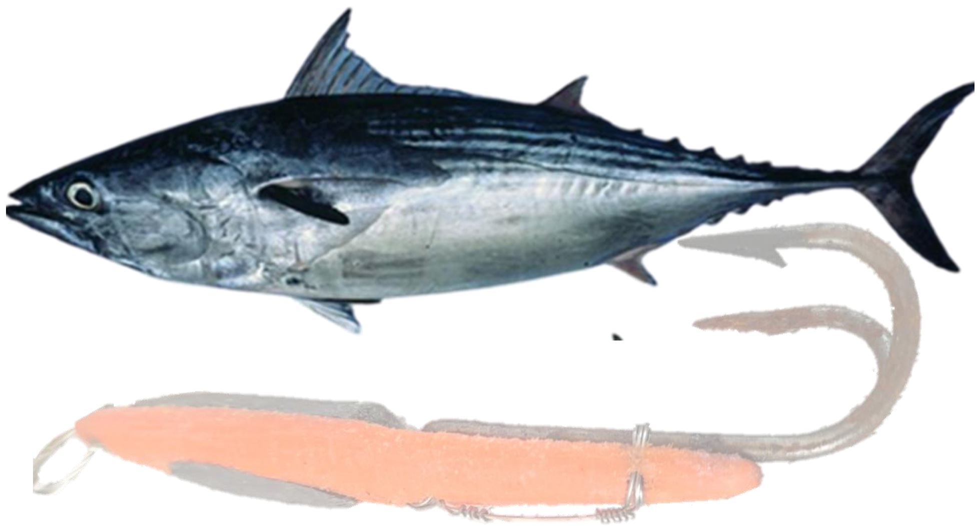
oaxaqueño para la conservación de la naturaleza

Population status analysis of the kite (*Euthynnus) lineatus*) with data on weight, size (2022–2025), and spines for the artisanal black skipjack tuna fishery in Puerto Ángel, Oaxaca, Mexico.



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Content

Final Report: Analysis of the capture strategy and population status of the skipjack tuna (Euthynnus lineatus) using biological-fisheries

information from the artisanal skipjack tuna fishery in Puerto Ángel, Oaxaca, Mexico.

I. INTRODUCTION

The black kite (*Euthynnus) The Atlantic bluefin tuna (Amanita lineatus*) is one of the most important small tuna species for artisanal fishing on the Mexican Pacific coast, especially in Puerto Ángel, Oaxaca. Its capture represents an essential source of income and food for numerous families, establishing it as a strategic component in the socioeconomic dynamics of the region.

However, despite its ecological and fisheries importance, there is limited availability of up-to-date scientific information on the population structure and biometric trends of this species in the region. This lack of reliable data is one of the many obstacles hindering the design of evidence-based fisheries management strategies, which increases the risk of overexploitation and vulnerability of the skipjack tuna resource in Puerto Ángel.

I.1 Basic data of the organization benefiting from the services

The organization benefiting from the services is the Oaxaca Fund for Nature Conservation AC, in collaboration with various cooperative fishing societies from Puerto Ángel, Oaxaca.

I.2 Problem that you wish to address with the requested services:

Fishing for the black skipjack tuna *(Euthynnus) The skipjack tuna (Amanita lineatus*) represents a key source of sustenance for coastal communities on the Mexican Pacific coast, particularly in Puerto Ángel, Oaxaca. Despite its socioeconomic and nutritional importance to this community, information on the skipjack tuna population status is scarce and scattered, hindering decision-making for its regional management and jeopardizing the continuity of this artisanal fishery at optimal catch levels.

The analysis of biometric data series (weight and size) collected between 2022 and 2025, as well as the integration of complementary information derived from the study of spines, allows for the generation of a rigorous technical diagnosis on the current population structure, and specific to the population of black skipjack tuna in Puerto Ángel, Oaxaca, providing valuable inputs to guide responsible fishing practices and strengthen local capacities for present and future monitoring and evaluation.

The development of this analysis is fundamental to establishing scientific bases that support future sustainable management actions, promoting the conservation of the artisanal skipjack tuna fishery on the Oaxacan coast.

II. GENERAL OBJECTIVE

Assess the population status of the kite (*Euthynnus) lineatus*), through the analysis of biometric data (weight and size) obtained between October 2022 and May 2025, including a comparison of the size structure estimated by direct measurement (morphological study) of spines collected between October 2013 and November 2014, for the skipjack tuna fishery in Puerto Ángel, Oaxaca.

II.1 Specific Objectives

1. **Generate a systematized database** (2022–2025) of the weight and size records of the black skipper (*Euthynnus) lineatus*) from monitoring carried out for the Skipjack Tuna Fisheries Improvement Project (FIP) in Puerto Ángel, Oaxaca.
2. **To characterize the size structure of the skipjack tuna population** during the period 2022–2025, identifying temporal trends and possible variations associated with fishing activity.
3. **Estimate the population growth parameters for black kite** : ***Lt*** (Expected length of the individual at age t); $L\infty$ = Asymptotic length (the maximum theoretical length the fish would reach if it grew indefinitely); K = Growth coefficient (rate at which the fish approaches $L\infty$); t_0 : Theoretical age at which the fish would have zero length. Using statistical tools in Excel programs. To compare growth and feed population assessment models.
4. **Compare the size structure observed in the field for the period 2022–2025,** with that estimated by means of cross-sections of black skipper spines (growth line count), as a cross-validation mechanism of the results.

III. METHODOLOGY

The methodology includes, in order to begin, the **integration of weight and size databases** of the kite *(Euthynnus). lineatus*) collected during the period 2022–2025, within the fisheries improvement project (FIP) for skipjack tuna in Puerto Ángel, Oaxaca. Also, the analysis of the cohorts with the size records, to subsequently estimate the age structure corresponding to the identified cohorts, and finally to compare it with the size structure estimated from the study of bones collected between October 2013 and November 2014. All of the above under the following order.

III.1. Integration and systematization of the database.

- **Data** : Weight (grams) and size (cm) records generated by the monitoring of the Skipjack Tuna Fisheries Improvement Project (FIP) in Puerto Ángel during the period 2022–2025 were integrated. Subsequently, the consistency between physical formats of data capture in the field and the available monitoring records was reviewed.
- **Organization** : The data were then digitized and organized into Excel spreadsheets. A structured database was generated with the following 30 fields: year, month, monitoring date, reference site (fishing site), locality, selective fishing gear (artisanal trolling), lunar phase, cooperative, vessel name, captain's name, scientific name, individuals caught, associated species, total length (cm), weight (g), liters of gasoline, observations (e.g. , weather, vessels monitored, type of food, injuries), and other fields.

  Note 1: The data in the Excel column "Total individuals captured" represents the total number of fish caught during the entire fishing trip, and the column "Number of individuals monitored (including associated species)" represents the fish for which length and weight data could be effectively obtained. Associated species are the group of species caught incidentally during the harvesting of the target species (NOM-065-SAG/PESC-2014).

- **Validation:** 2,859 records of weight (kilograms) and total length (cm) corresponding to the period 2022–2025 were analyzed. These records were obtained through beach monitoring by the Fisheries Improvement Project (FIP) for black skipjack tuna in Puerto Ángel, Oaxaca. A preliminary review was then applied to identify inconsistencies, capture errors, and outliers by plotting the total length (cm) records on a scatter plot in Excel.
- **Data Cleaning and Standardization** : The records were standardized to a numerical format. Subsequently, based on the consultant's current knowledge of the skipjack tuna fishery, inconsistencies, catch errors, and outliers were corrected within the overall *FIP* monitoring database *for skipjack tuna in Puerto Ángel 2022–2025* . The names of captains, vessels, fishing sites, months , dates, total catches , and species associated with skipjack tuna fishing were standardized . For example, names such as *Don Cuco, Cuco, and Héctor Márquez* were consolidated under a single entry *: Héctor Márquez (Don Cuco)* . Similarly, the spelling variations of sites such as *Frente a Estaca, Playa Estacahuite, or Estaca* were integrated as *Frente a Estacahuite* . This allowed for the systematic organization and analysis of key information related to the catch records.

  Note 2. Of the 17,014 total catch data obtained, the data from 2022 were omitted because they did not report total catches, only records of the species that were measured and weighed without viscera during monitoring .

III.2. Data Systematization

The refined and organized Microsoft Excel database generated in Objective 1 was used, which includes the 17,014 total catch data points and the 2,859 monitored length and weight records. The length and size records of previously identified associated species were filtered from this database to obtain only data for the black skipper (*Euthynnus). lineatus*).

From the general database of the *FIP_black kite monitoring in Puerto Ángel 2022–2025 (2,859 measurements), the data corresponding only to the black kite (Euthynnus)* were filtered. *lineatus*) captured artisanally using hand lines and artisanal trolling lines. This filtering allowed for the formation of a final subset of 2,644 validated records with complete information on total length (cm) and weight (g), corresponding to individuals captured between October 2022 and May 2025, as part of the monitoring promoted by the *FIP* in Oaxaca.

Note 3: As in the analysis of the catch during the period 2022-2025, of the 2,859 length and weight data monitored, the data corresponding to the year 2022 (n = 43) were included only for comparative reference, since the fish were measured without head or viscera, which could affect the length and body weight estimates that will be made later.

III.3. Analysis of catch abundance

To conduct the catch abundance analysis, the general database generated from the *FIP_black skipjack tuna monitoring in Puerto Ángel from 2022 to 2025* (excluding 2022) was used. This database had been previously integrated, validated, and systematized. This information yielded 17,014 catch records, independent of size and weight data, providing a comprehensive overview of fishing activity. From this database, the most representative fishing sites were identified, considering those with the highest number of records, in order to pinpoint the most frequent operating areas of the artisanal fleet and thus establish a spatial reference for the distribution of effort and catch.

III.4. Identification of classes and cohorts with length data

Characterizing size structure is a key tool for interpreting the population dynamics of fishery resources, as it allows for inferences about processes such as recruitment, growth, and mortality. In this study, a systematic approach was used to classify the length records of the black skipjack tuna (*Euthynnus). lineatus*) obtained in Puerto Ángel, Oaxaca, during the period 2022–2025. Through the grouping of individuals into size classes and the identification of cohorts, it was possible to describe the composition of the population and generate baseline information that contributes to the understanding of the state of the resource and to decision-making for its sustainable management.

III.4.1. Classification of class intervals and cohorts.

Length class intervals (2 cm) were defined to allow the construction of a suitable size frequency distribution for analysis. Frequency histograms were generated for each year (2022, 2023, 2024, and 2025).

First, the estimation of basic indicators such as upper limit, lower limit, data range, number of classes, amplitude was proposed, in order to make a frequency histogram with the total length data and thus be able to identify the cohorts (group of fish of the same age based on their length) present most frequently, where theoretically the frequency peaks would be the average of an age group.

Subsequently, the maximum likelihood estimator (MLE) was used, and the The statistical resampling technique with replacement, " *Bootstraps* ," available in Excel, takes random samples with replacement from the original dataset ("total length, estimated parameters") and estimates more accurate parameter values for each cohort in the kite population. Subsequently, the Akaike Information Criterion (AIC) (Akaike, 1981) was used, where a lower AIC value indicates a better fit of the theoretical model to the data, which is interpreted as a better estimate of the cohorts and parameters in the black kite population.

III.4.2. Akaike Information Criterion (An Information Criterion , AIC).

It provides a simple and objective method for selecting the most appropriate model to characterize experimental data. This criterion, which falls within the field of information theory, is defined as:

$$AIC = -2\log(L(\theta)) + 2K$$

Where:

- $\log(L(\theta))$: is the logarithm of the maximum likelihood, which allows determining the values of the free parameters of a statistical model.
- K is the number of free parameters of the model.

This expression provides an estimate of the distance between the model and the mechanism that actually generates the observed data, which is unknown and in some cases impossible to characterize. Since the estimate is based on experimental data, this distance is always relative and dependent on the experimental dataset. Therefore, an individual AIC value is not interpretable on its own, and AIC values only make sense when comparisons are made using the same experimental data. However, one heuristic considers the first term of this equation as a measure of how well the model fits the experimental data, while the second would be a penalty that increases with the complexity of the model (Martínez *et al.* 2009).

Within the estimations for model comparison, a low AIC value means that the model fits the data better. In other words, this criterion allows for objective model comparison because it combines the precision of the fit with the simplicity of the structure (Martínez *et al* ., 2009).

III.4.3. Coefficient of variation

The following statistical indicators were used:

- Arithmetic mean of sizes per year (X).
- Mode of the size distribution (*peak frequency*), which may suggest possible dominant age classes.
- Standard deviation (SD) to assess dispersion
- Coefficient of variation (CV):

$$\mathbf{CV=(DE/X)\times 100}$$

This index allows for comparison of relative variability between years. If the variations are less than 30.0%, the data are considered homogeneous; conversely, if CV > 30.0%, heterogeneity is considered present. With this value, we can characterize whether the kite population exhibits homogeneous structure (sizes) either heterogeneous during the period 2022–2025.

III.4.4. Temporal comparison

A matrix was constructed with the main statistical indicators per year:

Year	**Average (cm)**	**OF**	**CV (%)**	**Mode (cm)**
2022	**39.8**	**6.4**	**16.1**	**40–42**
2023	**…**	**…**	**…**	**…**

This information was used to analyze year-on-year trends, answering some of the following questions: Does the average height decrease or increase over time? Is there a higher proportion of juveniles (smaller sizes)? Is there a loss of size?

The study also seeks to compare size structure information with fishery-related variables (when available), such as: season (dry/rainy), catch intensity, type of fishing gear used, presence of climatic events (currents, ocean surface temperature).

III.5. Size structure estimation using maximum likelihood and bootstrap .

Estimating the age structure of the black skipper (*Euthynnus) The study of the size distribution in the black skipjack tuna (Amanita lineatus*) was conducted using the maximum likelihood method (MLM) applied to total length data collected between 2022 and 2025. This statistical approach will serve as the basis for fitting the size frequency distribution to theoretical models describing population growth. To assess the accuracy of the estimated ages, a *bootstrap* resampling procedure with 1,000 replicates was used. This approach integrated fisheries statistics tools with simulation methods (*bootstrap*), increasing the reliability of the size structure estimates. The procedure successfully aligned observed and expected values, providing a robust representation of the size distribution in the black skipjack tuna population. To facilitate visual interpretation, each age was represented by a distinct color, allowing for the visualization of its relative distribution in the observed size frequency histogram.

The estimation of the parameters associated with each age was described in the following section:

III.5.1. Average length and standard deviation.

1. **Average (mean length):**

$$\bar{L} = \frac{\sum_{i=1}^{N} L_i}{N}$$

Where Li is the length of each individual within the cohort and N is the total number of individuals estimated for that cohort (observed).

2. **Standard deviation (±):**

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(L_i - \bar{L})^2}{N-1}}$$

This value indicates the dispersion of sizes within the cohort. It is reported as “mean ± standard deviation”, for example: 46.79 ± 2.17 cm.

Using the parameters obtained from the four previously identified cohorts (Fig. 7, 2023–2025 estimate), the limits for a 99% confidence interval were estimated. This was done by taking the sample mean, standard deviation, and sample size (ni) for each cohort and determining the margin of error by multiplying the critical value (approximately 2.54) by the standard error (standard deviation divided by the square root of the sample size). This margin of error was then subtracted from and added to each mean, thus obtaining the lower and upper limits of the confidence interval for the four ages. Finally, the corresponding height ranges for each of the identified ages were estimated.

III.6. Estimation of population growth parameters of the black kite (*Euthynnus lineatus*) in Puerto Àngel, Oaxaca.

The individual growth of fish is a key process for understanding population dynamics and assessing the exploitation status of a species. For the black skipjack tuna in Puerto Ángel, an approach based on size (length in centimeters) and weight data, collected between 2022 and 2025, was used to estimate population growth parameters using the Von Bertalanffy model, which is presented below.

III.6.1. Von Bertalanffy model

Von Bertalanffy function (1938) has been applied in various areas, including forestry since 1963 (Piennar & Turnbull, 1973). In fish, organismal growth is reflected in increases in size and weight at different life stages over time (Jennings *et al* ., 2001), influenced primarily by some crisis process, where temperature and food availability are the main factors that directly affect changes in body tissues (Jobling , 1985; Guerra-Sierra & Sánchez-Lizaso, 1998).

Estimating growth parameters is essential, as they constitute basic inputs for fisheries assessment models. For this purpose, nonlinear fitting methods are used, notably the maximum likelihood method employed by various authors (Kimura, 1980; Francis, 1988; Cerrato, 1990).

This model allows us to describe the growth pattern of fish over time and is expressed with the following equation **:**

$$L_t = L_\infty (1 - e^{-K(t-t0)})$$

where:

Lt : length at age t
L∞: theoretical maximum length
K : growth coefficient
t0 : theoretical age at birth with zero length

Where the asymptotic length value (**L∞):** reflects the theoretical maximum size of the species in the region, a growth coefficient (k) indicates the relative speed of approach to that length and the theoretical age (t_0) at which the organisms would have zero length.

To estimate the parameters, a size frequency matrix was constructed. Subsequently, the parameters were estimated using the Von equation Bertalanfy , using the *maximum likelihood* function and the Bootstrap *data* resampling tool in Excel. In practice, the parameters***L∞ , Lt, t0*** These values are unknown, so it was necessary to approximate them from the data calculated for the previously estimated cohorts, and later to be able to compare these direct estimates with those made by the measurements and counting of the growth lines in the barrel spines analyzed from 2013 to 2014.

III.7. Comparison and validation

The results obtained from the size structure analysis were compared with the age estimates obtained by Velásquez-Polanco in 2017, based on the study of cross-sections of black skipjack tuna dorsal spines, treated and analyzed at the Universidad del Mar, Puerto Ángel campus, Oaxaca, from October 2013 to November 2014. The following steps were taken:

The information contained in the file of spinal cross-sections was previously obtained using the following procedure:

a. **Collection of spines** : To estimate the age of the skipjack tuna (*Euthynnus) lineatus)*, the first dorsal spines of each specimen were collected directly on the beach in Puerto Ángel.

b. **Spine cleaning** : In the laboratory, the spines were immersed in hot water (60–70 °C) for three minutes to facilitate the removal of soft tissue. They were then carefully cleaned using dissecting instruments (scissors, scalpel, needles).
c. **Drying and labeling** : The cleaned spines were left to air dry for three days and were individually labeled with the data for each skipjack tuna (date, place of capture, size, weight).
d. **Measurement and marking : The distance between the upper condyles (** Dc) of each spine was measured using an electronic caliper. Then, two guide lines were marked on the spine: one at 50% and the other at 100% of the Dc distance , to define the cutting zone.
e. **Resin embedding and sectioning** : Each spine was embedded horizontally in synthetic resin. Cross-sections of the spine body were made using a precision cutter, with an approximate thickness of 0.4 mm.
f. **Observation of growth rings** : The sections were washed in 70% ethanol and observed under a microscope in dry conditions, in water, and in glycerin. Growth rings (alternating light and dark bands) were identified and counted in each section.
g. **Counting criteria** :

- ➢ **Single ring** : combination of an opaque band and a hyaline (translucent) band = 1 year.
- ➢ **Double or multiple ring** : a set of thin, grouped bands, also considered as a year if they followed a regular pattern.
- ➢ The side of the spine where more complete rings were observed was preferred.
- ➢ Highly vascularized central areas that hinder reading were ruled out.
- ➢ **Age reading:** Two readers performed independent counts to assign the preliminary age, repeating the count at different times to validate accuracy.
- ➢ **Ring reading** : The spines were analyzed under stereoscopic microscopy.
- ➢ The number of growth rings (areas of opacity and translucency) was identified.
- ➢ Each ring was interpreted as an annual or semi-annual mark (according to bibliographic validation).
- ➢ **Height-age relationship** :

    - The individual's size was associated with the number of rings observed to construct an empirical height-age growth curve.
    - This curve was compared with the one obtained by fitting morphometric data to assess consistency.

The size structures of the period 2022–2025 were compared with those inferred from the analysis of spines from 2013 to November 2014.

III.8. Drafting an information brochure

Finally, with the most relevant information obtained in this research, a draft of the information brochure was prepared, addressed to presidents of fishing cooperatives, black skipjack fishermen and the general public , with the intention of sharing the results of this research with the people who participate in the FIP, in the collection of information, and all those who are directly or indirectly interested in the artisanal black skipjack fishery in Puerto Ángel, Oaxaca, Mexico and other artisanal fisheries in developing countries.

IV. RESULTS

IV.1. Integration and systematization of the database 2022–2025 (objective 1)

The information contained in the physical and digital formats of the beach monitoring of the Fisheries Improvement Project (FIP) of the black skipjack tuna in Puerto Ángel, Oaxaca from 2022-2025, was reviewed, organized into a new structured database with the 30 fields, mentioned above, as shown in Table 1.

Table 1. Excerpt from the general monitoring database of the black kite *(Euthynnus) lineatus*) period 2022–2025.

# individuos	Año	Mes	Fecha	Sitio de referencia (Sitio_Pesca)	Coordenadas	Tipo de arte de pesca	Fase lunar durante el viaje de pesca	# Embarcaciones muestreadas (xdia)	Cooperativa	Nombre de embarcacion
1211	2024	MAYO	02/05/2024	Coyula		Curricán artesanal	Cuarto menguante	13	Curricaneros	Irene
1212	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1213	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1214	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1215	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1216	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1217	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1218	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1219	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1220	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1221	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene
1222	2024	MAYO	02/05/2024	Coyula		Curricán artesanal				Irene

IV. 2. Integration Process

A total of 2,859 records were integrated, monitored by 30 columns in Excel, distributed as shown in Table 1. The analysis found that the records of species captured from 2022 to 2025 are divided as shown below in Table 2.

Table 2. Distribution of data collected in monitoring of the FIP_ Black Kite 2022-2025.

Monitoring year	Beachfront check-ins
2022	43
2023	865
2024	1662
2025 (May)	289

IV. 3. Data validation:

These data were subjected to a preliminary review to detect inconsistencies and outliers by plotting the 2,859 total length records (cm) in an Excel scatter plot, as shown in Figure 1. From this scatter plot, 38 incomplete records with only zero data were identified and removed (outliers in the red circle of Figure 1), and approximately 490 records with capture errors were corrected (e.g. , unbelievable sizes such as 5 cm with a weight of 1,700 kg, incorrect vessel names, missing numbers, unwritten species).

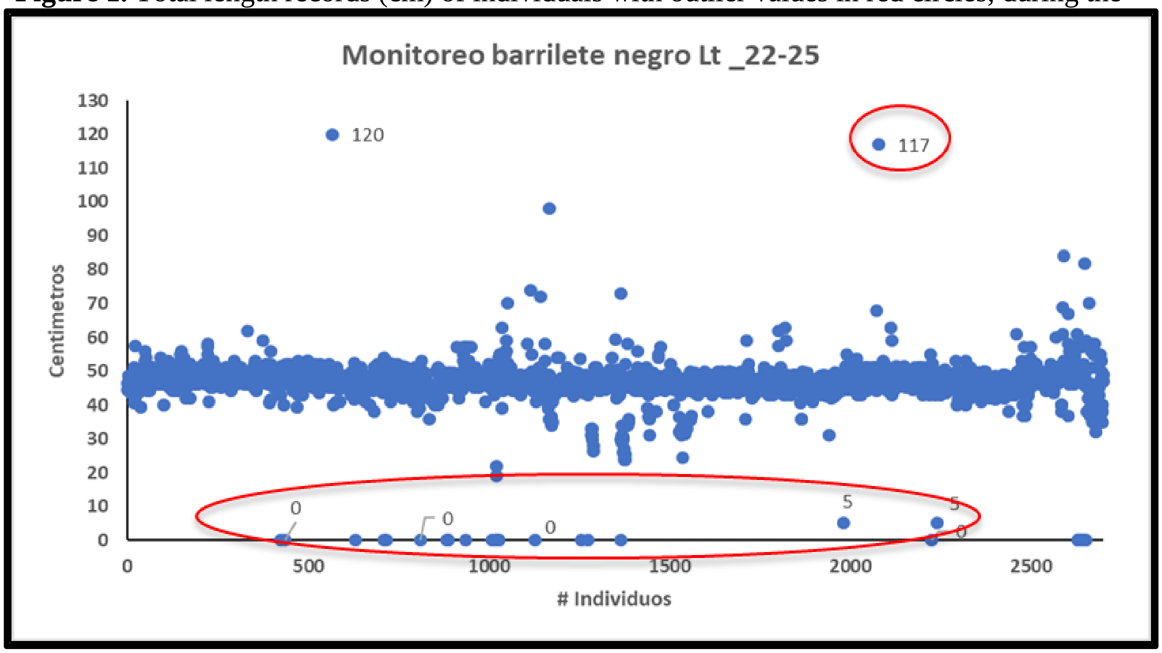


Figure 1. Total length records (cm) of individuals with outlier values in red circles, during the FIP kite monitoring 2022–2025.

IV.4. Purging and standardization.

As part of the process of cleaning the *FIP_black skipjack tuna monitoring database in Puerto Ángel 2022–2025* , all records were normalized to a standardized numerical and categorical format. Based on current knowledge of the fishery, common errors such as duplicates, records with inconsistent weights/sizes, and incorrect associations between captains and vessels were corrected. Additionally, 19 records with species incorrectly classified as black skipjack tuna, which actually corresponded to Atlantic skipjack tuna (*Sarda orientalis*) according to field observations, were removed. Finally, the absence of outliers was verified by plotting the validated and systematized database, as shown in the scatter plot (Fig. 2).

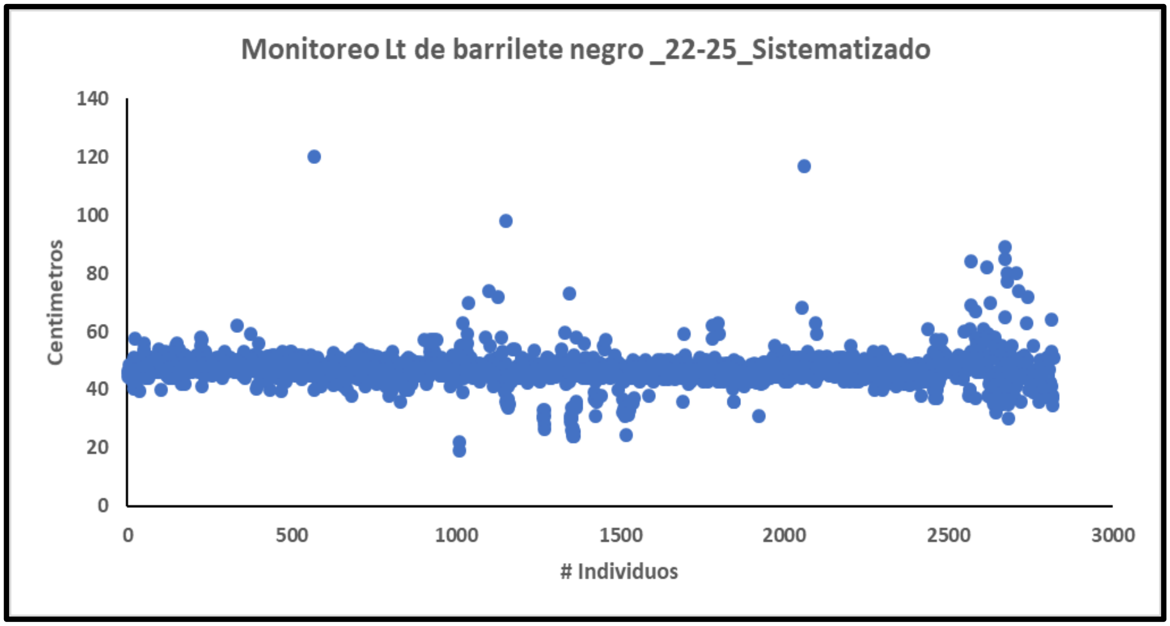


Figure 2. Dispersion of total length records (cm) of captured individuals, FIP kite monitoring 2022–2025, validated and systematized .

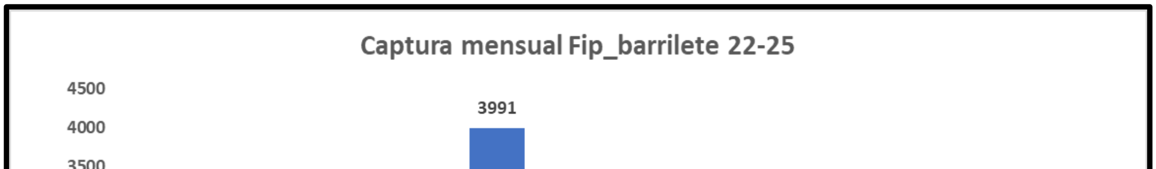
IV.5. Analysis of catch abundance

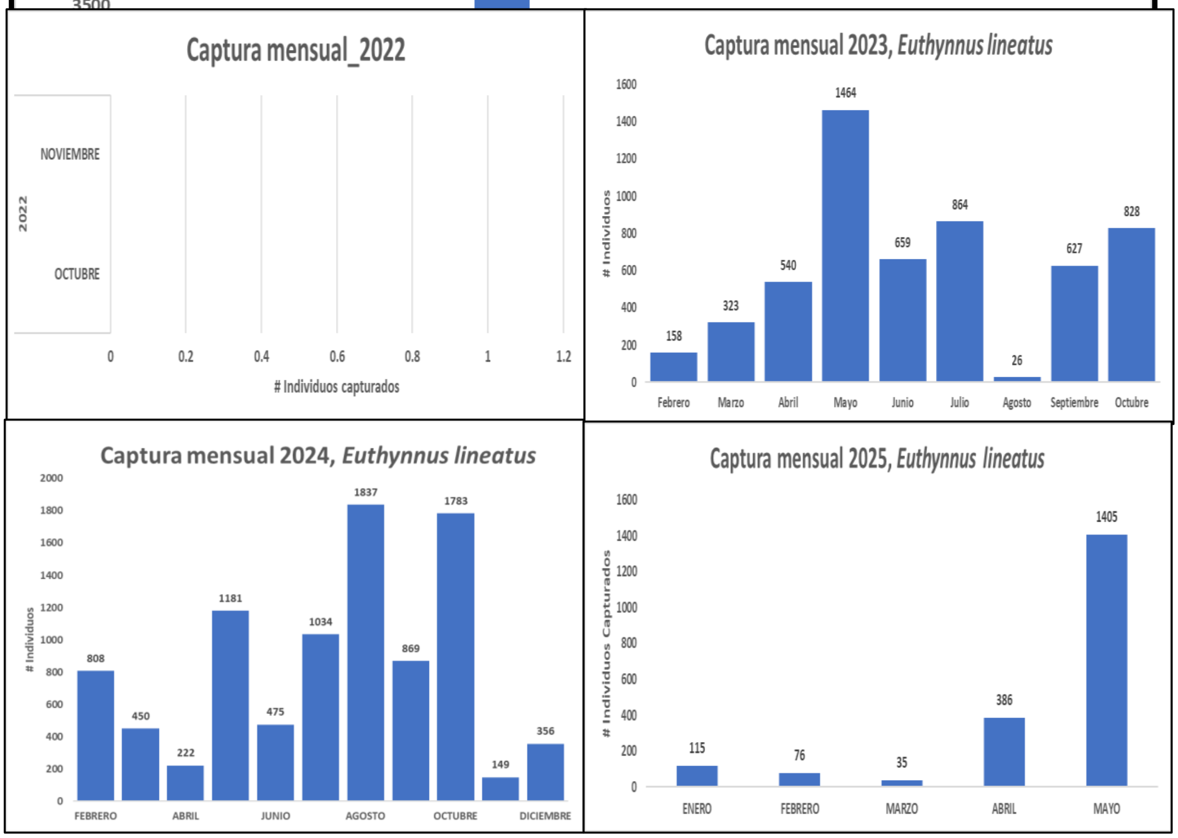
FIP_black kite monitoring database *in Puerto Ángel 2022–2025,* 17,014 catch data points were identified (distinct from the 2,859 length and weight data points monitored). For these

17,014 catch data points, the months of May, July, August, and October showed the highest catches during the 2022–2025 monitoring period, as shown in Figure 3.

Figure 3. Monthly capture within the FIP monitoring of black kite during the period 2022–2025.

The monthly distribution of total catches was then obtained, separated by monitoring year in Figure 4, where periods with higher catch intensity are observed, these being: **in 2022,**





2023 (May, July, October), 2024 (May, August, October) and 2025 (May), which will be taken into account later to see possible relationships between external conditions and the catch, as well as the months with fewer catches such as January and February, as observed below.

Figure 4. Variation in monthly catch, separated by year within the monitoring of *FIP_black kite in Puerto Ángel 2022–2025* .

In addition to the catch abundances, the total catch of black skipjack tuna by vessel was estimated, and the sites with the highest catch of black skipjack tuna were identified, dominated by five main fishing sites: *Off Salchi (1859 records), 1 mile off Puerto Ángel (1260), off Zapotengo (1170), off Tijera (1108), off Roca Blanca (1005)* , as shown in Figure 5. Following the analysis, it was identified that there are six main vessels with the highest reported catches from 2022 to 2025, these being: Kelly (1838 catches), La Odisea (1488), Santa Fe III (1441), Lichito (1434), Rebeca (1323), Arcángel (1260), which can be observed in Figure 6.

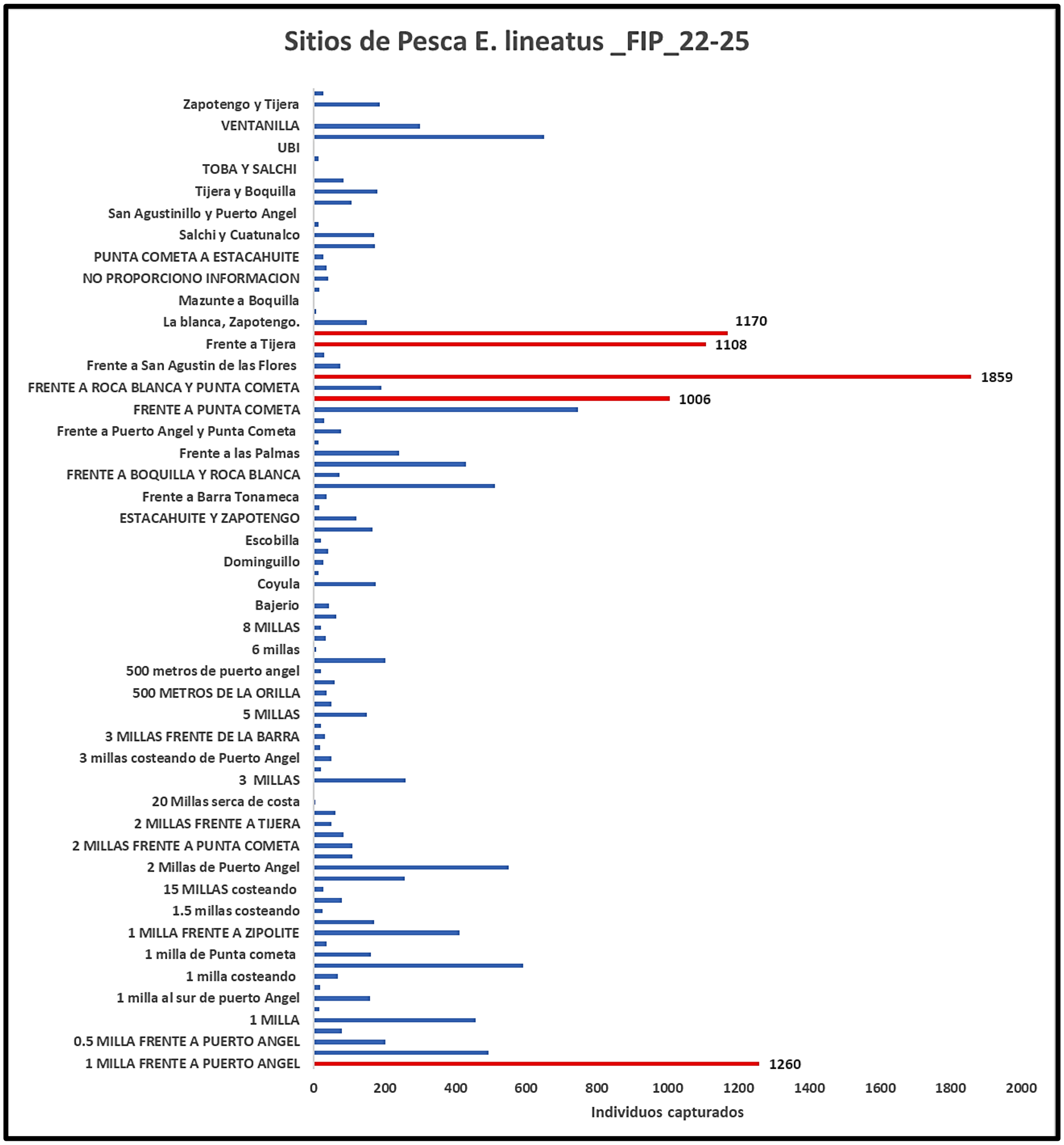


Figure 5. Fishing and catch sites for skipjack tuna (in red sites with higher catch) within the *FIP_black skipjack* tuna monitoring *in Puerto Ángel 2022–2025* .

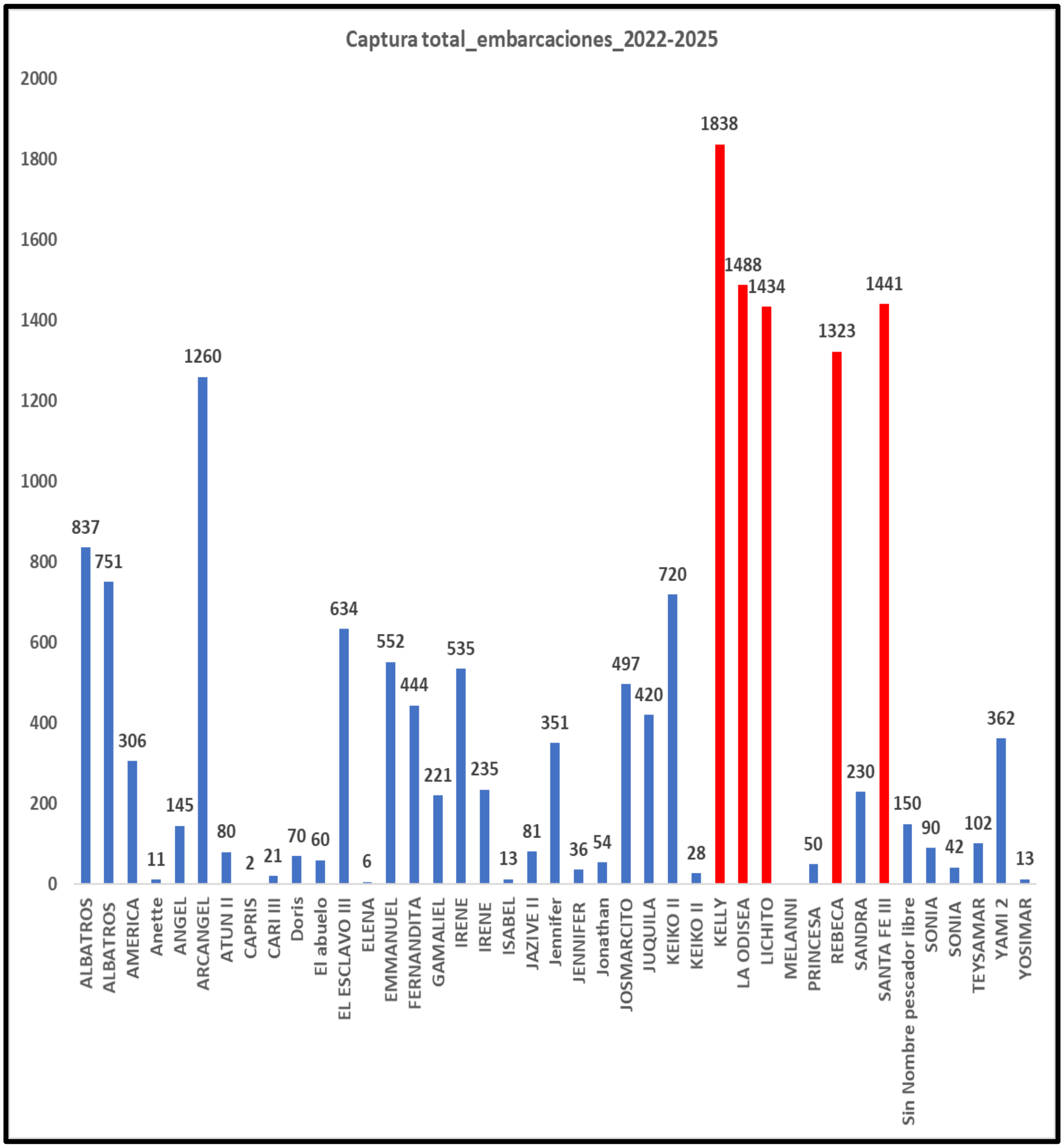


Figure 6. Variation in total catch by vessel (vessels with the highest catch in red), during the entire *FIP_black skipjack tuna monitoring period in Puerto Ángel 2022–2025*

Subsequently, the general database created was analyzed, managing to identify 13 species with 446 capture records, associated with the black skipjack fishery in Puerto Ángel, Oaxaca; where five are the main associated species: skipjack tuna, yellowfin tuna, jack, snook and sierra (fig.7) **,** the *snook species was filtered* , *being used only occasionally for comparative analysis because it is a species that was captured with hand line and artificial lures on the seashore* (observation in monitoring on the beach), as shown below in table 3.

Table 3. Species associated with the black skipjack tuna fishery during the monitoring of the *FIP_black skipjack tuna in Puerto Ángel 2022–2025* . In red, species that were captured with handline and bait.

#	Common name	Scientific name	Total number of individuals captured
1	**NEEDLE**	*Tylosurus fodiator* Jordan & Gilbert, 1882	1
2	**ALBACORE**	*Acanthocybium* Solandri (Cuvier, 1832)	2
3	**YELLOWFIN TUNA**	*Thunnus albacares (Bonnaterre , 1788)*	73
4	**TOOTH BARREL (WHITE)**	*Sarda orientalis* (Temminck & Schlegel, 1844)	330
5	**SKIPPERED TUNA**	*Katsuwonus pelamis (Linnaeus , 1758)*	2
6	**CABRILLA**	*Cephalopholis panamensis* (Steindachner , 1876)	2
7	**CHEF**	*Caranx caballus Günther, 1868*	50
8	**GOLDEN**	*Coryphaena hippurus* Linnaeus , 1758	1
9	**MACKEREL**	*Caranx caninus* Günther, 1867	53
10	**AMBERGAL**	*Seriola Rivoliana* Valenciennes , 1833	1
11	**PIRIL**	*Peruvian Seriola* Steindachner , 1881	1
12	**RED MULLET**	*Auxis brachydorax* Collette & Aadland , 1996	2
13	**SAW**	*Scomberomorus sierra*	84

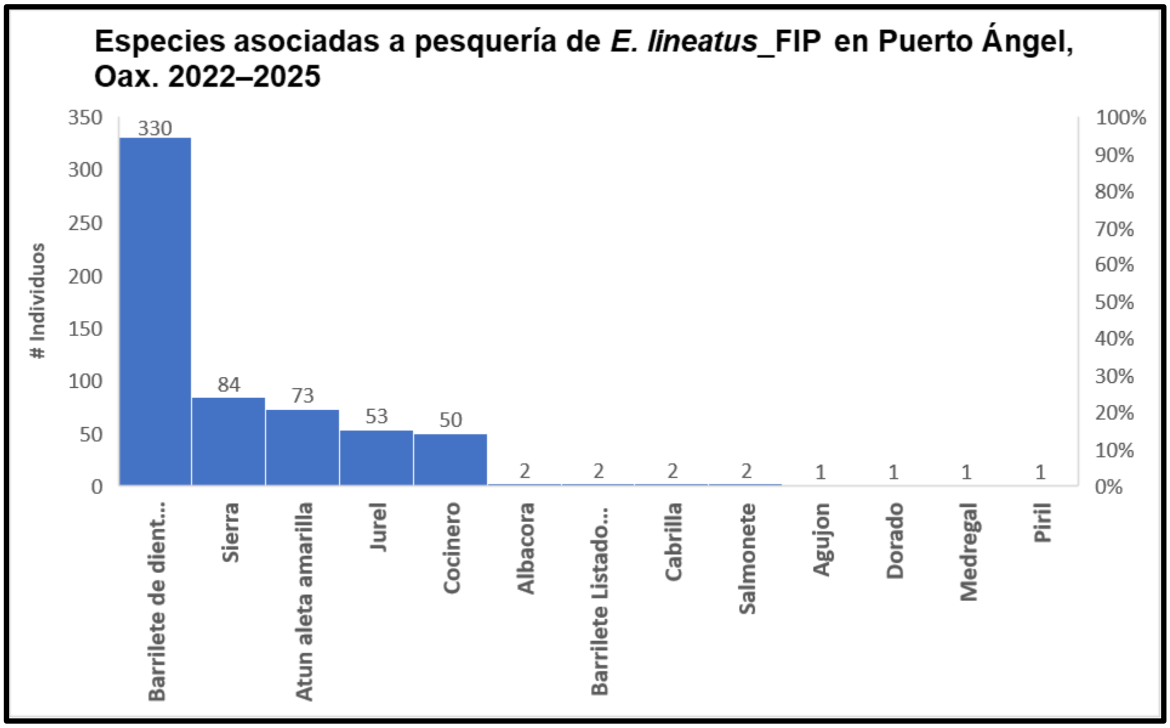


Figure 7. Species associated with the black skipjack tuna fishery (*Euthynnus) lineatus*) during the monitoring of the *FIP_black kite in Puerto Ángel 2022–2025* . Ordered from highest to lowest catch.

IV.6. Identification of classes and cohorts with length data.

A subset of 2,644 validated records with complete information on total length (cm) and weight (g) was created, corresponding to individuals captured between October 2022 and May 2025. The data were organized into separate Microsoft Excel spreadsheets, assigning each record a unique identifier and classifying them by year and month of monitoring.

IV.6.1. Cohorts within the black skipjack tuna fishery from 2022-2025.

This temporal organization made it possible to group and observe trends in the total length distribution over time, as well as calculate two different estimates for the number of age cohorts per year and choose the best estimate and fit considering the Akaike criterion, as shown in Table 4. The summary of records by year is shown below:

Table 4. Summary of the statistical indicators used to estimate the cohorts within the black skipjack tuna fishery 2023 to 2025. In red, the lowest values obtained with the Akaike criterion.

Year	No data	Lower limit	Upper limit	Range	No Classes	Class size	No cohorts	Akaike Information Criteria
2023	833	36.0	59.0	23.0	11	2	3	2737.67166
2023	833	36.0	59.0	23.0	11	2	4	2741.782549
2023	832	36.0	59.0	23.0	11	2	5	2748.78177
2024	1570	16	60	44	12	2	4	5111.974243
2024	1570	16	60	44	12	2	5	5148.114319
2025	200	20	58	38	9	2	4	1741.83376
2025	200	20	58	38	9	2	3	891.6951524
2022-2025	2603	24.5	60	35.5	13	2	4	9095.938564
2022-2025	2603	24.5	60	35.5	13	2	5	9445.387766

, the frequency histograms per year were constructed from the analysis and adjustment between observed and predicted data applying the maximum likelihood method (MLM) and Bootstrap resampling (1,000 repetitions) to estimate the average parameters of each identified cohort as shown below in Figure 8.

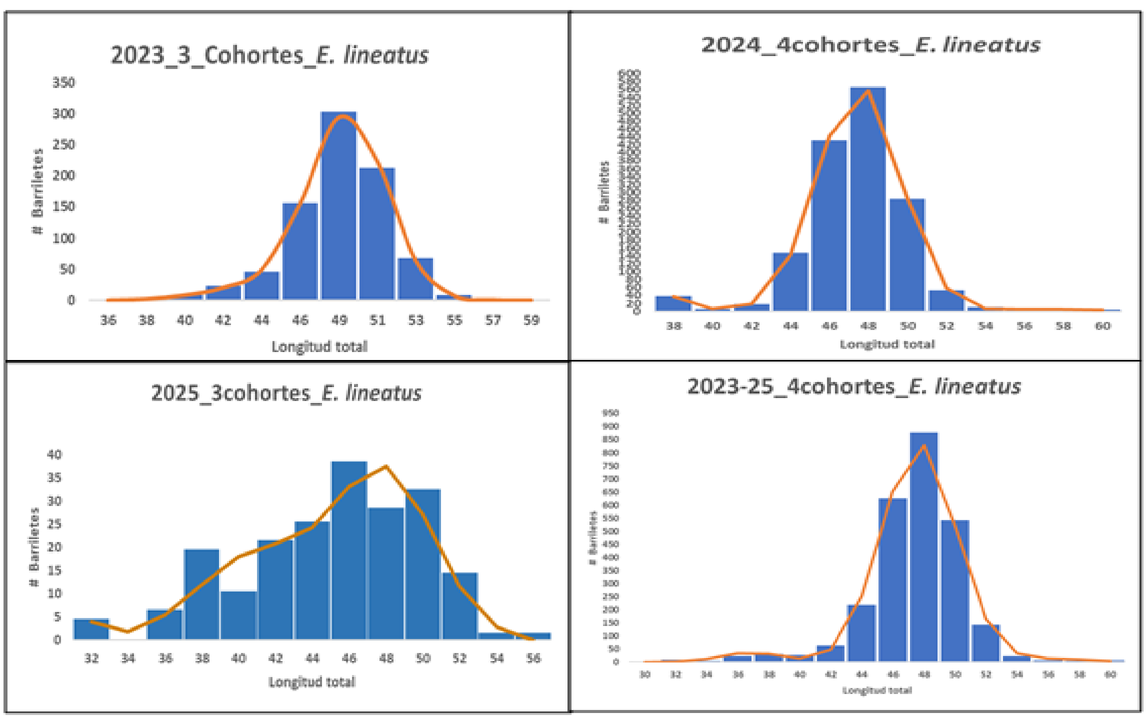


Figure 8. Total length frequency histograms (cm), from 2023 to 2025, adjusted with maximum likelihood (MLL) and the *bootstrap* resampling tool for the *FIP_black kite in Puerto Ángel 2022–2025.*

IV.6.2. Size structure estimation through maximum likelihood and bostrap

Based on the parameters obtained for the four previously identified cohorts (Fig. 7, 2023-25 period), the limits for a 99% confidence interval were estimated. A margin of error was calculated, allowing the lower and upper limits of each estimate to be obtained and the length ranges corresponding to each age to be described with greater certainty, as shown in Table 5.

Table 5. Summary of statistical indicators, confidence interval, frequency associated with the ages identified within the black skipjack tuna fishery 2022 to 2025.

99%	Confidence interval-4 cohorts_22-25			99% confidence
LimINF	LimSUP	Interval cm	Ages	Obs. frequency
33.9	35.0	33.9- 35.0	6	53.8
40.6	41.6	40.6- 41.6	7	93.8
46.7	46.9	46.7-46.9	8	2,404.1
50.8	52.5	50.8-52.5	9	53.0

For these four ages corresponding to the identified cohorts, the best fit between the observed and expected data was sought, through recalculation in Excel (maximum likelihood method (MLM) and resampling *Bootstrap*). With this procedure it was possible to estimate the size structure for the population of the black kite in Puerto Ángel, Oaxaca, identifying four cohorts corresponding to four main ages being 6, 7, 8 and 9 years (colored lines) with their respective confidence intervals and the associated parameters for each age (table 5, 6, and figure 9).

Table 6. Average total length (cm), standard deviations and number of individuals (estimated and observed) for ages 6 to 9 years of the black kite (*Euthynnus lineatus*) during 2022 to 2025.

Age	**6**	**7**	**8**	**9**
Average	34.4910853	41.1130027	46.7881272	51.6518302
Deviation est	1.6006792	1.90799239	2.17136635	2.39708347
Nor (estimated)	53.7864145	93.8061891	2404.13666	53.0164151
Neither (observed)	54	94	2404	53

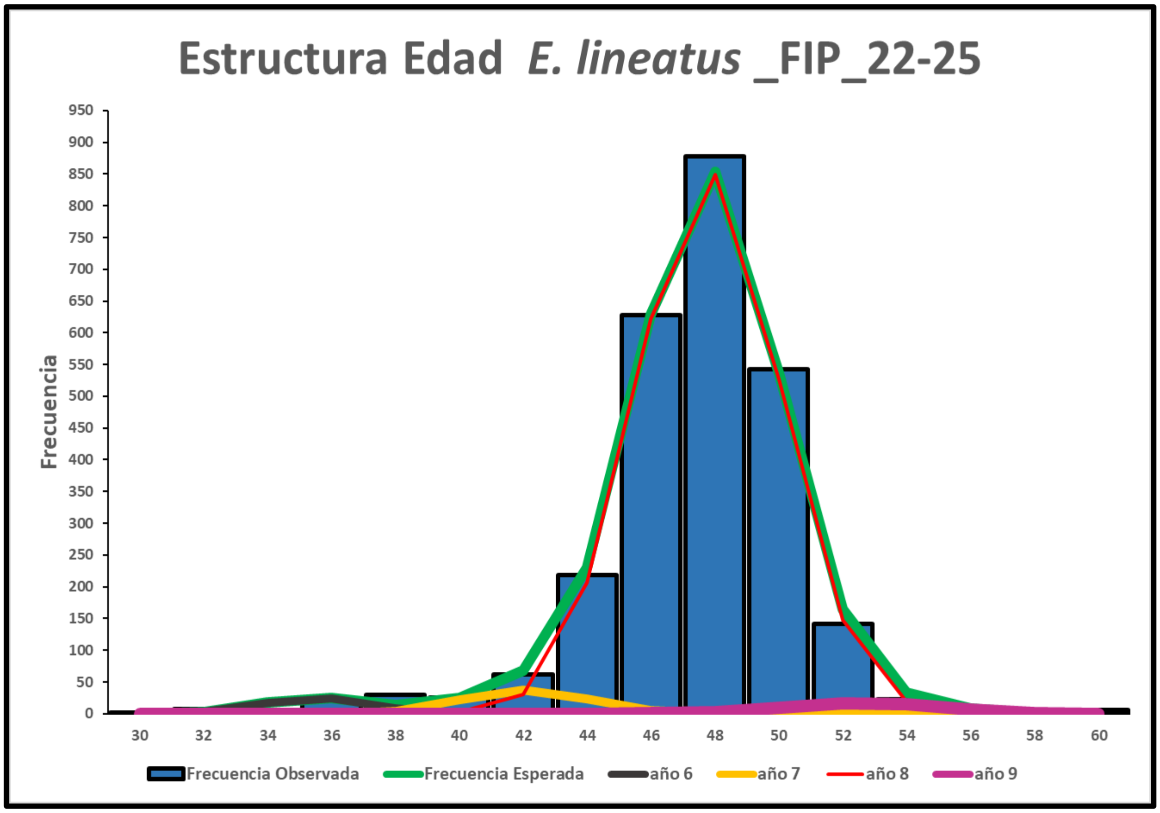


Figure 9. Frequency distribution of observed and estimated lengths of *Euthynnus lineatus* (2022–2025), with identification of ages between 6 and 9 years (color lines) in the artisanal fishery of Puerto Ángel, Oaxaca.

The histogram and data fit in Figure 9 show that the highest concentration of individuals was around 8 years old, with approximately 2,404 records and a length range of 46.7–46.9 centimeters (Table 5). This coincides with the dominance of black skipjack tuna captures within this length range in centimeters during each beach monitoring visit to Puerto Ángel. This graphical representation, which contrasts the observed frequencies (blue bars) with the estimated frequencies (green line), demonstrates the consistency of the identified ages (Figure 9).

IV.6.3. Coefficient of variation and Temporal comparison

Subsequently, some indicators were estimated to calculate the coefficient of variation (CV), as shown below in Table 7, to show the trend in the data.

Table 7. Summary of the statistical indicators used to estimate the coefficient of variation and its fluctuations within the skipjack tuna fishery 2022-2025. In red, the year 2024, with CV outliers.

Year	Average (X)	Fashion	Std . Dev .	CV (%)
2022	45.5	46.5	2.05	4.51
2023	47.5	48	2.57	5.40
2024	49.7	47	31.52	63.46
2025	44.5	45	5.23	11.74
22-25	46.8	47	3.25	6.94

Since the variations in CV, in table 5 are less than 30.0%, it can be inferred that the sizes of black skipper found during the monitoring are homogeneous, except for the year 2024.

IV.7. Population growth parameters of the black kite (*Euthynnus lineatus)* *with the* Von Bertalanffy Model

Population growth parameters of the black kite (*Euthynnus) The population growth parameters (lineatus*) were estimated using the von Bertalanffy model, maximum likelihood, and *Bootstrap validation* in Excel. The following values were obtained for the population growth parameters, as shown in Table 8.

The following table compares the von Bertalanffy growth parameters for *Euthynnus. lineatus* (Black skipjack) in the Pacific Ocean, including the estimates from the present research

Table 8. Comparison of von Bertalanffy growth parameters for *Euthynnus lineatus* in the Pacific Ocean

Parameter	**Your Estimate**	**FishBase 20**	**Velásquez-Polanco, in 2017**
L_∞ (cm)	80.81	60 common (max 84.0)	52.17
k (years^{-1})	0.15	Not reported	0.47
t_0 (years)	2.39	Not reported	3.73
Standard deviation	0.046	Not reported	Not reported

IV.8. Comparative population structure: FIP 2022–2025 vs. 2013–2014

Figure 10 presents the frequency histograms of the length of *Euthynnus lineatus* and their respective fit polygons. In the case of the monitoring carried out during the *FIP (2022–2025)* in the artisanal fishery of Puerto Ángel, Oaxaca (Figure 10a), the size structure was concentrated between 30 and 60 cm, corresponding to black skipjack tuna of 6 to 9 years of age, with a predominance of 7 and 8 years. The expected fit showed a narrow unimodal distribution, which suggests a relatively homogeneous population in the range of sizes observed.

In contrast, in the sampling previously carried out in the same area (Costa Chica, Oaxaca) from October 2013 to November 2014 (Figure 10b), the length structure showed a mode around 50 cm, with a wider range of variation (25–70 cm). The shape of the distribution was more symmetrical and less skewed, reflecting greater heterogeneity in size composition.

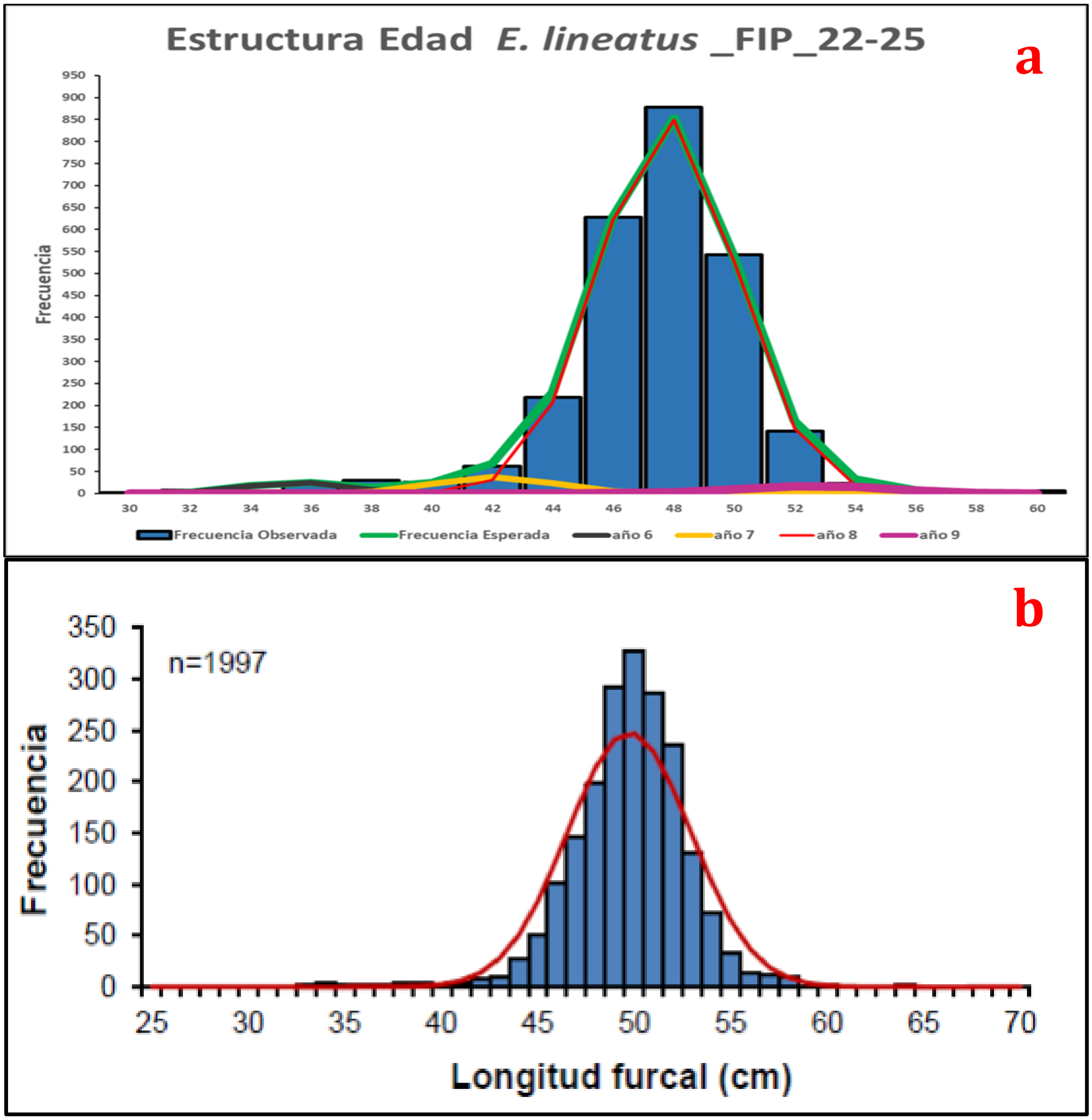


Figure 10. Frequency histograms of length (bars) and its fitting polygon for *Euthynnus lineatus* captured during: (a) monitoring in the *FIP of 2022–2025* , with ages of 6 to 9 years (color lines) artisanal fishery of Puerto Ángel, Oaxaca, and (b) the period of October 2013-November 2014 on the small coast of Oaxaca, Mexico.

Velásquez-Polanco, in 2017, identified, through analysis of the rings present in the cross-sections of the spines of the skipper, 10 estimated age groups, ranging from 2 to 11 years. The most frequent estimated age group was 8 years, with data from 2013 to 2014 (Figure 11).

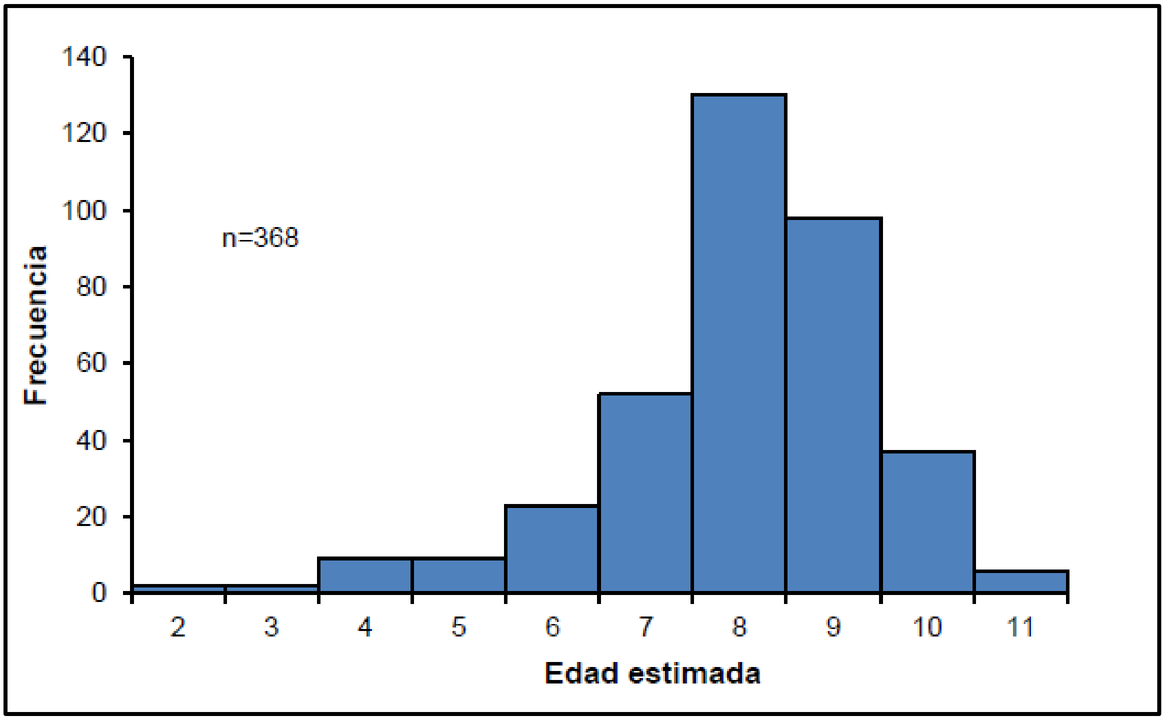


Figure 11. Frequency histogram of estimated ages based on the location method (bone cuts).

V. DISCUSSION

Analysis of the monitoring of the artisanal fishery of the black skipjack tuna (*Euthynnus) lineatus*) in Puerto Ángel, Oaxaca (2022–2025), allowed the generation of a robust and validated database, with biological and capture information (table 1) that constitutes a key input to characterize the population structure of the species in the region, as well as future research for the FIP of black skipper.

V.1. Fishing sites and predominant fleet in the artisanal fishery of *E. lineatus*

Spatial analysis of catches of the black kite (*Euthynnus) A survey of the black skipjack tuna (Ortega-García et al., 2000*) in Puerto Ángel between 2022 and 2025 revealed that fishing activity is concentrated in five main sites: off Salchi (1,859 records), 1 mile off Puerto Ángel (1,260), off Zapotengo (1,170), off Tijera (1,108), and off Roca Blanca (1,005). These fishing sites represent recurring areas of schooling, suggesting favorable oceanographic and bathymetric conditions for the black skipjack tuna, such as food availability and current dynamics that favor primary and secondary productivity, as described for other areas of high fishing importance in the eastern Pacific (Ortega-García *et al.,* 2000). The recurrence of the artisanal fleet in these areas indicates accumulated local knowledge about the distribution of the resource.

At the operational level, six vessels accounted for the highest catches during the monitoring period (2022 and 2025): Kelly (1,838 catches), La Odisea (1,488), Santa Fe III (1,441), Lichito (1,434), Rebeca (1,323), and Arcángel (1,260). This pattern reflects a fishing effort structure where a few vessels dominate production, possibly due to the greater experience of their crews, longer fishing times per day, and precise knowledge of fishing grounds. The variation among vessels suggests that, in addition to the natural availability of the resource, there are fishing efficiency factors that influence total catches, highlighting the importance of integrating the human and operational dimensions into the characterization of the fishery within the black skipjack tuna fishery.

V.2. Fishing dynamics of the black skipjack tuna (*Euthynnus) lineatus*) and environmental seasonality.

Analysis of the 17,014 catch records between 2022 and 2025 showed that the highest catch abundances for the black skipper (*Euthynnus) The presence of *Pyrax lineatus* * is concentrated in **May, July, August, and October (peak catches, Fig. 3),** demonstrating a close relationship between fishing dynamics and environmental seasonality on the Oaxacan coast. This pattern has already been documented in other pelagic species, such as the mahi-mahi in La Paz Bay, where horizontal and vertical movements are associated with water temperature and depth (Martínez-Rincón *et al.,* 2009).

These peak catches of black skipjack tuna coincide with the beginning and development of the rainy season from May to October (Trasviña & Barton, 1997), a period in which oceanographic factors such as sea surface temperature and nutrient input can favor food availability and, consequently, the aggregation of schools. Furthermore, Ramos-Cruz (2009) documented an increase in the condition factor in *E. lineatus* between **November and March,** reaching a maximum in the latter month, which was interpreted as a stage of sexual conditioning prior to reproduction or spawning.

Additionally, the oceanographic processes of the Gulf of Tehuantepec (GT) reinforce this relationship between the environment and population dynamics. Ortega-García *et al* . (2000) highlight that, in this area, high annual productivity is maintained due to its physiographic and bathymetric characteristics, which ensures a constant food base for pelagic species such as *Euthynnus. lineatus* . For their part, Ayala-Duval *et al. (1998) reported that* zooplankton biomass reaches intermediate values in January, maximums in May and minimums in November, with nuclei of greater density in the western part of the gulf during January, in the east during May and with a more dispersed distribution in November.

In this regard, the synchronicity between the peak catches in May (present study), the peak planktonic biomasses (maximum in May and minimum in November) during the rainy season, and the previously reported increase in the condition factor of *E. lineatus* (**November and March**), suggests that the catch abundance dynamics reported in this research could be influenced by both the environmental availability of food during the rainy season and the reproductive pulses of *E. lineatus* in the coastal zone off Puerto Ángel, Oaxaca. Additionally, the data from this research show that skipjack tuna tend to increase in weight before and during May, subsequently decreasing in weight.

V.3. Species associated with the black skipjack tuna fishery

Of the 17,014 catch records, only 446 corresponded (2022-2025) to 13 bycatch species, which confirms that their capture is incidental and minimal in the artisanal fishery of Puerto Ángel. This low proportion is explained by the high selectivity of artisanal trolling, which has used large hooks and lures specifically designed for black skipjack tuna for several decades, reducing the probability of catching small species.

However, the associated species caught in the *E. lineatus fishery* , mainly skipjack tuna (*Sarda orientalis*), yellowfin tuna (*Thunnus albacares*), and jack mackerel (*Caranx The skipjack tuna (E. caninus*) and Spanish mackerel (*Scomberomorus sierra*) are used for human consumption and sold directly on the beach, contributing to the comprehensive use of these resources. This pattern coincides with that reported in other artisanal tuna fisheries using highly selective gear, such as the pole and line fishery in the Maldives, where bycatch represents only 0.65% of the total 147 tons caught between August 2014 and November 2015, and where 95% of these bycatch species are utilized (Miller *et al.,* 2017). Consequently, the Puerto Ángel fishery should be considered as targeting the skipjack tuna (*E. lineatus*), with bycatch being an incidental component.

V.4. Cohort structure and sizes

The analysis of the subset of 2,644 validated *Euthynnus records The study of black kites (Euphorbia lineatus)* , captured between October 2022 and May 2025, identified four main cohorts corresponding to ages of 6, 7, 8, and 9 years, with a marked predominance of 8-year-old black kites (2,404 records; length range 46.7–46.9 cm, Tables 5 and 10). Cohort estimation was performed using length frequency histograms, adjusted using the maximum likelihood method (MLM) and *bootstrap* resampling , considering the Akaike information criterion to select the optimal number of cohorts per year (Table 4, Figure 8). The 99% confidence intervals for each cohort allowed for the precise definition of the length ranges associated with each age (Table 5), while the length averages, standard deviations, and numbers of observed and estimated individuals (Table 6) confirmed the consistency of the identified ages. The comparison with the estimates obtained by spine cuttings in 2013–2014 by Velásquez-Polanco, in 2017 showed a correspondence in the age structure and length in cm (figure 9 and table 9), validating the reliability of the indirect methods of EMV and *Bootstrap* to describe the current population.

Table 9. Comparison of length and age parameters of *Euthynnus lineatus* on the coast of Oaxaca

Study / Source	Length range (cm)	Fashion / Frequent Length (cm)	Age range (years)	Predominant ages	Estimation method
Present study (FIP 2022–2025)	24.5 – 60	48–50	6 – 9	7 and 8 years old	Size histograms (maximum likelihood and bootstrap)
Velásquez-Polanco (2017)	25 – 70	~50 (intermediate concentration)	2 – 11 (6 – 9 (mainly)	8 years	Spine sections (rings) Size histograms

The temporal analysis of the coefficient of variation (CV) showed homogeneous values (<30%) for 2022, 2023, and 2025, while a significant increase was recorded in 2024 (CV = 63.46%), likely associated with environmental variations or changes in fishing effort (Table 7). These findings demonstrate the robustness of the cohort and age estimates, the predominance of 8-year-old individuals in the artisanal black skipjack tuna fishery (Table 9), and the need to consider fishing gear selectivity and temporal variability when evaluating the population dynamics of *Euthynnus. lineatus* in Puerto Ángel, Oaxaca.

V.5. Population growth parameters with Von Bertalanffy.

Population growth parameters estimated from the Von Bertalanffy equation, for *Euthynnus The lineatus* in the artisanal fishery of Puerto Ángel, Oaxaca, presented in Table 8 ($L\infty$ = 80.81 cm; k = 0.154 a^{-1}; t_0 = 2.39 years), reflect a population with relatively slow growth, but with the potential to reach larger sizes than those reported in previous studies. In comparison, Velásquez-Polanco (2017) reported $L\infty$ = 52.17 cm and k = 0.47 a^{-1} (Table 8), which shows faster growth in early stages, but with smaller size limits. These differences may stem from both the methods used and local ecological factors. In the current monitoring within the FIP, the maximum recorded size was 60 cm, a value lower than the L∞ estimated with the von Bertalanffy model (table 8), which suggests that the largest individuals of the population are not yet being captured and that the observed size structure is influenced by the selectivity of the fishing gear, specifically the artisanal trolling, designed for skipjack tuna with large hooks, which tends to capture medium and large specimens, leaving out juveniles.

When comparing the results with international databases, such as FishBase (≈84 cm; Froese & Pauly , 2025) and Biogeodb (92.5 cm; Smithsonian Tropical Research) Institute , 2025), the L∞ estimated here falls within this range, reinforcing the biological validity of the estimates. The lower maximum size values observed during monitoring highlight the importance of considering fishing gear selectivity when interpreting size data, as it can bias the perception of population structure.

This suggests that the population maintains a relatively balanced size structure, with lower risks of early overexploitation by continuing to use the artisanal line and trolling capture method (high selectivity), as opposed to using nets where sizes are not respected, nor is it selective for species, provided that the capture of skipjack tuna is properly managed locally.

Taken together, the findings of this research highlight that the population parameters of *Euthynnus Lineatus* are highly sensitive to the estimation methodology, the selectivity of the fishing gear (artisanal trolling), as well as environmental factors and local fishing pressure. Therefore, it is essential to complement size frequency analyses (histograms and von Bertalanffy model) with validation techniques using calcified structures, such as the analysis of bone sections. Furthermore, it is recommended to reinforce This information is combined with reproductive studies, including the gonadosomatic index and histological analysis of gonads to identify maturation and the presence of mature oocytes. Integrating these approaches will allow for more robust estimates to support sustainable management strategies for the artisanal black skipjack tuna fishery within the *Puerto Ángel 2022–2025 Fisheries Investment Fund (FIP_barrilete negro)* on the coast of Oaxaca.

V.6. Comparative population structure: FIP 2022–2025 vs. 2013–2014

Comparing the size and age structure of *Euthynnus The presence of the black skipjack tuna (FIP_barrilete negro*) on the coast of Oaxaca shows both consistent patterns and contrasts depending on the sampling period and methodology. In the current monitoring of the FIP_barrilete negro in Puerto Ángel (2022–2025), the captured specimens were predominantly between 24.5 and 60 cm in length, with a mode close to 48–50 cm, corresponding to age classes of 6 to 9 years. The 7- and 8-year-old groups stood out, representing the majority of the individuals recorded (≈43% of the total). In contrast, the sampling carried out in 2013–2014 (Velásquez-Polanco, 2017) covered a wider range, from

25 to 70 cm, with a mode also close to 50 cm, reflecting greater heterogeneity in the population composition and possibly greater environmental variability or differences in fishing effort during those years.

Additionally, the spine analysis conducted by Velásquez-Polanco (2017) reported ages of *E. lineatus* between 2 and 11 years, with the 8-year-old group predominating (28.6% of the total). This demonstrates that the use of calcified structures allows for the identification of extreme cohorts—juveniles smaller than 30 cm and adults larger than 65 cm—which are not clearly detected in size frequency histograms. Our findings are in partial agreement with global reference databases, as FishBase indicates that *E. lineatus* reaches maximum sizes of 84 cm (Froese & Pauly , 2025), while Biogeodb reports a size distribution range of 25–80 cm on the eastern Pacific coast (Biogeodb , 2024). Comparing these sources and local studies underscores that population growth and structure estimates depend on both the methodological approach and regional ecological and fishing conditions, making it necessary to integrate different lines of evidence to strengthen the understanding of the population dynamics of the black skipper in Puerto Ángel.

Finally, the differences in the age structure of *Euthynnus The lineatus* between the *2022–2025 FIP* and the 2013–2014 sampling reflects methodological and ecological factors. Recent monitoring showed a predominance of intermediate ages (6–9 years; Figure 9, Table 5), while the 2013–2014 record presented greater heterogeneity and extreme cohorts of 2 to 11 years (Figures 10 and 11), probably associated with environmental variations, resource availability, and differences in fishing selectivity. The observed overlaps between both periods are explained by the combination of size histograms and bone analysis as a cross-validation method, which allows for the confirmation of consistent age ranges, and by biological factors of the species, which could be generating a predominance of intermediate-age catches in the black skipjack tuna fishery in Puerto Ángel, Oaxaca. This methodological integration strengthens the population characterization and allows for the detection of both juveniles and adult skipjack tuna that might be overlooked with a single approach.

VI. CONCLUSIONS

VI.1. Database and capture log

17,014 capture records were consolidated, with 2,644 validated records of *Euthynnus lineatus* between 2022 and 2025, generating a robust and validated base with biological and fisheries data, constituting a key input for population characterization and management strategies within the *FIP_black kite in Puerto Ángel 2022–2025* .

VI.2. Fishing sites and predominant fleet in the fishery.

Monitoring the artisanal fishery of *Euthynnus The study of black skipjack tuna* in Puerto Ángel (2022–2025) shows that catches are concentrated in five main fishing sites: **off Salchi, one mile off Puerto Ángel, Zapotengo, Tijera, and Roca Blanca (Fig. 5),** reflecting aggregation areas associated with favorable oceanographic conditions (Ortega-García *et al* ., 2000). Furthermore, six vessels **—Kelly, La Odisea, Santa Fe III, Lichito, Rebeca, and Arcángel** (Fig. 6)—accounted for the largest catches, demonstrating the influence of fishing effort and local knowledge on catch patterns. These findings indicate that the dynamics of black skipjack tuna catches depend on food availability, environmental conditions, crew experience, and possibly longer fishing times per day—key factors to consider when designing management strategies for the Puerto Ángel Fisheries Management Area.

VI.3. Capture dynamics and seasonality

Analysis of catch records for the *black skipjack tuna fishery in Puerto Ángel (2022–2025)* shows that peak abundances of *E. lineatus* occur in May, July, August, and October, closely related to the environmental seasonality of the Oaxacan coast (Fig. 3). These peak catches for black skipjack tuna coincide with the rainy season (May–October), when sea surface temperature and nutrient input favor the aggregation of schools (Trasviña & Barton, 1997), a pattern also described in other pelagic species (Martínez-Rincón et al., 2009).

zooplankton biomass productivity of the Gulf of Tehuantepec, peaking in May and reaching its lowest point in November (Ayala-Duval *et al.*, 1998), confirms this link. Likewise, the increase in the condition factor of *E. lineatus* between November and March, with a peak in the latter month (Ramos-Cruz, 2009), suggests a reproductive preparation phase. Overall, abundance during these peak catch periods (May, July, August, and October) would be regulated by food availability during the rainy season (May–October) and the reproductive pulses (November and March) in the black skipjack tuna fishery off the coast of Puerto Ángel, Oaxaca.

VI.4. Associated species and selectivity

Of the 17,014 records, only 446 (≈2.6%) correspond to 13 species associated with human consumption (Fig. 7), with a predominance of four species: skipjack tuna (*Sarda orientalis*), yellowfin tuna (*Thunnus albacares*), jack mackerel (*Caranx caninus*) and sierra (*Scomberomorus sierra*). This confirms the high selectivity of the artisanal black skipjack fishery in Puerto Ángel using artisanal trolling, with minimal incidental catch and comprehensive use of bycatch species, justifying the recommendation to include *S. orientalis* and *T. albacares* in the FIP. The absence of smaller sizes in the records (2022–

2025) is due to the selectivity of the trolling, whose number and hook size direct the catch to specimens larger than 20 cm; therefore, although juvenile *E. lineatus* were present in the ecosystem, their presence was not recorded in the beach monitoring.

VI.5. Cohort structure and sizes

From the analysis of the 2,644 validated records (October 2022–May 2025), the following were identified for the *Euthynnus population Lineatus* in Puerto Ángel, Oaxaca, to four cohorts corresponding to ages from 6 to 9 years, with a predominance of 8-year-old skipjack tuna (2,404 individuals; 46.7–46.9 cm). For the present study, the CV was homogeneous (<30%) in 2022, 2023 and 2025, indicating that the population has homogeneous sizes and ages, except for 2024 with a CV of 63.46% (Table 7), reflecting temporal variability in the population for that specific year, possibly associated with environmental factors or changes in fishing effort.

VI.6. Population growth parameters

Euthynnus were estimated using the Von Bertalanffy equation. *lineatus* In Puerto Ángel, Oaxaca, the following parameters were observed: $L\infty$ = 80.81 cm, k = 0.15 a^{-1}, and t_0 = 2.39 years (Table 8). These parameters reflect the potential of the black skipjack tuna population to reach sizes larger than those recorded during beach monitoring (60 cm). The maximum recorded size of 60 cm (2022–May 2025) is less than the estimated $L\infty$ (80.81 cm), indicating that the artisanal trolling primarily captures medium and large individuals. The high value of t_0 estimated in this study (t_0 = 2.39 years) is due to the absence of juveniles during beach monitoring and the predominance of adult sizes (40 to 60 cm), a result of the artisanal trolling's selectivity. Therefore, it should be interpreted with caution as a methodological rather than a biological effect.

VI.7. Comparative population structure: FIP 2022–2025 vs. 2013–2014

The size and age structure for the *Euthynnus population The lineatus* sample in Puerto Ángel, Oaxaca (FIP 2022–2025) shows a distribution dominated by adult black skippers between 40 and 60 cm and ages of 6–9 years, with the 8-year-old group dominating (46.7–46.9), while Velásquez-Polanco (2017) also identified 8-year-old groups as predominant (28.6%) and detected juveniles <30 cm and adults over 65 cm, corresponding to 10–11-year-old adults, which were more evident in the spine cut analyses (Figure 11).

However, the maximum observed sizes of 60 cm (FIP 2022–2025) and the estimated ages (6–9 years) are within the international ranges reported by FishBase (84 cm, common 60 cm) and Biogeodb (25–80 cm), which confirms that the age estimates of the present work for *Euthynnus The lineatus* in Puerto Ángel reflects the expected population growth dynamics, validating the reliability of the estimates obtained as shown in Figure 12

Taken together, this structure confirms the predominance of intermediate classes in the catches of the artisanal black skipjack tuna fishery (artisanal trolling line) and validates the representativeness of the sampling (2022 to 2025) against the known population dynamics for the species, as we seek to represent it in the fusion of both age structure estimates in figure 12.

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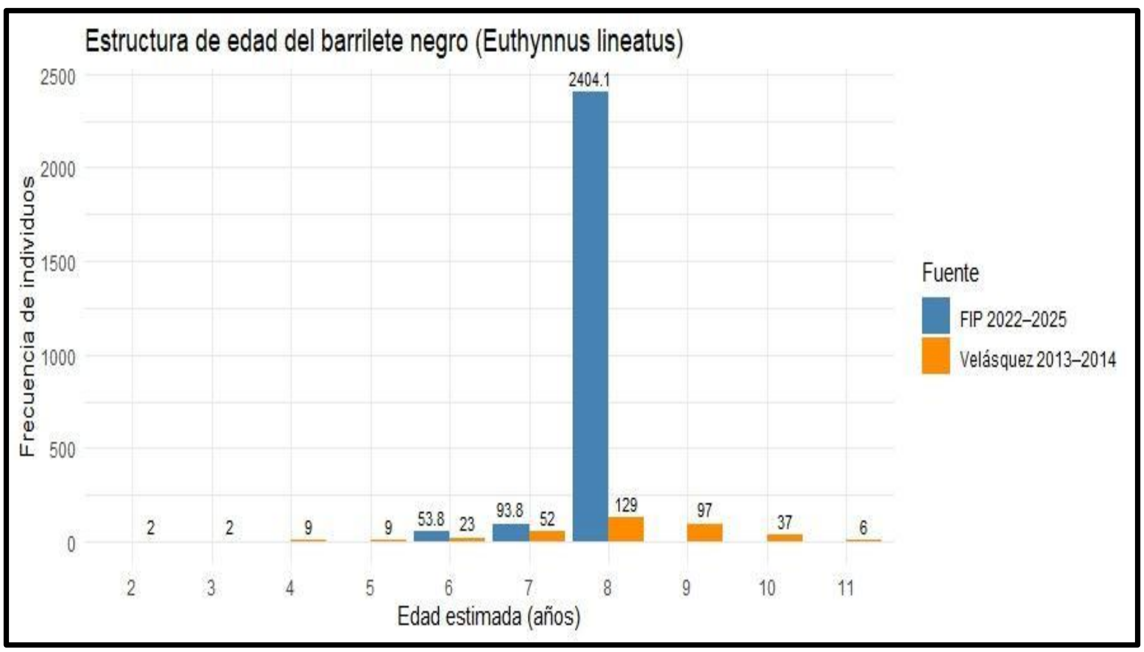

Figure 12. Representation of the age structure for the *Euthynnus population lineatus* in Puerto Ángel, Oaxaca by merging the estimates through size (FIP 2022–2025) and through growth lines in cross-sections of spines (Velásquez-Polanco 2017).

VI.8. Catches and operating costs of the artisanal black skipjack tuna fishery

The artisanal fishery of *Euthynnus The lineatus* fishing project in Puerto Ángel for the 2022–2025 FIP (Fishing and Fishing Program) showed catches with an average length of 42.25 cm and a weight of 1.86 kg, with black skipjack tuna ranging from 24.5 cm (0.616 kg) to 60 cm (3.5 kg). The beach sale price fluctuated between $15 and $70 pesos per skipjack tuna, averaging $42.5 pesos from 2022 to 2025, indicating direct sales that reduce additional costs. However, operating costs were concentrated in fuel consumption, averaging 17 liters, equivalent to $437.5 pesos (at the gasoline price per liter for the sampling month and year), and an average fishing time of 2.15 hours, factors that affect economic efficiency.

The total effective catch recorded (length and weight measurements) during the present monitoring was 5,619.8 kilos of black skipjack tuna, reflecting that the profitability of this fishery depends mainly on the size of the skipjack tuna caught and the purchase price on the beach (manipulated by buyers and hoarders), which underlines the need for the implementation of the FIP, which seeks to revalue (add value) the black skipjack tuna to strengthen its economic, ecological and social sustainability in Puerto Ángel Oaxaca.

Kite monitoring increased significantly from 2023 onwards. This could reflect an operational maturation of FIP monitoring over time and likely greater involvement of vessel captains, which improves the reliability of future results.

In conclusion, these results provide solid evidence for the management of the black skipjack tuna fishery in Oaxaca, although it will be necessary to complement the analyses with detailed environmental variables and sexual maturity studies to assess the long-term sustainability of the resource.

VII. MANAGEMENT RECOMMENDATIONS

1. Recognize and promote the active participation of women and young people, relatives of fishermen, in value-added and marketing processes for the appropriation of the processes carried out in the UBI.
2. Promote black skipjack tuna fishing with artisanal trolling (not gillnets) , due to high selectivity and establish it as a core sustainability practice.
3. Include within the *FIP_black skipjack tuna in Puerto Ángel* , the species skipjack tuna (*Sarda orientalis*) and yellowfin tuna (*Thunnus albacares*), due to availability, selectivity of the fishing gear, and high demand in the region.
4. Perform histological studies of gonads to determine size and age of first maturity, to complement the present analysis and thus know the breeding season exactly.

5. To provide official and social recognition to the fishermen who participate in the FIP, generating identity and community pride.
6. It is recommended not to integrate 2022 data into trend analysis unless it is supplemented with additional information (because they are gutted kites).

In conclusion, the identified patterns allow us to move towards an adaptive management model. As the analyses of effort, maturity, and mortality are completed, more precise recommendations can be generated, and eventually, formal local management measures based on evidence generated from the FIP can be proposed.

As an external input, after the delivery of this consultancy, the data generated will serve for the preparation of a scientific article (manuscript in preparation) that will be submitted for publication in an indexed journal with a fisheries focus, strengthening the dissemination of results and the scientific evidence of the *FIP_black skipjack tuna in Puerto Ángel* , Oaxaca.

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