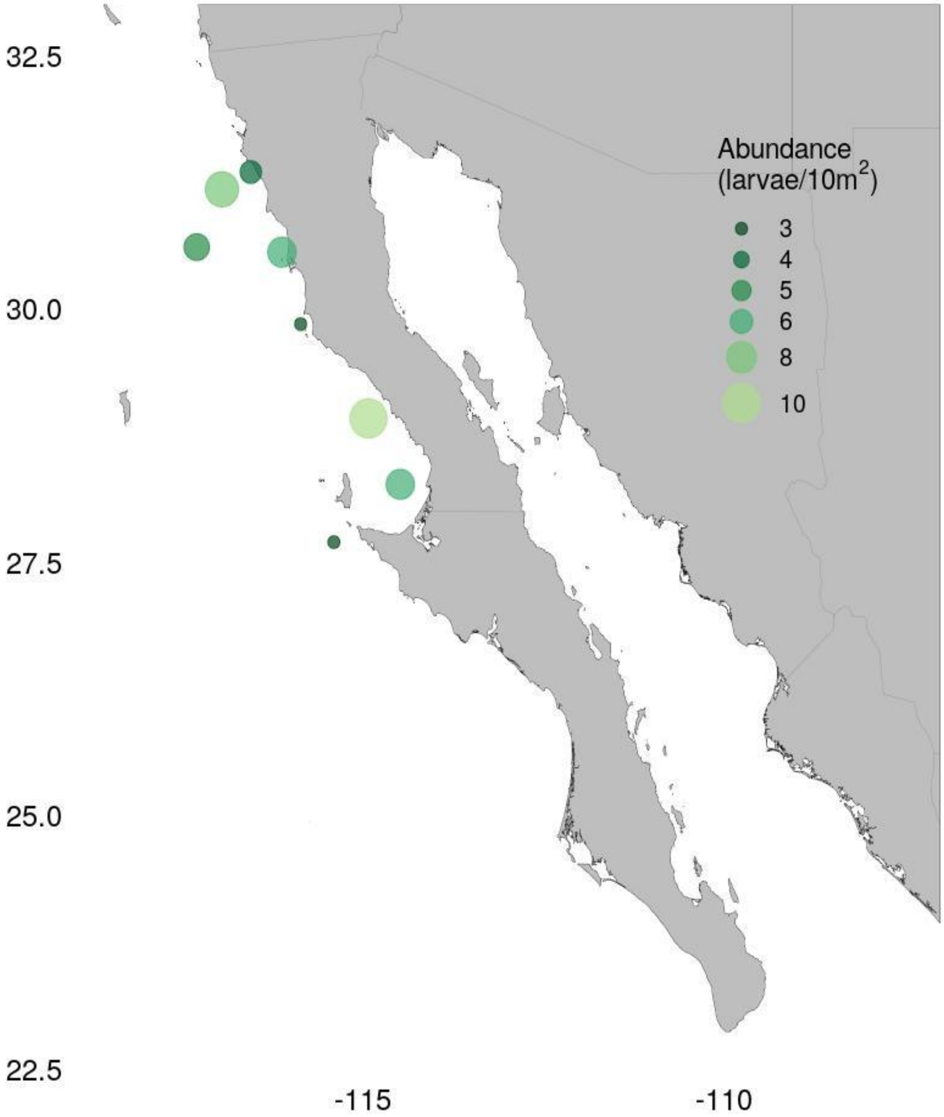

Figure 14. White seabass larvae distribution from IMECOCAL ichthyological collection.

3.4 Discussion

In this study, we used both macro and microscopic observations to estimate the size at maturity of the WSB in the SBCP region. In this region, sampling for reproduction studies had been lacking and our results suggest differences between individuals captured in the northern part of its distribution (California). Also, we provide an update on the larvae distribution of the WSB information along the west coast of the Baja

California Peninsula. These data allow us to better understand reproductive dynamics of this valuable resource.

3.4.1 Female and male reproductive classification

We considered microscopic classification of WSB female gonads essential because it exposes gamete development not identifiable macroscopically. Based on the presence of asynchronous oocyte development, we support the idea that the WSB is an indeterminate multiple-batch spawner (Aalbers & Drawbridge, 2008; Gruenthal & Drawbridge, 2012). Moreover, the WSB has asynchronous ovarian development since the most advanced oocyte stage concurs with previous oocyte stages' development regardless reproductive phase (Lesyna and Barnes, 2016; Murua and Saborido-Rey, 2003).

The microscopic and macroscopic maturity classification for WSB males had the same result, allowing us to assert that maturity curves may be estimated without a histology process. Therefore, maturation of male WSB could be determined in the field based on the presence of milt in the sperm duct. Moreover, our results align with the findings of other species, such as the California halibut (*Paralichtys californicus*; Lesyna and Barnes, 2016) and Gulf corvina (*Cynoscion othonopterus*; Gherard et al., 2013).

3.4.2 Importance of our maturity at length estimation

Our study is the first to estimate the size-at-maturity of WSB males and females for the SBCP region. When we compared our results against those published in the 1930s by Clark (1930), we did not find significant differences between our estimates and theirs. We considered two reasons for these non-significant differences: the first one, Clark (1930) did not state where the samples came from, and by the time the study was undergoing the California WSB fishery used to harvest in Mexican waters (Croker, 1932), the study could have estimated the size-at-maturity of organisms from its southern distribution off the Baja California Peninsula. Moreover, the second reason could be related to the fact that Clark (1930) only estimated the maturity phases macroscopically, which could under or overestimate the results.

Significant differences were found between the 50% size at maturity from WSB females and males of SBCP compared to those of California. These differences might be related to WSB from California and SBCP experiencing different oceanographic conditions when reared. Following the "temperature-size rule"

(Atkinson, 1994), where ectotherms organisms are suggested to reach maturity at a smaller size in warmer environments, WSB from SBCP were reared in warmer conditions than those from California, as shown by Romo-Curiel et al. (2016). Moreover, Romo-Curiel et al. (2015) determined that WSB from SBCP grew faster in the first year of life than in California. These differences are associated with warmer temperatures experienced from the WSB in the SBCP region.

Along the west coast of the Baja California Peninsula, a geographic break occurs in waters around Punta Eugenia which produces two distinct biogeographic provinces with differences in seasonal oceanographic features (Durazo, 2015; Ramírez-Valdez et al., 2015). The differences between these biogeographic regions are more apparent in summer and autumn. The northern part is influenced by subarctic waters characterized by colder temperatures, lower salinity, higher oxygen content, and upwelling persistence (Durazo et al., 2010). Two climatic regimes characterized the southern region: the warm and cold. The presence of subtropical and tropical surface waters indicates the warm regime. Meanwhile, the cold regime strengthens the intensity of seasonal winds and coastal upwelling events during the winter and spring (Durazo et al., 2010). These seasonal oceanographic conditions might be responsible for the differences in size-at-maturity of WSB from SBCP and California.

Reproductive life history parameters are crucial for understanding the biological characteristics that influence the stock structure (Begg, 2005). These parameters offer valuable insights into the mechanisms that maintain stock integrity and are fundamental in defining the fish stock's productivity (Begg, 2005; Begg & Waldman, 1999). The results shown in this study strengthen the hypothesis of two stocks of WSB along its Pacific distribution. Latitudinal variations in size-at-maturity, as determined in this study, have also been reported for the Dover sole (*Microstomus pacificus;* Abookire and Macewicz, 2003), the winter flounder (*Pseudopleuronectes americanus;* McBride, et al., 2013), and the California halibut (P*aralichthys californicu*s; Lesyna and Barnes, 2016).

3.4.3 Methods, biases, and improvements

Estimating size-at maturity based on a macroscopic and microscopic maturity classification relies on spatial and temporal sampling coverage, where spawning season and spawning location should be known (Domínguez-Petit et al., 2017; Murua & Saborido-Rey, 2003). However, when collections are fisheries-dependent there is the potential of being biased towards those commercial selective sizes, which can cause biases in maturity estimates (Domínguez-Petit et al., 2017; Hilborn & Walters, 1992). Preferably, maturity estimates should include a good representation of fish of various sizes (Domínguez-Petit et al., 2017).

Our sampling design provided only a snapshot of reproductive activity. Moreover, our sampling was fisheries-dependent, which produces a bias resulting mainly by the lack of immature WSB individuals in the collection. This is likely due to the size of the net used, the limited sampling time window, and the collection efforts, and because the collection efforts were performed in known aggregation areas. Gonad samples were taken in the first days of June of all three years which could indicated us that the WSB has a regularity of its spawning season. The regularity of the spawning season has been described for other marine fish species such as the Pacific sockeye salmon (*Oncorhyncus nerka*), the Norwegian herring (*Clupea harengus*), the North Sea plaice (*Pleuronectes platessa*) and Artic cod (*Gadus morhua*, Cushing, 1969).

However, because this study was focused on assessing size at maturity, the work targeted individuals who were either mature or approaching maturity. From this study, we can now narrow the range of sizes at which future studies should focus and sustain the importance of sampling during the spawning season. Moreover, our results set the baseline of size-at-maturity estimates of WSB from the SBCP region.

3.4.4 1994-2014 larvae distribution vs Moser et al. (1983) larvae distribution

WSB larvae occurred in only eight IMECOCAL tow stations from 1998 to 2014. All WSB larvae samples were collected in July, which matches the peak of the WSB spawning season (Aalbers, 2008; Moser et al., 1983). Two occurrences were sampled in April (3.28 org/10m^2) of 2014 and January (8.38 org/10m^2) of 1998. The occurrence in April might be related to the tow that was made at the early spawning season of WSB since the spawning season occurs from March to September. However, the occurrence of larvae in January of 1998, which is also a high abundance compared to the other years, could be the response to a late spawning event due to an intense El Niño period of 1997 and 1998. Studies have shown changes in the distribution and abundance of fish larvae during strong El Niño Southern Oscillation (ENSO) events (Aceves-Medina et al., 2019a; Jiménez-Rosenberg et al., 2010). Moreover, intense ENSO events have been responsible for shifts in adult spawning ranges and timing, as might happen to WSB (Jiménez-Rosenberg et al., 2010; Moser et al., 1987).

Our results align with the larvae distribution estimated by Moser et al. (1983). These authors mentioned that 15% of the WSB larvae occurrences were in southern California waters, meanwhile the remaining 85% were along the west coast of the Baja California Peninsula, with 50% above and 35% below of Punta Eugenia. The regions of Sebastian Vizcaino Bay and the west coast of the Baja California state are important areas for the WSB larvae since the higher abundance was estimated for those regions in both studies. The Sebastian Vizcaino Bay and adjacent oceanic region have been identified as an important area of high faunistic diversity since many fish larvae taxa have been found there (Jiménez-Rosenberg et al., 2007). Several authors have mentioned that the Sebastian Vizcaino Bay region is a highly productivity area suitable for fish larvae growth (Aceves-Medina et al., 2019b; Jiménez-Rosenberg et al., 2007; 2010).

Nonetheless, occurrences of WSB larvae in San Juanico Bay were not recorded in this study, whereas Moser et al. (1983) did find larvae in this region. We considered that the lack of WSB larvae abundance estimates in the region of San Juanico Bay in this study is related to differences between the CalCOFI and IMECOCAL surveys instead of nonexistent WSB larvae since our research found spawning capable females in the San Juanico Bay area. Moreover, CalCOFI has more years of sampling than IMECOCAL, increasing the probability of the occurrence of WSB larvae.

Chapter 4. Movement patterns and habitat utilization of white seabass (*Atractoscion nobilis*) along the west coast of the Baja California Peninsula

4.1 Introduction

Fish movement is essential for their ecological and evolutionary processes (Berdahl et al., 2018; Morais & Daverat, 2016). Movement is fundamental for fishes since it allows them to find food, reproduce, avoid predators, and identify appropriate habitats to rear early-life individuals; most of these movements are related with migration (Cooke et al., 2022; Secor, 2015). In fisheries, understanding fish movements along with demographic patterns (i.e., sex, size) and population dynamics (i.e., natural mortality, growth, maturity) information allows identifying the spatial structure of a fishery resource to develop management strategies to ensure its sustainability (Cadrin, 2020; Cooke et al., 2022).

For example, understanding the movement patterns and habitat utilization of the Atlantic bluefin tuna *(Thunnus thynnus)* enabled scientists to evaluate the hypothesis of two stocks that assumes no connectivity between two productive areas (the Mediterranean Sea and the Gulf of Mexico) from observations of trans-oceanic movement and populations mixing is now known to occur (Arregui et al., 2018; Galuardi et al., 2010; Galuardi & Lutcavage, 2012; Rooker et al., 2008; Rooker & Secor, 2004).

The white seabass (WSB, *Atractoscion nobilis*) is a transboundary fishery resource that ranges from California (CA), U.S., to Baja California Sur (BCS), Mexico, and within the north of the Gulf of California; during warmer years, it has been reported up to Alaska (Thomas, 1968). It has been exploited for over 100 years by the U.S. fishery and almost 70 years by the Mexican fishery (Fajardo-Yamamoto et al., 2022; Valero & Waterhouse, 2016; Vojkovich & Reed, 1983). WSB harvested from the northern Gulf of California has been proposed to be a genetically different stock from those that inhabit the Pacific (Franklin et al., 2016).

Meanwhile, two hypotheses have been proposed for the stock structure of WSB along its Pacific distribution. One hypothesis suggested that WSB harvested from California and the Baja California Peninsula are part of a single breeding stock (Ríos-Medina, 2008). Based on regional differences in otolith microchemistry (Romo-Curiel et al., 2016), growth rates at the first age (Romo-Curiel et al., 2015), landings (Fajardo-Yamamoto et al., 2022), and genetics (Franklin et al., 2016) of WSB, alternative hypotheses suggest two stocks which are isolated by an oceanographic barrier around Punta Eugenia, BCS. Moreover, tagging studies have been carried out to improve our knowledge about the population dynamics and structure of the WSB (Aalbers et al., 2021; Aalbers & Sepulveda, 2015; Hervas et al., 2010).

Based on archival tags that recorded depth and temperature, vertical movement studies of WSB showed markedly seasonal shifts in depth and temperature profiles during winter, inhabiting deeper and colder waters, changing to shallower and warmer waters during spring and summer (Aalbers et al., 2021; Aalbers & Sepulveda, 2015). The observed vertical seasonal shifts may be related to foraging habits due to changes in prey availability caused by oceanographic conditions during winter and for reproductive purposes during spring and summer (Aalbers, 2008; Aalbers & Sepulveda, 2012). Moreover, WSB occupies a constrained thermal range between 13 and 16 °C and depths <50m; however, depths up to 245m have been recorded (Aalbers & Sepulveda, 2015).

Horizontal movement patterns have been described for the WSB (Aalbers et al., 2021; Aalbers and Sepulveda, 2015; Hervas et al., 2010). Based on a conventional tagging study, hatchery-reared juvenile WSB showed limited seasonal migrations along the coast of California. They recorded that 50% of recaptures occurred within 47 km off the coast (Hervas et al., 2010). In contrast, Aalbers and Sepulveda (2015) recorded longer distance movements (>500 km deployment to recapture) for adult, wild-caught white seabass in an archival tagging study. Subsequent work has shown similar seasonal movements, and over the course of the study, they estimated a net distance of 720 km for an adult WSB (Aalbers et al., 2021).

These studies have also reported southward and northward movements across the U.S. and Mexico border, however, movements below Punta Eugenia have not been recorded. Moreover, these studies have also proposed evidence for seasonal site fidelity, with individuals being recaptured proximal to the deployment site after being at liberty for several years (Aalbers et al., 2021; Aalbers and Sepulveda, 2015). However, these studies only provide snapshot information (deployment and recapture trends) and do not provide information on long-term fish behavior, spatial habitat use or migration pathways. Therefore, this study aims to describe the horizontal movement patterns of adult WSB using geolocation archival tags. The work describes WSB migratory routes and spatial use patterns along the west coast of the Baja California Peninsula.

4.2 Methods

4.2.1 Tagging procedure

Between 2014 to 2020, a total of 77 TDR-MK9 Wildlife Computers electronic archival tags were surgically implanted into the peritoneal cavity of wild-caught WSB following techniques reported by Aalbers and Sepulveda (2015) and Aalbers et al. (2021). White seabasses were tagged between Punta San Jose (31.33oN/-116.46oW) and San Quintin (30.34oN/-115.94oW), Baja California (Table 6). Most of the WSB tagging occurred during the spawning season (Aalbers, 2008), with deployments during May (n=1), June (n=17), July (n=23), August (n=25), and October (n=11). The total length (TL) of WSB (66 to 162 cm in TL) was measured to the nearest centimeter and the sex of fish was recorded based on the presence or absence of sonic musculature (Aalbers and Sepulveda, 2015). To increase the probability of recovering a greater number of tags, a monetary reward of $200 USD cash was offered upon recovery of the archival tag along with recapture information (i.e., fish total length, date, geographic location of recapture, and fishing gear used). Along with reward information that was printed on the body of the MK9 tag, the team also distributed posters with contact and reward information printed in Spanish and English to local fishermen and within fishing camps.

4.2.2 Temperature and depth profiles

All archival tags were programmed to record internal and external temperature, light level, and depth once per minute. Time series data for each archival tag were transformed to Pacific Standard Time before generating summary statistics. Temperature and depth seasonal profiles were estimated monthly by pooling records of all recaptured tags.

4.2.3 Horizontal movements

4.2.3.1 Geolocation

To estimate the daily positions of the WSB tagged, we used the GPE3 hidden Markov model developed by the tag manufacturer Wildlife Computers, which based its methods on Pedersen et al. (2011). This space-state model estimates geolocations by incorporating the animal movement (swimming speed) and observations recorded by the archival tag, such as the light level, sea surface temperature, and maximum swimming depth. This model can also include known locations from different data sources such as Argos, acoustic tags, or visual observations (Kohin, 2018; Wildlife Computers, 2018). The output is a gridded position likelihood with a spatial resolution of 0.25 degrees, and a score of 0 to 100 is given to represent the average fit of the tag's observations (light level, sea surface temperature known locations) with those estimated by the state space model (Kohin, 2018; Perle et al., 2020).

The GPE3 model was run with animal speed from 2 to 4 m s^{-1} at increments of 0.5 m s^{-1} for each tag (per manufacturer recommendations). The best model was chosen based on observations scores above 50, which, on average, produced the highest pooled score.

4.2.3.2 Movement patterns

To understand WSB movement patterns, the distance from shore and the displacement rate were estimated. The distance from shore was defined as the closest distance (km) to shore for each geolocation point, and the displacement rate was the distance traveled per day (km day^{-1}) between each geolocation point. The displacement rate was estimated using the haversine function from the *Pracma* package in the R software. These variables were standardized to a daily resolution and presented seasonally into percentiles using boxplots. Autocorrelation tests were performed to avoid periodic patterns, and spurious data points were discarded (i.e., offshore points of distances >250 km and displacement rates above 90 km day^{-1}, representing values above the percentile 90 and 95, respectively). Moreover, linear regression analyses were performed to determine if the increase in size is related to long offshore displacements.

4.2.3.3 Habitat utilization areas

Areas of high use for all tagged WSB were determined across years following the methodology of Galuardi & Lutcavage (2012) and Lam et al. (2022). The utilization distribution was calculated using the *adehabitat* package in R with a grid resolution of 0.25° for the entire range (22 °N, 40 °N, 125 °W, and 110 °W) and converted into volume. Utilization distribution values between 0% and 30% were considered high-use areas. Afterward, we determined overall, seasonal (spawning and no spawning), and monthly utilization distribution to estimated high-use areas and migratory pathways. Moreover, to aid the interpretation of the migratory pathways, we calculated the distribution and density of the longitude and latitude values by performing monthly violin plots.

4.3 Results

4.3.1 Tag recoveries

Table 6. Tags deployment and recapture information for 16 adults white seabass.

ID	TL (cm)	Sex	Deployment date	Deployment location (°N,°W)	Recapture date	Recapture location (°N,°W)	Days at liberty	Net displacement (km)
1390457	139.7	F	13/08/2014	30.34,-115.94	23/06/2018	26.12,-112.43	1411	582
1390457b	93.9	M	03/08/2020	31.18,-116.35	01/04/2022	30.69,-116.11	606	60
1390460	82.6	M	12/08/2014	30.34,-115.94	09/05/2015	30.50,-116.11	270	24
1390474	83.8	M	25/07/2020	31.18,-116.36	25/05/2020	30.67,-116.13	669	61
1390493	134.6	F	13/08/2014	30.35,-115.93	31/12/2016	31.9,-116.75	872	189
1390496	114.3	M	12/08/2014	30.34,-115.94	01/09/2020	29.89,-115.73	2212	54
1590003	81.3	M	28/06/2020	31.18,-116.36	30/07/2022	30.77,-116.09	762	53
1590008	118.1	M	14/07/2015	30.36,-115.91	25/04/2019	29.86,-115.78	1382	58
1590008b	87.6	F	03/08/2020	31.18,-116.36	10/04/2022	30.94,-116.28	615	28
1590017	96.5	M	11/07/2020	31.18,-116.36	29/07/2022	31.24,-116.46	748	12
1590018	88.9	M	03/10/2017	30.49,-116.1	16/12/2017	31.03,-116.37	74	66
1590023	150	F	24/06/2015	31.16,-116.32	19/04/2017	31.78,-116.63	665	76
1590029	137.2	M	28/08/2015	31.33,-116.46	19/03/2018	30.49,-116.13	934	98
1590039	149.9	F	12/08/2016	31.33,-116.46	14/06/2018	31.12,-116.35	671	25
1590039b	80	M	29/07/2019	31.09,-116.34	20/12/2020	31.09,-116.34	510	0.4
1590042	109.2	M	29/06/2020	31.18,-116.36	17/12/2020	31.33,-116.53	171	23

Eighteen tags of the 77 WSB tagged were recaptured, which represents a ~23% recapture rate. Recaptures occurred between Ensenada, Baja California. (31.9 N, -116.75 W) and El Chicharron, Baja California Sur (26.12 N, -112.43 W) (Fig. 1; Table 1). The recaptures occurred between 2016 and 2022 in the months of February (n=1), March (n=1), April (n=4), May (n=2), June (n=2), July (n=2), August (n=1), September (n=1), and December (n=4). All recaptures were reported by Mexican commercial fisheries.Of the 18 recaptured individuals, 11 were males, 6 were females, and for one individual, sex was not recorded. Based on existing information on WSB size of maturity (Clark, 1930; Fajardo-Yamamoto et al. in prep), we considered that tagged white seabass greater than 75 cm in TL as mature individuals. Therefore, because this study focused on adult white seabass, only the information from 16 tag are presented. One individual was considered immature (66 cm), and the other had no information on sex or length (Table 6). Adult tagged WSB were, on average, at liberty for 785 days (ranging between 74 and 2,212 days), with a mean net displacement distance of 88 km, with a minimum of 0.43 km and a maximum of 582 km (Table 6). This work also reports on the first movements of a WSB from northern Baja California to the waters of Southern Baja California. Fish with a total length of 139.7 cm was tagged off San Quintin, BC and recaptured ~1400 days later off the coast of El Chicharrón, Baja California Sur (Fig. 15).

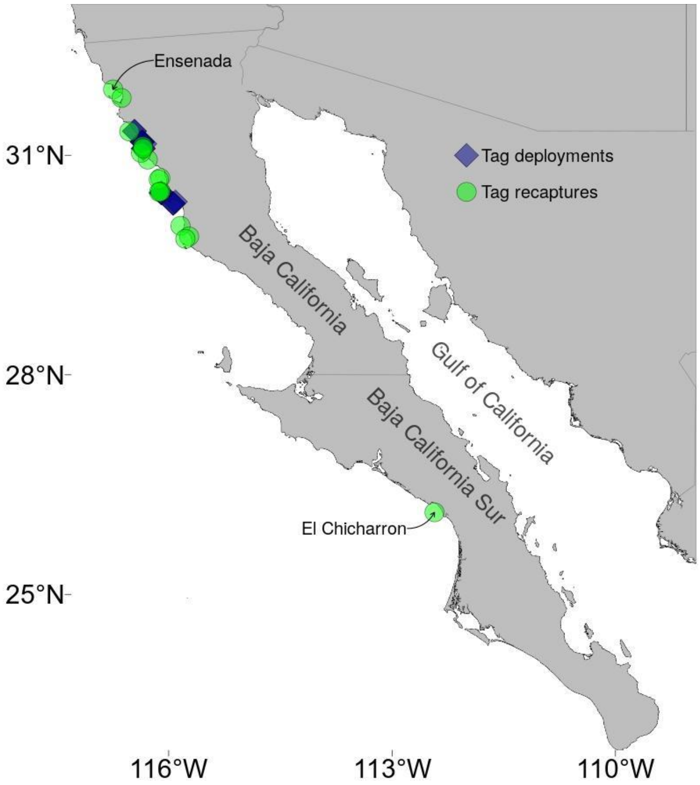

Figure 15. Tag deployments and recapture's locations of 16 tagged white seabass. The blue diamond represents the deployment locations, and the green circle represents the recapture locations. The most northern and southern recapture locations are shown on the map (Ensenada, B.C. and El Chicharron, B.C.S.).

4.3.2 Temperature and Depth profiles

Although the maximum depth of up to 210 m was recorded, 95% of the records were <50 m (Fig. 16a). The overall mean depth was 19.3 ± 15.9m. The month with the maximum mean depth was January at 29.2 ± 15.9 m, and the minimum mean depth was June at 9.7±6.3 m (Fig. 17a). Tagged individuals experienced an overall mean water temperature of 16.1 ± 2.4 °C and ranged from 9.6 °C to 23.9 °C. However, individuals spent the majority between 14°C and 18°C, with a peak in 15°C (Fig. 16b). Mean monthly temperatures achieved a maximum of temperature in September with a mean of 17.7 ± 1.8 °C and a minimum of 13.9 ±1.6°C in April (Fig. 17b).

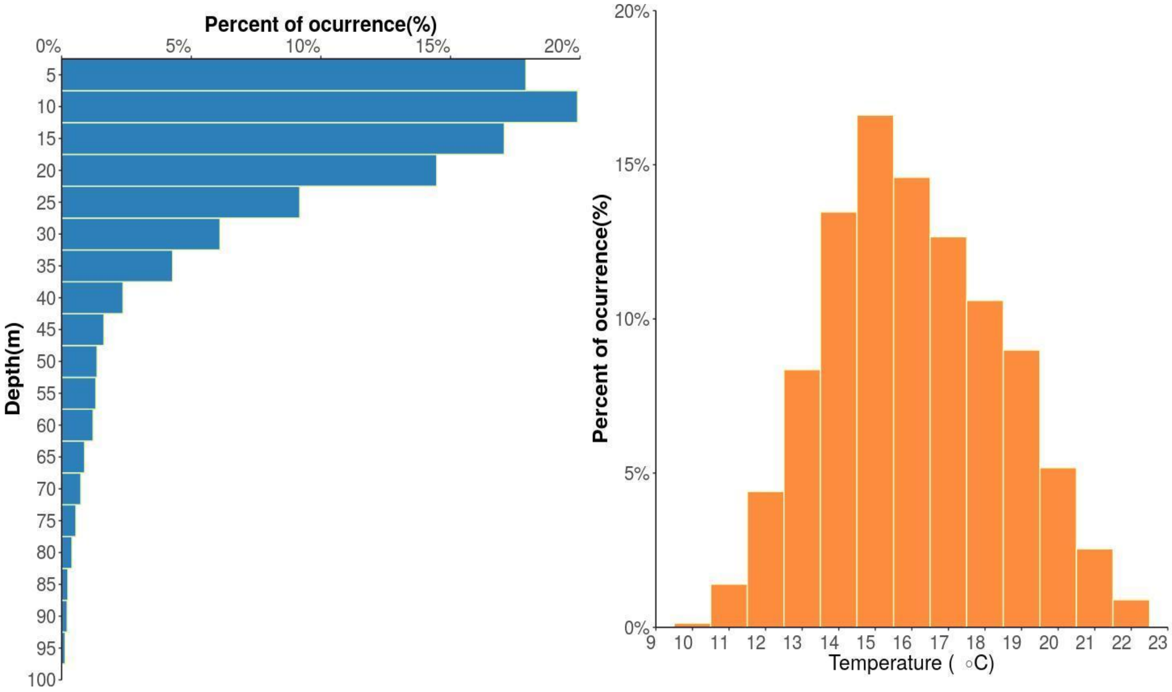

Figure 16. Depth and Temperature histograms based on 16 tagged white seabass. A) depth histogram by 5-m bins. B) temperature histogram by 1-degree bins.

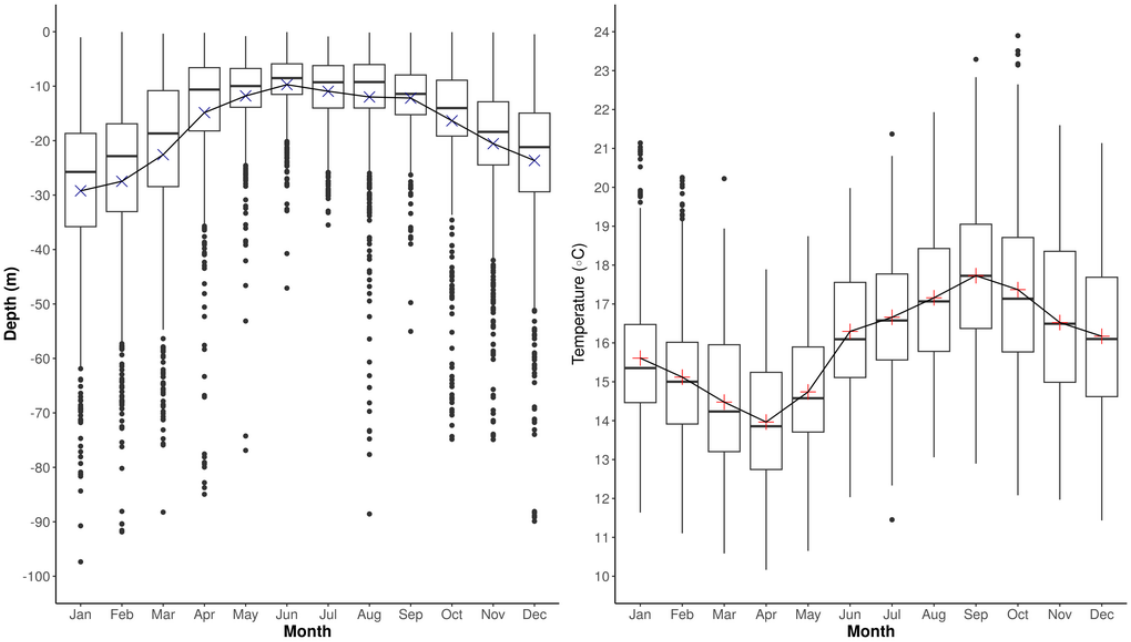

Figure 17. The seasonal depth and temperature boxplot profiles from 16 white seabass tag recoveries. The blue cross represents the mean depth, and the red cross represents the mean temperature. A) Monthly depth. B) Monthly temperature.

4.3.3 Horizontal movements

4.3.3.1 Geolocation and movement patterns

Location estimation outputs had the highest observation scores (i.e., average fits between tags observations and those estimated by the model) with a swimming speed of 2.5m s^{-1}. All the output models' observation scores were above 70, with the highest score of 82 and the lowest score of 71.

Tagged individuals showed marked seasonal trends in the distance offshore as well as displacement rates (Fig. 18). Tagged WSB showed the closest distance to the shore in the winter (November-February). Through March and October, the opposite trend was observed (Fig. 18a). The closest distance to the coast was estimated to be in November at 33.3±28.6 km and the farthest distance to the coast was recorded in June at 80.4±69.6 km (Fig. 18a). Similar to the distance offshore, the highest displacement rate was estimated to be from March to October, and the lowest displacement was calculated for the winter period (November-February; Fig. 18b). The fastest displacement rate was observed in August (27.5±22.4 km day1) and the lowest in November (16.0±15.1 km day-1) (Fig. 18b)

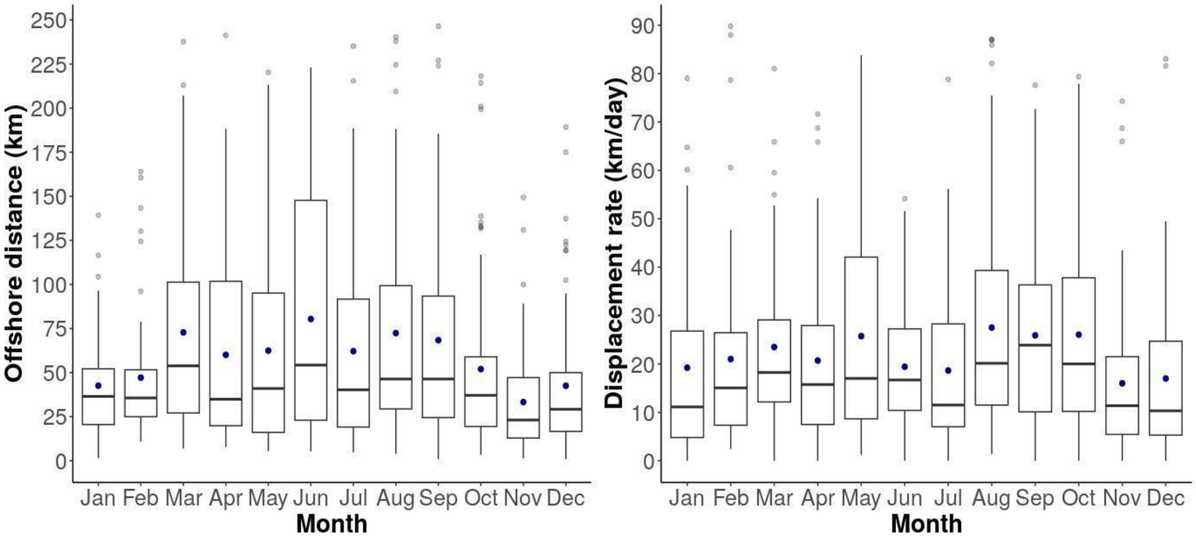

Figure 18. Seasonal distance from shore (km) and displacement rate (km/day) for adult white seabass. Blue points in both figures represent the mean. A) Offshore distance. B) Displacement rate**.**

4.3.3.2 Habitat utilization

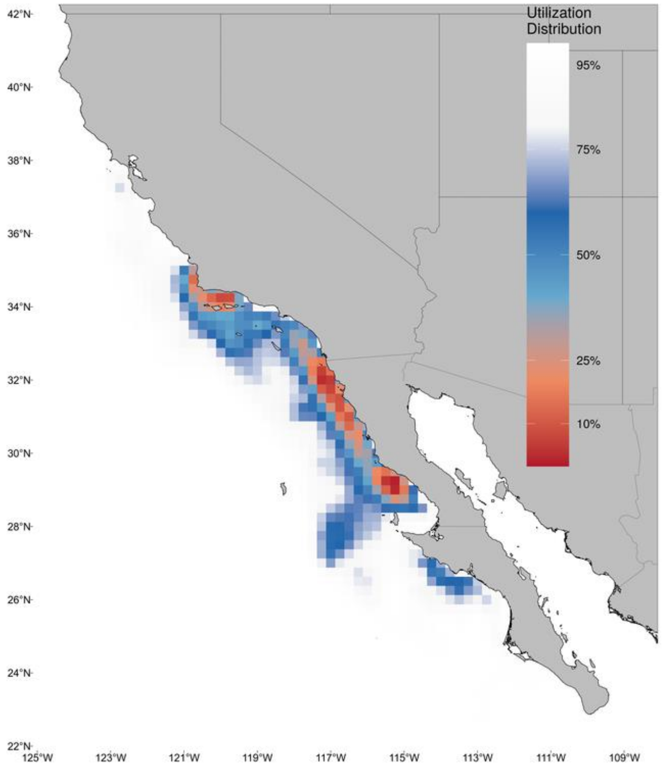

Figure 19. Aggregated habitat utilization for all tagged fish during their time at liberty. Habitat utilization values less than 30% signify high-use areas**.**

The overall utilization distribution of adult WSB showed four high-use areas: around the Channel Islands, off the coast of Coronado Islands-Ensenada, off the coast of San Quintin, and in the Sebastian Vizcaino Bay area (Fig. 19). However, the high-use areas changed when utilization distribution was estimated for the spawning season (March-September) and no-spawning season (October-February) (Fig. 20). During the spawning season four high-use areas were estimated: around the Channel Islands in California, around the Sebastian Vizcaino Bay area and near Punta Eugenia in Baja California, and the last one off the coast of Bahia Asuncion and La Bocana in Baja California Sur (Fig. 20a). Meanwhile, during no-spawning season a large and restricted to the coast high-use area off the coast between Tijuana and San Quintin was estimated (Fig. 20b).

Moreover, the high-use area changed seasonally in location and extent of distribution. During winter (November-January), distributions were more restricted to coastal areas, and the high-use regions were centered off the coast of Tijuana and Ensenada. In early spring (February-March), dispersal movements are evident to the northern and southern areas. For late spring and summer (April-August), high-use areas are scattered throughout the region. However, distinct north and south high-use areas became apparent. By late summer and autumn (September-October), the movements return to a constrained high-use coastal (Fig. 21).

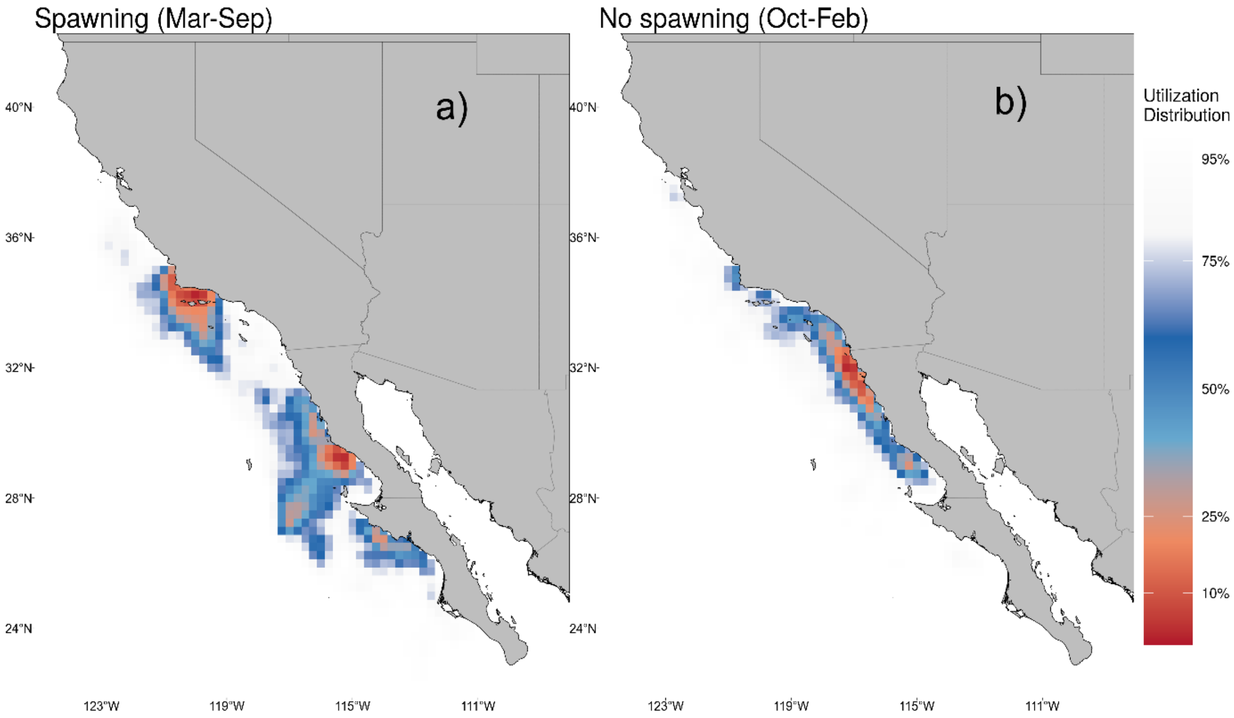

Figure 20. Aggregated habitat utilization for all tagged fish during their spawning (March - September) and no spawning seasons (October-February).

4.4Discussion

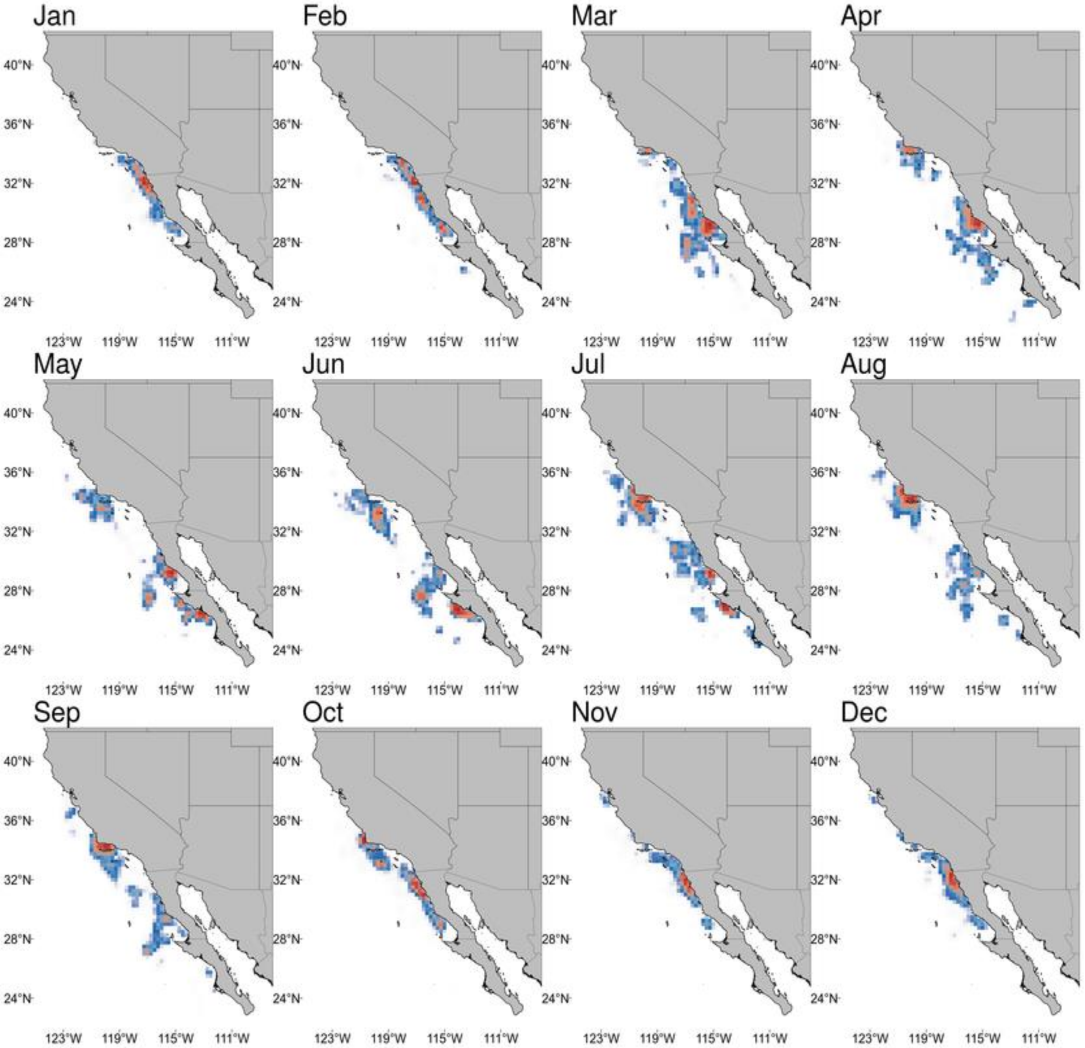

Figure 21. Habitat utilization aggregated for all tagged adult white seabass for each month.

This is the first study to show year-round spatial distribution data for adult WSB along the west coast of the Baja California Peninsula. Its findings provide insight into this valuable bi-national resource's movements and habitat utilization. The movement data identify marked seasonal patterns that correspond with the spawning season (spring-summer) and those periods outside the spawning window (winter). Furthermore, we observed two dominant migration pathways: (1) a dispersal movement where adult WSB moved northward to an area around the Channel Islands in California and a southward movement along the coast of the west coast of the Baja California Peninsula where multiple high-use regions were occupied and, (2) a return movement from north and south areas to a constrained and restricted space off the coast of Tijuana and San Quintin. These movement patterns show how the WSB population expands and contracts its use of the coastal habitat along the west coast of the Baja California Peninsula and California. The specific level of connectivity of adult WSB between the coasts of California and the west coast of the Baja California Peninsula reinforces the need for binational cooperation to manage this important transboundary fishery resource.

4.4.1 Depth and temperature profiles

The depth and temperature profiles obtained from the adult WSB were consistent with tag records from previous studies (Aalbers et al., 2021; Aalbers & Sepulveda, 2015). Moreover, fish displayed similar seasonal changes in depth and temperature distribution, with fish moving to shallower waters in summer and remaining within a narrow range of temperature throughout the entire deployment (14-17 °C; Fig. 17). However, because this study used electronic tags with both internal and external temperature sensors, the present study offers higher resolution data.

4.4.2 Horizontal movements

As well as the depth and temperature seasonality, the distance offshore and the displacement rate showed similar seasonal trends (Fig. 17 & 18). During winter, adults WSB are closer to the coast (<50 km, Fig. 18a) and have the lowest displacement rates (<20 km day^{-1}, Fig. 18b), which also coincided with the most profound records and lowest temperatures recorded. The opposite trend was estimated for spring and summer when tagged individuals were more distant from the coast (>50km, Fig. 18a) and displayed a higher rate of displacement (>20 km day^{-1}). The observed winter movements by adult WSB may be related to forage availability (Aalbers et al., 2021; Aalbers and Sepulveda, 2015) and a reduced locomotion-gonad synthesis trade-off. For example, Koch and Wieser (1983) found that during one seasonal cycle, the swimming activity of the common roach (Rutilus rutilus) is diminished during the gonad synthesis period by defraying the energetic costs of reproduction with reduced locomotion. Meanwhile, increased displacement rates and movements offshore might be associated with migrations to spawning areas during spring and summer. Large displacements of mature fishes to warmer waters thus equate to accelerated development of their eggs and larvae (Jørgensen et al., 2008). Similar movements have been described for the Pacific bluefin tuna (*Thunnus orientalis*; Fujioka, et al., 2021), Atlantic bluefin tuna (*Thunnus thynnus*; Richardson, et al., 2016), and several marine species in the Gulf of California (Sala et al., 2003) where adults move to known spawning areas in spring-summer.

However, a lower displacement rate for June and July was estimated at 19.4 and 18.6 km day^{-1}, respectively, corresponding to the peaks of the WSB spawning season, which might indicate that WSB remains within the spawning areas during these months. The WSB is a broadcast spawner that forms aggregations during the spawning season (Aalbers and Drawbridge, 2008). This aggregation behavior makes them vulnerable to being harvested, as reflected in the Mexican commercial fisheries' highest landings records reported for June and July (Fajardo-Yamamoto et al., 2022). Moreover, using long-term acoustic recordings, Aalbers and Sepulveda (2012) detected continuous spawning chants of WSB in two coastal regions of south California. Near San Mateo Point, California, they recorded ten spawning chants in three months, with an increasing frequency of spawning chants due to increased water temperature. Although we cannot assure that the same individuals frequent the spawning areas, we can infer that the WSB often uses specific areas for spawning.

4.4.3 Habitat utilization

Coastal areas and areas around islands emerged as important high-use areas for adult WSB (Fig. 19). The Channel Islands, the region off Coronado Islands-Ensenada, the San Quintin region, and the Sebastian Vizcaino Bay area have all been reported to be essential areas for different WSB ontogenic stages (Allen and Franklin 1992; Donohoe, 1997; Escobedo-Olvera, 2009; Moser et al., 1983). In this study we note marked differences in habitat utilization both during and outside of the spawning window (Fig. 20). During the spawning season, four high-use areas were determined (Fig. 6a). Based on ichthyoplankton samples from 1950 to 1978 taken by the California Cooperative Oceanic Fisheries Investigations (CalCOFI), Moser et al. (1983) reported the highest larval abundance (85%) of WSB along the Baja California Peninsula, with 50% north and 35% south of Punta Eugenia. Between May and August, they reported the highest concentrations of larvae in the coastal areas of Sebastian Vizcaino Bay and San Juanico Bay; the peak of occurrences and individuals was recorded in July. Moreover, between 1998 and 2014, the highest peak collection of larvae from the Mexican Monitoring Program of the California Current (IMECOCAL, for its Spanish acronym) ichthyoplankton collection was recorded in July, and the regions between Ensenada and San Quintin and Sebastian Vizcaino Bay concentrated the highest abundance of WSB larvae.

Furthermore, Fajardo-Yamamoto et al. (2022) showed the highest landings records during the spawning window (May to August) in areas where high-use areas were determined during the same season (Fig. 20). White seabass Young of the Year (YOY) nursery areas have been proposed at the Channel Islands, Southern California Bight coastal areas, and the San Diego Bay area (Allen and Franklin, 1992; Donohoe, 1997). Based on the logbooks of a Mexican medium-scale fishery vessel, the highest catches of adult WSB were performed between May and August, with a peak in July in the central Baja California Peninsula and around the coast of Punta Abreojos. Together, this information allowed us to determine that the regions of the Channel Islands, the Sebastian Vizcaino Bay, the area around Punta Eugenia, and the coastal region between Bahia Asuncion-San Juanico Bay might be considered spawning grounds for the WSB.

In addition, near the spawning areas determined in this study are coastal lagoons, such as the Estero de Punta Banda, the San Quintin Bay, the Ojo de Liebre Lagoon complex, the San Ignacio lagoon complex, and the Magdalena Bay complex, which represent highly productive and diverse environments which serve as nursery areas for WSB YOY and juveniles (Donohoe, 1997; Ibarra-Obando et al., 2001). Moreover, WSB juveniles have been recorded in these ecosystems (Mendoza-Portillo, 2020; Rosales-Casián, 1997; Rosales-Casián & Gonzalez-Camacho, 2003).

The non-spawning habitat use was shown to be a large coastal area between Tijuana and San Quintin (Fig. 20b). WSB adults may be concentrated within this larger area due to prey availability in deep water (Aalbers and Sepulveda, 2015) and the need to feed for gonad development and energy acquisition needed for growth and to support spring and summer migrations. The distribution of adult WSB during this period also overlaps with the northward migration pathway of the Pacific sardine estimated by Félix-Uraga et al. (2004). Furthermore, in a previous tagging study (Aalbers et al., 2021), the deployment and the recapture sites were recorded almost in the same region as ours, and half of the individuals were recaptured within 50 km of their initial tagging site as we also recorded. Overall, this information supports that adult WSBs display some form of regional site fidelity to both the reproductive and foraging areas.

4.4.4 Migration patterns

The migratory patterns observed in this study support the idea of a north and westerly direction migration from July to September (see Appendix, Fig. 22 and 23) described by Aalbers & Sepulveda (2015). Moreover, this study showed south and westerly direction migration from March to June (see Appendix, Fig. 22 and 23). Migration pathways might respond to the reproductive behavior of adults WSB and to variability in oceanographic conditions that trigger the start of the reproductive season. Moreover, our habitat utilization estimates overlap with concentrated patches of larvae and YOY of WSB reported in previous studies (Allen and Franklin, 1992; Donohoe, 1997; Moser et al., 1983). Adult individuals select distinct spawning areas favorable to offspring and for developing embryos and larvae (Secor, 2015).

Chapter 5. General discussion

This thesis aimed to improve the knowledge of the transboundary white seabass (*Atractoscion nobilis*) fisheries resource. Its results attempted to fill several data gaps related to the fisheries baseline information of the Mexican WSB fishery (Chapter 2), the size-at-maturity of the WSB in the southern part of its Pacific distribution (Chapter 3), and the horizontal movement patterns and habitat utilization of WSB along the west coast of the Baja California Peninsula (Chapter 4). This information is expected to preclude effective bi-national management and help to understand the stock structure of the WSB along its Pacific distribution.

The catch or landings statistics are the baseline information to manage fisheries (Pauly, 1998). However, species-specific catch data are unavailable or deficient for most developing countries, such as Mexico. For transboundary fishery resources, data asymmetry (i.e., dissimilar distribution of information across the full range of a fishery) between countries makes national and international management more difficult (Cisneros-Montemayor et al., 2020; Ishimura et al., 2013). This information offers crucial evidence that allows for the delimitation of geographic boundaries that potentially represent individual fish stocks (Begg, 2005; McBride, 2014). The estimated baseline information (landings and CPUE) of the WSB Mexican fishery in this study integrates the best available information for the landings of this historic transboundary fishery resource in a data-poor context. Fluctuations in WSB annual landings were associated with shifts in contextual factors, such as fisheries management policies and market changes during five specific periods over the past 70 years. Moreover, the small-scale fishery along the west coast of the BCP reported the highest landings of WSB over the past 20 years, firmly establishing the regional importance of this fishery and for Mexico.

In addition to time-series catch data, basic life history parameters such as size at maturity are critical for sustainable management and differentiating and identifying potential differences for a species that may consist of more than one stock (Begg, 2005). In this study, we estimated that WSB from the SBCP region reached a smaller size at maturity than those from California. These results align with the results of Romo-Curiel et al. (2015), who found a higher increase in the first growth ring of WSB from the SBCP region than those from California. In addition to the maturity differences between sites, as Romo-Curiel et al. (2016) suggested, we agreed on unlikely connectivity during the WSB larvae stage since multiple spawning areas (considerable geographical separation between them) are evident, as shown by the WSB habitat utilization estimated for this season (Chapter 4). During this season, two climatic regimes are evident along the Baja

California Peninsula's west coast, limiting the larval dispersal (Durazo, 2015; Gaxiola-Castro and Durazo, 2010). Nevertheless, we found the highest concentration of WSB larvae in the Sebastian Vizcaino Bay area, north of Punta Eugenia, which also has been identified in previous studies as an essential area for WSB larvae (Moser et al., 1983).

Like fisheries baseline information and size at maturity data, studies on a fishery resource's movements and migration behavior are also critical for effective management (Galuardi and Lam, 2014). Movement patterns provide valuable insights into migration timing, identification of potential spawning areas, and habitat utilization, helping to understand the potential for stock mixing (Galuardi and Lam, 2014). The electronic tagging of adult WSB in this study has identified seasonal and migration pathways not known previously along California and the west coast of the Baja California Peninsula. Four high-use areas were identified during the spawning season (March-August) (Channel Islands, California, Sebastian Vizcaino Bay, Punta Eugenia, and Bahia Asuncion to La Bocana, Mexico). Due to their aggregating behavior during the season, WSB is vulnerable to being caught, as shown by the higher landings recorded for these months for the Mexican WSB fishery (Fajardo-Yamamoto et al., 2022, Chapter 2). Mainly, WSB migratory behaviors show westerly southward movement up to the north of Punta Eugenia from March to June, while from July to September, the fish tend to move to the north and west. However, the connectivity between California and the southern Baja California Peninsula region cannot be ruled out, as part of the individuals reached waters south of Punta Eugenia, with additional confirmation from one recaptured individual.

Contrasting regional trends in fishery landing rates and effort between BC and BCS (Fajardo-Yamamoto et al., 2022; Chapter 2) combined with evidence from life history (Romo-Curiel et al., 2015; Chapter 3), otolith microchemistry (Romo-Curiel et al., 2016), genetic (Franklin et al., 2016), and previous tagging studies (Aalbers and Sepulveda, 2015; Aalbers et al., 2021), all provide evidence of differences between California (north) and the SBCP region (south) regions of WSB within its Pacific distribution. Collectively, the results of this thesis show regional differences in fisheries intensities across California, Baja California, and Baja California Sur, which have resulted in 75% of the American market being supplied by the Mexican fishery (Fajardo-Yamamoto et al., 2022). When compared between California (U.S.) and the SBCP (Mexico), the size-at-maturity suggests the existence of two stocks and that stock assessments and management efforts should be distinct. Nevertheless, when coupled with seasonal movement patterns exhibited by WSB adults and regional connectivity (Chapter 4), findings support the need for a comprehensive stock assessment comprising information from the U.S. and Mexico and developing cohesive fishery policies.

In the meantime, based on the best practices for defining the spatial structure of the population (Cadrin, 2020), three scenarios of population spatial structure should be assumed when assessing the WSB fishery: 1) one population across California and the Baja California peninsula ignoring any stock structure; 2) one subpopulation distributed from California to the north of Punta Eugenia and one south from this region; and 3) two subpopulations but considering certain degree of connectivity based on the contingent stock concept (Secor, 1999; Hare, 2005). Nonetheless, further investigations between the two regions are needed to understand better the stock structure, fishery dynamics, and management needs of the WSB. Future studies should focus on estimates of the natal homing of WSB using otolith element tracers, enlarge gonad samples of immature individuals to estimate a more robust size-at-maturity, improve methodologies to estimate the genetic structure of the WSB and determine which oceanographic variables influence the habitat utilization of WSB, among other studies.

Chapter 4. Conclusions

The landings of the Mexican WSB fishery showed an overall increase over the past 70 years. Landing fluctuations were associated with shifts in contextual factors, such as market changes and geopolitical events. Over the past 20 years, the estimated WSB landings show a significant increase (228%), and the small-scale fishery accounts for more than 97% of the total catch; most of the harvest has come from Baja California Sur, with landings concentrated primarily in the fishery offices of Ciudad Constitucion, Punta Abreojos, and San Carlos.

White seabass females from the southern Baja California Peninsula region were estimated to mature at a size of 72.7 cm TL, while the males at a length of 58 cm TL. Regional differences in maturity were identified between WSB from California and those from the southern Baja California Peninsula region. The Sebastian Vizcaino Bay area may comprise an essential habitat for WSB, as it was found to have the highest abundance of WSB larvae.

Electronic tagging data has identified connectivity between WSB from California and the west coast of the Baja California Peninsula. Overall, areas around islands and coastal habitats are high-use areas for adult WSB. The Channel Islands, the region off Coronado Islands-Ensenada, the San Quintin region, and the Sebastian Vizcaino Bay region were all found to be areas of seasonal high use. The spawning (March-September) and no spawning (October-February) seasons for adult WSB have marked differences in habitat utilization. Two migration pathways were identified: (1) a period of dispersion where WSB moved northward to an area around the Channel Islands in California and the south towards the west coast of the Baja California Peninsula, and (2) we also identified a return movement from the northern and southern areas to a constrained and regionally restricted area off the coast of Tijuana and San Quintin.

Considering the information generated in this thesis, we have attempted to fill several data gaps that continued to preclude effective bi-national management of this important transboundary resource and generated more information to understand the stock structure of the WSB along its Pacific distribution.

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Supplementary material

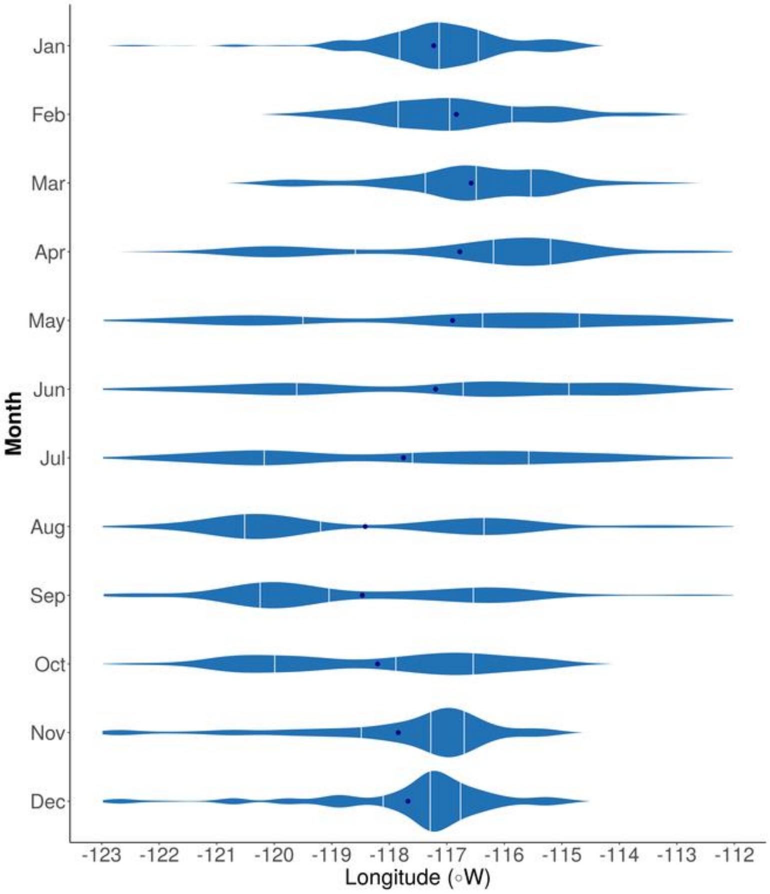

Figure 22. Seasonal violin plots of the Longitude for all daily location estimates**.**

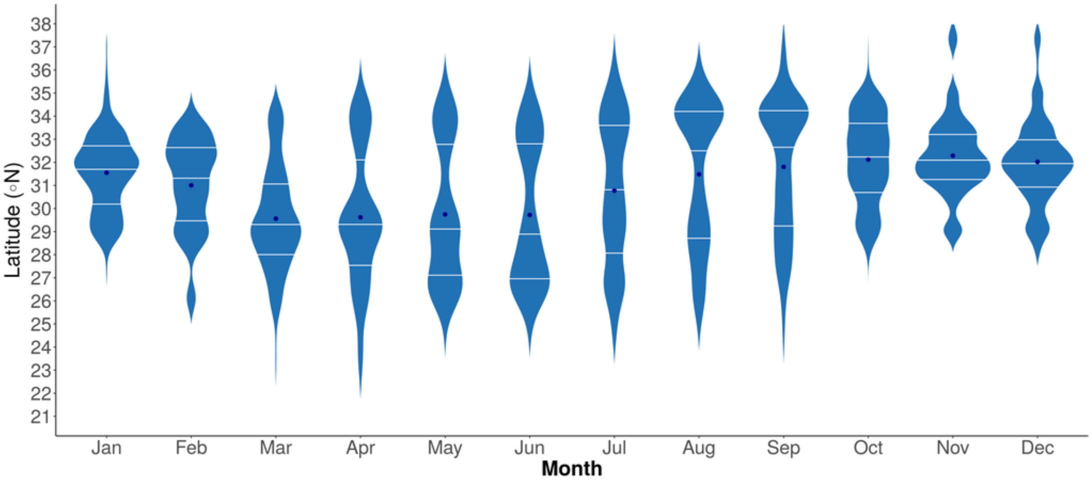

Figure 23. Figure 23 Seasonal violin plots of the Latitude for all daily location estimates.