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# Morphologic and Morphometric Analysis of the Otoliths: Sagitta, Asteriscus and Lapillus of Kajikia audax and Makaira mazara (Perciformes: Istiophoridae) in the Mexican Pacific Coast

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## ABSTRACT

*In the present study morphologic and morphometric analysis is carried out for striped marlin Kajiria audax and blue marlin Makaira mazara for the first time in the three pairs of otoliths: sagittae, asterisci and lapilli. K. audax data were obtained from 2000 to 2002 in 4 tournaments in Barra de Navidad and Manzanillo (ports on the Pacific coast of México) and 8 fishing cruises in two commercial vessels. For M. mazara only eight data were obtained in 2001 in tournaments of Puerto Vallarta and Manzanillo and two commercial cruises. As with other billfishes, sagittae are characterized by having four bodies: a rostrum and antirostrum separated by the excisura major and a postrostrum and pararostrum separated by an excisura minor; being this a peculiar character observed in these species and in the dolphinfish. The growth of the three pairs of otoliths is eccentric to the core; a larger quantity of material is deposited in the dorsal areas and borders, in relation to the ventral areas. No statistically significant morphometric differences were observed between the right and left otolith and between sexes of K. audax. Seasonal growth rings could not be observed in the sagittae, but were present in some asterisci. Results are discussed with those reported by other authors. It is recommended that studies of daily growth increases in one-year organisms or less be carried out. We suggest that a capture quota of this fishery is given to the commercial fisherman.*

**Key words:** *Kajikia audax, Makaira mazara,otolith, sagitta, asteriscus, lapillus.*

## INTRODUCTION

The distribution of the striped marlin Kajikia audax (Philippi 1887)is in template and tropical waters of the Pacific and Indic Oceans between 45° North Latitude and 35-40° South Latitude (Nakamura 1974). The blue marlin Makaira mazara(Jordan & Snyder 1901) is broadly distributed in tropical waters and templates of the Atlantic and Pacific Oceans(Mather et al. 1975).

In the case of *K. audax* there are few studies on the biology of these species (Eldridge & Wares 1974). Ponce et al. (1991) analyzed the length distribution; González-Armas (1993) reported striped marlin larvae in the Mexican Pacific; Abitia *et al*. (1997) wrote of the species that feed the striped marlin; Ueyanagi & Wares (1975) reported an analysis of length frequency. Melo-Barrera & Uraga (2004) studied length and age structure of the striped marlin Tetrapturus audax (also Kajikia audax) in Cabo San Lucas, Baja California Sur, México.

Also, Prince et al. (2005) studied migrations and spawning aspects of the white marlin Tetrapturus albidus and the blue marlin Makaira mazara in Punta Cana, Dominican Republic. Likewise, studies on *M.mazara* are scarce.

According to this, the objectives of this study are: analyze the morphology of the sagitta, asteriscus and lapillus of the striped marlin and the blue marlin; carry out the morphometric analysis of the otoliths of the striped marlin and the variations respect right and left otoliths and their gender;

identify the growth rings and compare results obtained by other authors.

## Materials And Methods

The striped marlin Kajikia audax data were obtained from 2000 to 2002 in 4 tournaments in Barra de Navidad, Jalisco and Manzanillo, Colima (ports on the Pacific coast of México), and during 8 fishing cruises in two commercial vessels in Mexican Pacific.

Only eight data were obtained of blue marlin Makaira mazara in 2001 during tournaments in Puerto Vallarta, Jalisco and Manzanillo, Colima, México and two commercial cruises. Organisms were captured with long line and hand line.

Measurements were taken in situ for each organism: eye to fork length (EFL, cm) and sex. Sagittae, asterisci and lapilli were obtained by doing a transversal cut in the organism's skull, removing the brain, and extracting the semi-circular canals (left and right). Otoliths were liberated from the optic capsules, sagittae from sacculus, asterisci from lagena and lapilli from utriculus, and cleaned in water and dried. They were preserved dry in Eppendorf tubes with the number of the organism, capture date, eye to fork length and sex.

The structure and microstructure of the otoliths were studied with a scanning electronic microscope, from the Institute of Physics of the Universidad Nacional Autónoma de México.

Otoliths were analyzed with a dissecting microscope. The terminology of the Sector et al. (1992) glossary was used to describe the sagittae of this species. In the case of the asterisci and lapilli, similar concepts were used for their description as in Gallardo-Cabello et al. (2006, 2011, 2012, 2014, 2016 and 2017) and Espino-Barr et al. (2006, 2013 and 2015).

Measurements of the length and width of the three pairs of otoliths (right and left) were registered, with the help of a graduated measuring ocular in the microscope. Sample size was corroborated (Daniel 1991).

Regressions by least squares were used to calculate the relationship constants of the sagitta rostrum length (SL) vs. antirostrum length (SA) and width (SW). In the case of the asterisci and lapilli, the regression indexes were only used for length (L) vs. width (W). The allometric relationships between total length of the fish and the length and width of each otolith were also obtained by least square regression.

A one way variance analysis (ANOVA) (Zar 1996) was used to determine if there were morphometric differences between male and female otoliths, and between right and left otolith.

## Results

### Kajikia Audax

The sample was of 285 individuals: 106 females, 168 males and 11 undetermined. Organisms' sizes were 165.0cm average eye-fork length (from 104.0 cm to 212.0 cm) and average total weight of 32.7 kg (from 9.0 kg to 66.2kg).

The calculated sample sizes of otoliths are: for sagitta 213 individuals, asteriscus 162and lapillus 221.

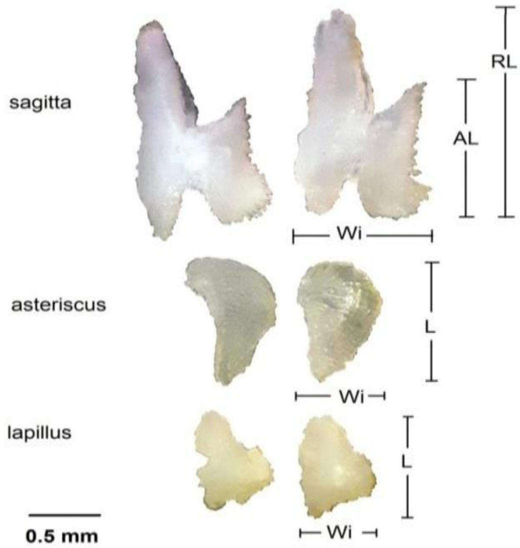


**Figure1**. *Relationship between the three pairs of otoliths of Kajikia audax: left the external aspect, right the internal aspect; RL = rostrum length, AL = antirostrum length, Wi = width, L = length.*

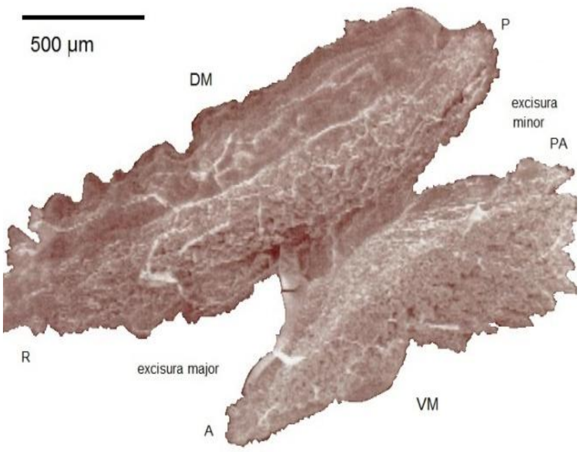


**Figure2.** *Scanning photograph of the right sagitta internal aspect of Kajikia audax. R= rostrum, A= antirostrum, P= postrostrum, PA = pararostrum, D= dorsal margin, V= ventral margin.*

## Description of the otoliths of Kajikia audax

Description of the sagitta. Billfish sagittae are, in general terms, very small if compared with other bony fish and very fragile. The excisura major (divides the otolith in a bigger rostrum oriented towards the frontal part of the fish, and a shorter antirostrum and thicker. The excisura minor divides the otolith's posterior area in a postrostrum and a pararostrum of similar size (Figs. 1, 2).

The acoustic canal is very well developed, very broad and deep (Fig. 3), and it covers the entire surface of the sagitta, increasing its amplitude from the front to the back. Unlike other otoliths of bony fish, this does not show a differentiation in ostium and cauda.

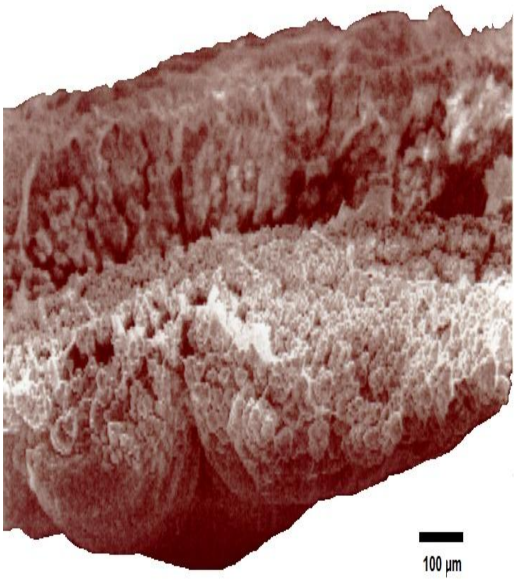


**Figure3.** *Scanning photograph of the base of the acoustic canal, in the right sagitta internal aspect of Kajikia audax, showing the calcic carbonate crystals.*

The external aspect is concave and the internal face is convex. This character is accentuated as the age of the individual increases. The sagittae show a differential growth with respect to the core, that is, the rostrum grows more than the postrostrum and the pararostrum more than the antirostrum, therefore more material is deposited in the dorsal than in the ventral side. Growths in sagittae are eccentric to the core.

The dorsal margin shows a first part with many irregularities that diminish towards the medium part of the sagitta and the posrostrum. The ventral border presents many denticles in the pararostrum, showing a serrated structure. The internal aspect of the sagitta is convex, characteristic that increases with age. The external aspect of the sagitta is concave, thicker towards the medium part. In the sagitta darker lines can be observed, both inside and on the edges, which correspond to growth rings of different periodicities. There was no difference between the right and left *sagittae* ($F'_{0.05\ (2,\ 213\ =3.86)}$ = 2.600), nor between females and males ($F'_{0.05(2,\ 248\ =\ 3.865)}$ = 2.747).The average width of the sagitta (SW) is 0.59 times its average length (SL).

## Description of the asteriscus

The shape of the asterisci can vary in the specimen (Fig. 1), but there are no statistical differences between the length of right and left otoliths ($F'_{0.05(2,\ 155\ =\ 3.875)}$ = 0.798). Also, between females and males, no difference was found in the asterisci ($F'_{0.05(2,\ 164\ =\ 3.877)}$ = 0.337).A blunt projection is present in the anterior margin which divides the *asteriscus* in two areas: a dorsal area with a larger surface than the ventral area (Fig. 4). The anterior margin presents a serrated surface from the dorsal border to the ventral. Similarly, the ventral edge also presents irregularities along its entire length.

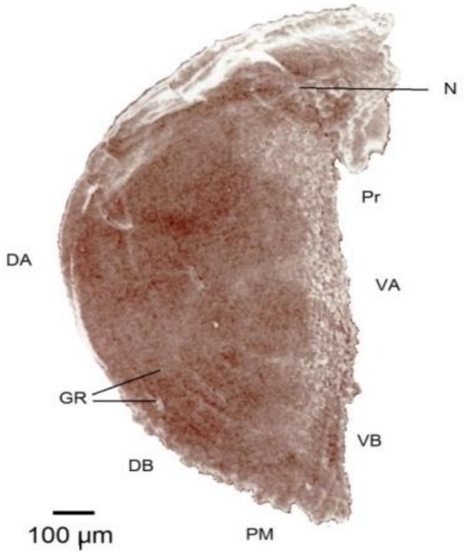


**Figure4.** *Scanning photograph of the right asteriscus, internal aspect of Kajiki aaudax: Pr= projection, N= core or primordia, DA = dorsal area, VA = ventral area. GR = growth ring, DB =dorsal border, VB = ventral border, PM = posterior area.*

The posterior margin is curved and shows irregularities. This curved section presents a groove all around the dorsal and ventral margin; on the surface of the asterisci calcium carbonate crystals are present, forming the seasonal periodicity growth rings (Figs. 5, 6). The external aspect is convex and the internal aspect is concave this feature increases as the fish ages. Small indentations are present in both aspects of the asteriscus (Figs. 1, 4, 5). The average length of the asteriscus (AL) is 1.82 times its average width (AW).

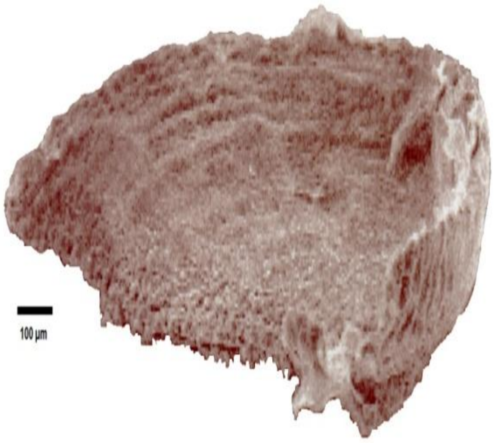


**Figure5.** *Scanning photograph of the right asteriscus, internal aspect of Kajika audax, showing lateral details of the otolith.*

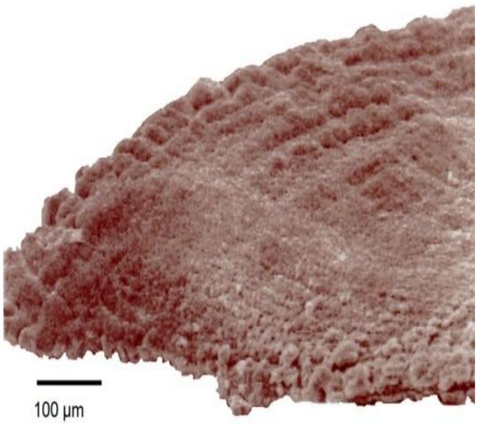


**Figure6.** *Scanning photograph of the right asteriscus, internal aspect of Kajikia audax, showing details of the calcic carbonate crystals design.*

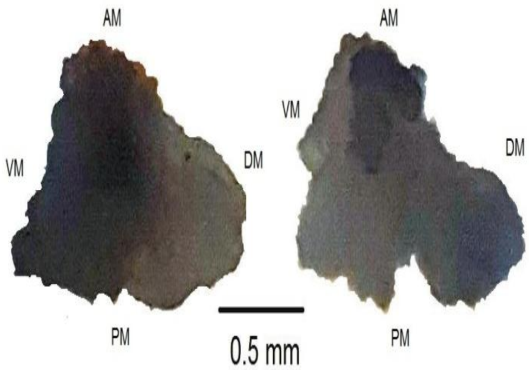


**Figure7.** *Photographs of both lapilli of Kajikia audax: left side internal aspect, right external aspect. DM = dorsal margin, VM = ventral margin, AM = anterior margin, PM = posterior margin.*

## Description of the lapillus

The anterior margin of the lapillus is oriented toward the front of the fish and can be rounded or completely irregular (Figs.1, 7, 8).In figure 9 it is observed that the anterior margin shows the appearance of the crest, although this structure can vary from one otolith to another, between left and right or from one organism to the next. Dorsal and ventral margins show a rounded structure similar to a fan. The ventral border can be rounded and of a smaller size than the dorsal border, which can be elongated. The posterior margin can present big variations between right and left otolith as observed in figure 7, where the left lapillus shows a huge notch in the posterior margin, not present in the right lapillus.

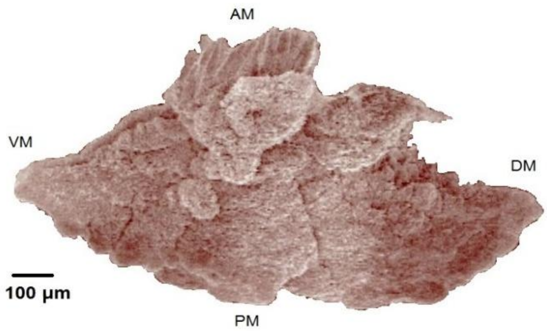


**Figure8.** *Scanning photography of the left lapillus external aspect of Kajikia audax. DM = dorsal margin, VM = ventral margin, AM = anterior margin, PM = posterior margin.*

The external aspect of the lapillus shows an enormous variety of carbonate calcic crystals organized in different groups whose sizes and orientation vary in very different ways, and could be related to the transmission of the impulses of the eighth cranial nerve (Figs. 8, 9).

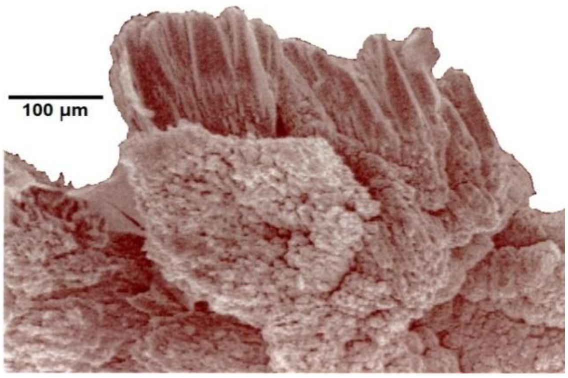


**Figure9.** *Scanning photography of the details of the left lapillus external aspect of Kajikia audax.*

The inner lapillus surface is concave, a feature which increases with age. The otolith is divided in several lobes by radios. In the posterior margin the lapillus comes into contact with the acoustic macula through which the deposition of both calcium carbonate and otoline is carried out, and the impulses to the eighth cranial nerve and the brain are transmitted. The outer aspect is convex; its dorsal margin shows indentations and other irregularities, which become smaller at the ventral margin (Fig. 8).

No difference between the right and left lapilli were found ($F'_{0.05\ (2,\ 200=3.864)}$ = 0.037), nor between females and males ($F'_{0.05(2,\ 267\ =\ 3.865)}$ = 1.865). Average length of the lapillus (LL) is 1.08 times its average width (LW)

## Morphometric analysis of otoliths of Kajikia audax

*Growth of the sagitta.* Table 1 shows the relation between rostrum, antirostrum and width of sagitta and the length classes for the species and sexes. Growth of the rostrum of sagitta is bigger in females at lengths of 100 cm to 200 cm. From 210 to 220 cm on, the rostrum's length is the same in males and females. In all cases the rostrum has a longer size than the antirostrum.

**Table1.** *Calculated measures of rostrum (SL), antirostrum (SA) and width (SW) of sagitta at different size classes de eye-fork length of Kajikia audax.*

| | Both sexes | | | females | | | males | | |
|---|---|---|---|---|---|---|---|---|---|
| Classes (cm) | SL (mm) | SA (mm) | SW (mm) | SL (mm) | SA (mm) | SW (mm) | SL (mm) | SL (mm) | SW (mm) |
| 100 | 1.72 | 1.23 | 1.02 | 1.75 | 1.22 | 1.02 | 1.69 | 1.22 | 1.00 |
| 110 | 1.83 | 1.31 | 1.08 | 1.86 | 1.30 | 1.08 | 1.80 | 1.30 | 1.07 |
| 120 | 1.94 | 1.38 | 1.14 | 1.96 | 1.37 | 1.14 | 1.91 | 1.38 | 1.13 |
| 130 | 2.04 | 1.45 | 1.20 | 2.06 | 1.45 | 1.19 | 2.02 | 1.45 | 1.20 |
| 140 | 2.14 | 1.52 | 1.26 | 2.16 | 1.52 | 1.25 | 2.12 | 1.52 | 1.26 |
| 150 | 2.23 | 1.59 | 1.31 | 2.26 | 1.59 | 1.31 | 2.22 | 1.59 | 1.32 |
| 160 | 2.33 | 1.66 | 1.37 | 2.35 | 1.65 | 1.36 | 2.32 | 1.66 | 1.37 |
| 170 | 2.42 | 1.72 | 1.42 | 2.44 | 1.72 | 1.41 | 2.42 | 1.73 | 1.43 |
| 180 | 2.51 | 1.79 | 1.47 | 2.53 | 1.78 | 1.46 | 2.51 | 1.79 | 1.48 |
| 190 | 2.60 | 1.85 | 1.52 | 2.62 | 1.84 | 1.51 | 2.60 | 1.86 | 1.54 |
| 200 | 2.68 | 1.91 | 1.57 | 2.71 | 1.91 | 1.56 | 2.70 | 1.92 | 1.59 |
| 210 | 2.77 | 1.97 | 1.62 | 2.79 | 1.97 | 1.61 | 2.79 | 1.98 | 1.64 |
| 220 | 2.85 | 2.03 | 1.67 | 2.87 | 2.03 | 1.65 | 2.87 | 2.04 | 1.70 |

The relationship between length of rostrum and length of antirostrum of sagitta is expressed by the exponent value b = 0.723 (Table 2), which shows a negative allometric growth (Fig. 2). In the case of sexes, results show the same tendency and the relationship between rostrum and antirostrum length of sagittain males is b = 0.753 and females b = 0.696. In all cases the growth is negative allometric, which means that the rostrum tends to enlarge as the fish grows old.

**Table2.** *Relationships between the rostrum and antirostrum and width of the sagitta of Kajikia audax.*

| Sagitta length (mm) | | a | b | n | $r^2$ | F |
|---|---|---|---|---|---|---|
| Antirostrum | Both | 0.905 | 0.723 | 410 | 0.499 | 409.145 |
| Width | | 0.874 | 0.543 | 388 | 0.288 | 157.856 |
| Antirostrum | Females | 0.918 | 0.696 | 145 | 0.487 | 137.936 |
| Width | | 0.872 | 0.532 | 140 | 0.266 | 51.400 |
| Antirostrum | Males | 0.883 | 0.753 | 247 | 0.508 | 255.385 |
| Width | | 0.867 | 0.556 | 230 | 0.297 | 97.649 |

The relationship between rostrum's length and sagitta's width shows higher values of negative allometric growth, that is, the sagitta tends to enlarge more in length than width with a significant negative allometric growth index of b = 0.543 in all the individuals, b = 0.532 in females and b = 0.556 in males (Table 2). There is a trend to diminish the width of the sagittal, where the rostrum and antirostrum come closer as they develop, to have more contact with the acoustic macula and increase the transmission to the brain through the eighth cranial nerve. Growth of the sagitta changes as the organism ages. There are morphologic differences between right and left sagittae and with other individuals. Results also show that the growth of the sagitta is eccentric with respect to the nucleus and that the growth of the rostrum is different from that of the postrostrum, which grow differently in the dorsal and ventral borders, and that different amounts of material are deposited on the internal and external aspects.

The relationship between fish length and length and width of sagitta is shown in Table 3. The higher value of the allometric index relating fish length to rostrum length is for the males with a value of b = 0.672, smaller values are found for the species (all organisms) and females, b = 0.636 and b = 0.631, respectively. In the case of fish length and antirostrum, the observed values were for all organisms: b= 636, lower values were calculated for males b = 0.653 and females b = 0.640. The higher values between length of the fish and sagitta's width were in males (b = 0.665), and for the species, was b = 0.625 and b = 0.616 for females. In all cases negative allometric growth values were observed, that is, the sagittae do not grow.

**Table3.** *Relationship between eye-fork length and rostrum length (SL), antirostrum (SA) and width (SW) of sagitta of Kajikia audax.*

| | | a | b | $R^2$ | F | n |
|---|---|---|---|---|---|---|
| SL (mm) | All individuals | 0.0918 | 0.6369 | 0.252 | 140.000 | 413 |
| | Female | 0.096 | 0.631 | 0.321 | 70.032 | 147 |
| | Male | 0.077 | 0.672 | 0.240 | 79.033 | 248 |
| SA (mm) | All individuals | 0.066 | 0.636 | 0.245 | 134.750 | |
| | Female | 0.064 | 0.640 | 0.332 | 72.999 | |
| | Male | 0.060 | 0.653 | 0.211 | 67.415 | |
| SW (mm) | All individuals | 0.057 | 0.625 | 0.242 | 124.240 | |
| | Female | 0.059 | 0.616 | 0.294 | 58.940 | |
| | Male | 0.047 | 0.665 | 0.229 | 69.040 | |

## Growth of the asteriscus

The relationship between fish length and length and width of asteriscus is shown in Table 4. The length of the asterisci is larger in males of the length classes from 100 cm to 130 cm; from 180 cm to 220 cm, the length is bigger in females than in males.

**Table4.** *Calculated measures of length (AL) and width (AW) of the asteriscus at different size classes of eye-fork length Kajiki audax.*

| | Both sexes | | Females | | Males | |
|---|---|---|---|---|---|---|
| **Classes (cm)** | **AL (mm)** | **AW (mm)** | **AL (mm)** | **AW (mm)** | **AL (mm)** | **AW (mm)** |
| 100 | 1.18 | 0.63 | 1.17 | 0.63 | 1.19 | 0.63 |
| 110 | 1.26 | 0.68 | 1.25 | 0.67 | 1.27 | 0.68 |
| 120 | 1.33 | 0.72 | 1.32 | 0.71 | 1.34 | 0.72 |
| 130 | 1.40 | 0.76 | 1.39 | 0.75 | 1.41 | 0.77 |
| 140 | 1.47 | 0.80 | 1.47 | 0.79 | 1.47 | 0.81 |
| 150 | 1.53 | 0.84 | 1.53 | 0.83 | 1.54 | 0.85 |
| 160 | 1.60 | 0.88 | 1.60 | 0.87 | 1.60 | 0.90 |
| 170 | 1.66 | 0.92 | 1.67 | 0.91 | 1.66 | 0.94 |
| 180 | 1.72 | 0.96 | 1.73 | 0.94 | 1.72 | 0.98 |
| 190 | 1.78 | 1.00 | 1.80 | 0.98 | 1.78 | 1.02 |
| 200 | 1.84 | 1.04 | 1.86 | 1.01 | 1.84 | 1.06 |
| 210 | 1.90 | 1.07 | 1.92 | 1.05 | 1.90 | 1.10 |
| 220 | 1.96 | 1.11 | 1.98 | 1.08 | 1.95 | 1.14 |

The relationship between the length and width of the asterisci (Table 5) is described for the species by the allometric index b = 0.578 ($r^2$ = 0.259, F' = 99.074); higher values were obtained for males b = 0.653 and smaller for females b = 0.620. These results show a tendency to a negative allometric growth in which the increase in width is higher than in length. Growth of asteriscus is eccentric to the core; its anterior border grows more than the posterior border and the dorsal margin grows more than the ventral margin.

**Table5.** *Relationships between the length (AL) and width (AW) of the asteriscus of Kajikia audax.*

| AL vs AW | a | b | n | $r^2$ | F |
|---|---|---|---|---|---|
| All | 0.684 | 0.578 | 281 | 0.259 | 99.074 |
| Females | 0.657 | 0.620 | 102 | 0.448 | 83.009 |
| males | 0.669 | 0.653 | 163 | 0.253 | 55.844 |

Table 6 shows the relationship between total length of fish and length and width of asteriscus. The allometric index value closest to one is for males b = 0.753, for fish total length and asteriscus width. These indexes decrease for the specie b = 0.715, and females b = 0.689. In the case of the relationship between total length and asteriscus length, females show the higher value b = 0.669, decreasing for the species b = 0.637 and males b= 0.623. In all cases there is a relation of negative allometric growth in which the asteriscus does not show a growth proportional to that of the fish, therefore it is not useful to determine the age of this organism.

**Table6.** *Relationship between eye-fork length (EFL) and asteriscus length (AL) and width (AW) of Kajikia audax.*

| EFL | Sex | a | b | $r^2$ | F | n |
|---|---|---|---|---|---|---|
| AL (mm) | All | 0.063 | 0.637 | 0.235 | 86.908 | 281 |
| | Female | 0.054 | 0.669 | 0.353 | 55.998 | 102 |
| | Male | 0.068 | 0.623 | 0.190 | 39.094 | 163 |
| AW (mm) | All | 0.023 | 0.715 | 0.232 | 85.550 | |
| | Female | 0.026 | 0.689 | 0.443 | 81.376 | |
| | Male | 0.020 | 0.753 | 0.167 | 33.377 | |

**Table7.** *Calculated measures of length (LL) and width (LW) of the lapillus at different size classes of eye-fork length of Kajikia audax*.

| | Both sexes | | Females | | Males | |
|---|---|---|---|---|---|---|
| **Classes (cm)** | **LL (mm)** | **LW (mm)** | **LL (mm)** | **LW (mm)** | **LL (mm)** | **LW (mm)** |
| 100 | 1.01 | 0.92 | 1.12 | 0.95 | 0.92 | 0.90 |
| 110 | 1.06 | 0.97 | 1.15 | 0.99 | 0.99 | 0.95 |
| 120 | 1.10 | 1.01 | 1.17 | 1.04 | 1.05 | 1.00 |
| 130 | 1.15 | 1.06 | 1.20 | 1.08 | 1.10 | 1.05 |
| 140 | 1.19 | 1.10 | 1.22 | 1.12 | 1.16 | 1.09 |
| 150 | 1.23 | 1.14 | 1.25 | 1.16 | 1.22 | 1.13 |
| 160 | 1.27 | 1.18 | 1.27 | 1.19 | 1.27 | 1.18 |
| 170 | 1.30 | 1.22 | 1.29 | 1.23 | 1.33 | 1.22 |
| 180 | 1.34 | 1.26 | 1.31 | 1.27 | 1.38 | 1.26 |
| 190 | 1.37 | 1.29 | 1.33 | 1.30 | 1.43 | 1.30 |
| 200 | 1.41 | 1.33 | 1.35 | 1.33 | 1.48 | 1.33 |
| 210 | 1.44 | 1.36 | 1.36 | 1.37 | 1.53 | 1.37 |
| 220 | 1.47 | 1.40 | 1.38 | 1.40 | 1.58 | 1.41 |

## Growth of the lapillus

Table 7 shows the relationship between fish length and length and width of the lapillus. As in the asteriscus, growth is larger in females from 100 cm to 150 cm.In the case of males growth is higher from 170 mm to 220 mm.

The relationship between the length and width of lapillus (Table 8) show very low values of the allometric index b = 0.321 for the species, b = 0.288 in female, and b = 0.354 for males. These values represent negative allometric growth, in which lapillus grows more in length than in width. Lapillus growth is eccentric to the core, but the anterior and ventral margins show a higher deposition of growth materials than the posterior and dorsal margins.

**Table8.** *Relationships between the length (LL) and width (LW) of the lapillus of Kajikia audax.*

| LLvs LW | a | b | n | $r^2$ | F |
|---|---|---|---|---|---|
| all | 0.762 | 0.321 | 419 | 0.160 | 80.895 |
| female | 0.758 | 0.288 | 138 | 0.157 | 26.428 |
| male | 0.761 | 0.354 | 266 | 0.173 | 56.499 |

**Table9.** *Relationship between eye-fork length and lapillus length (LL) and width (LW) of Kajikia audax.*

| | | a | b | $r^2$ | F | n |
|---|---|---|---|---|---|---|
| LL (mm) | all | 0.113 | 0.476 | 0.094 | 28.360 | 419 |
| | female | 0.325 | 0.269 | 0.019 | 3.759 | 138 |
| | male | 0.040 | 0.681 | 0.215 | 24.059 | 266 |
| LW (mm) | all | 0.079 | 0.532 | 0.150 | 74.500 | |
| | female | 0.097 | 0.495 | 0.171 | 29.347 | |
| | male | 0.067 | 0.564 | 0.149 | 47.368 | |

The relationship between fish length, and the length and width of the lapillus is shown in Table 9. The higher value of the allometric index for the eye-fork length of fish and lapillus length was: males with a value of b = 0.681, smaller indexes were found for the species and females: b = 0.476 and b = 0.269, respectively. The higher value of the relationship between fish eye-fork length and lapillus width, corresponds to males b = 0.564, smaller values were encountered for the specie b = 0.532, and females b = 0.495.

## Description of the otoliths of Makaira mazara

*Description of the sagitta.*This species shows a very developed excisura major (Fig. 10) that divides the sagitta in a very prominent rostrum, bigger than the one observed in striped marlin (Fig. 1) and sailfish (Gallardo-Cabello *et al*. 2017). The dorsal border of the rostrum presents big denticles where growth rings of different periodicities can be seen. The antirostrum is of smaller size but widens as the pararostrum forms (Fig. 11). This structure: antirostrum-pararostrum shows on its surface an enormous variety of calcium carbonate crystals with different forms and orientations that could be related to the transmission of the impulse through the acoustic macula (Fig. 12). The acoustic canal is prominent, deep and specialized, and offers contact with the antirostrum-pararostrum body, which hasn't been seen in other billfishes. In the figures 10, 11 and 12 this variety of crystals is shown at different enlargements.

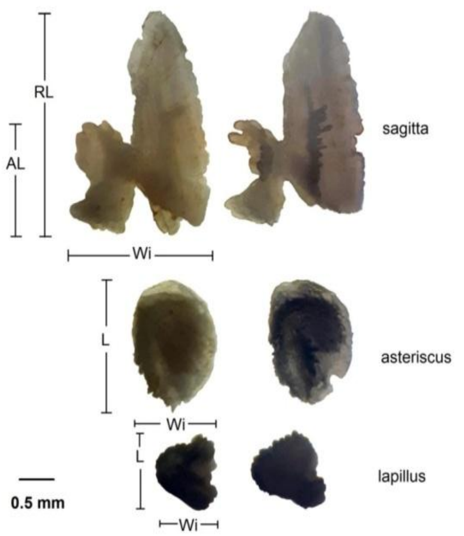


**Figure10.** Relationship between the three pairs of otoliths of *Makaira mazara*: left the external aspect, right the internal aspect; RL = rostrum length, AL = antirostrum length, Wi = width, L = length.

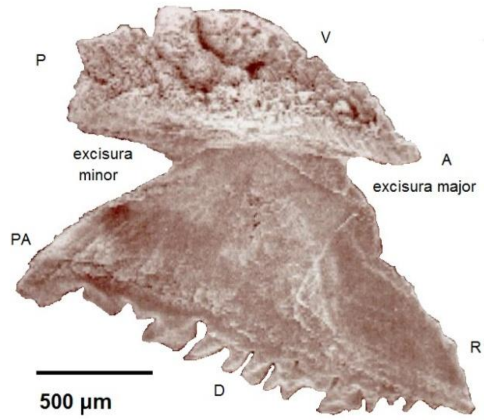


**Figure11.** Scanning photograph of the right sagitta internal aspect of *Makaira mazara*. R= rostrum, A= antirostrum, P= postrostrum, PA = pararostrum, D= dorsal margin, V= ventral margin.

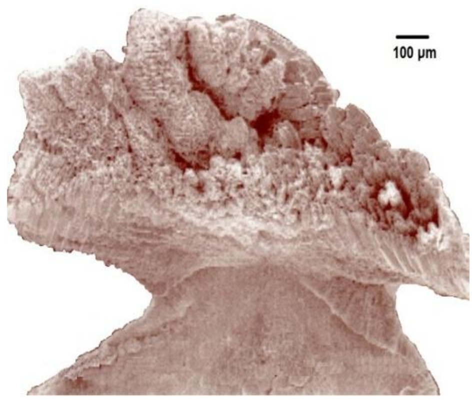


**Figure12.** Scanning photograph of the base of the acoustic canal, in the right sagitta internal aspect of *Makaira mazara*, showing the calcic carbonate crystals.

As it happens with sagittae of other species of billfishes, the internal aspect is convex, and the external concave. As the organism grows old otoliths become more eccentric in their growth in relation to the core, developing the proportions of the different parts of the rostrum, postrostrum, antirostrum and pararostrum in different form.

The excisura minor divides the posterior part of the otolith in a postrostrum and a pararostrum. The postrostrum shows smooth borders.

## Description of the asteriscus

The shape of the asterisci can vary between specimens and right from left (Fig. 10). A blunt projection is present in the anterior margin which divides the asteriscus in two areas: a dorsal area with a larger surface than the ventral area. (Fig. 13). The anterior margin presents a serrated surface from the dorsal to the ventral margin. Similarly the ventral border also presents irregularities in all its length.

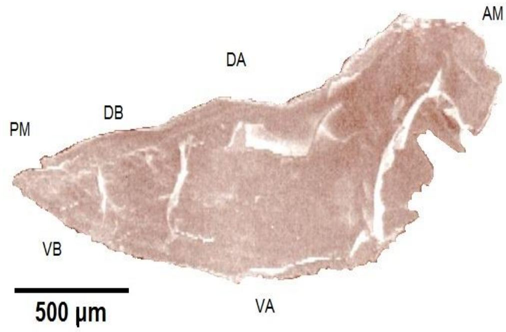


**Figure13.** Scanning photograph of the right asteriscus, internal aspect of *Makaira mazara*:AM = anterior area, DA = dorsal area, VA = ventral area, DB =dorsal border, VB = ventral border, PM = posterior area.

The posterior margin is curved and shows irregularities. This curved section presents a groove all around the dorsal and ventral margin. On the surface of the asteriscus growth rings are observed of different periodicities, as concentric darker lines.The internal aspect is concave and the external aspect is convex this feature increases as the fish ages. Small indentations are present in both aspects of the asteriscus (Fig. 13). The average length of the asteriscus (AL) is 1.82 times its average width (AW).

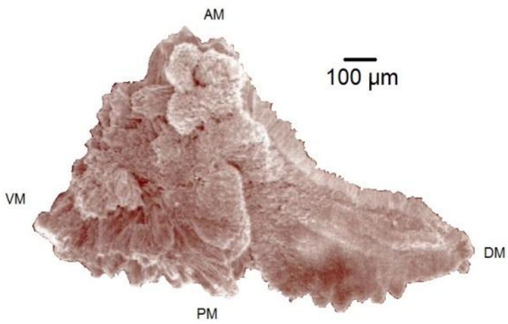


**Figure14.** Scanning photography of the right lapillus external aspect of *Makaira mazara.*AM = anterior margin, PM = posterior margin, DM = dorsal margin, VM = ventral margin.

## Description of the lapillus

The anterior margin of the lapillus is oriented toward the front of the fish showing strong irregularities (Fig.14). Dorsal and ventral margins show a rounded irregular structure that tends to resemble a fan. The dorsal margin is elongated and of bigger size than the ventral margin which tends to be rounded.

The enormous variety of crystals of different sizes and orientations appear in the external aspect of the lapillus, may be related to the transmission of the impulse through the acoustic macula, that in addition to feeding this otolith, also sends messages to the brain through the eighth cranial nerve (Figs. 14, 15). The inner lapillus surface is concave, a feature which increases with age. The otolith is divided in several lobes by radios.The union between the acoustic macula and the lapillus occur in the posterior margin of the otolith and goes from the dorsal to the ventral margin. The outer aspect is convex; its dorsal margin shows indentations and other irregularities, which become smaller at the ventral margin (Fig. 14).

Average length of the lapillus (LL) is 1.95 times its average width (LW).

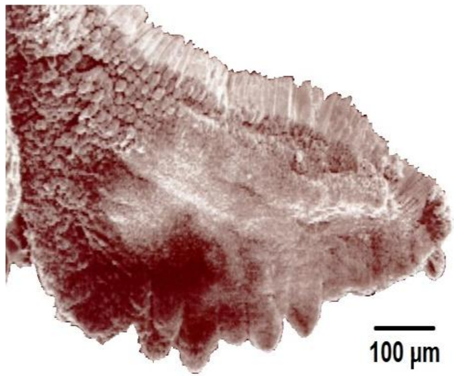


**Figure15.** Scanning photography of the details of the right lapillus external aspect of *Makaira mazara.*

## Morphometric analysis of otoliths of Makaira mazara

Table 10 shows the relation between rostrum, antirostrum and width of sagitta, asteriscus and lapillus of *M.mazara* in relation to the eye-fork length. In all cases the rostrum length is larger than the antirostrum.

**Table10.** Average, maximum and minimum otoliths of *Makaira mazara.*

| | EFL (cm) | SL (mm) | SA (mm) | SW (mm) | AL (mm) | AW (mm) | LL (mm) | LW (mm) |
|---|---|---|---|---|---|---|---|---|
| Average | 198.75 | 2.55 | 1.78 | 1.77 | 2.11 | 1.08 | 1.40 | 0.90 |
| Maximum | 239.00 | 3.15 | 2.20 | 2.40 | 3.00 | 1.30 | 1.90 | 1.15 |
| Minimum | 168.00 | 1.75 | 1.35 | 1.35 | 1.25 | 0.80 | 1.00 | 0.75 |

*Note: EFL = eye-fork length, SL = sagitta length or rostrum, SA = sagitta antirostrum, SW = sagitta width, AL = asteriscus length, AW = asteriscus width, LL = lapillus length, LW = lapillus width.*

## Discussion

The size of these sagittae is so small that it is difficult to extract, manage and analyze. The sagitta of an individual of billfish of 170 cm eye-fork long measures 2.42 mm.

No periodical growth rings were observed on the sagittae of the striped marlin or blue marlin as described by Radtke (1983), who located them on the dorsal and ventral borders of the otoliths (Radtke & Dean 1981). Also no growth rings were observed in the sagittae of *M. nigricans* in Kona, Hawaii, reported by Hill *et al.*(1989). However, growth rings were observed in the asterisci of striped marlin *K. audax* whose periodicity need to be analyzed (Figs.4,5, 6).

Observation and interpretation of daily growth increments in dolphin fish *Coryphaena hippurus* by Solano *et al*. (2015),has made possible the study of age and growth in organisms that have not yet reached one year of age.To do this, the sagittae were polished at the nucleus level and the counts of daily growth increments observed towards the periphery.

Likewise, daily growth increases in blue marlin *M. mazara* larvae have also been observed by Prince *et al.* (1991) in Kona, Hawaii.

The difficulty of obtaining organisms of less than one year of age makes the study of the daily growth increases in these organisms not easy. Also, it is very difficult to polish otoliths of striped marlin or blue marlin due to its enormous fragility, since it is very easy for these to split in their middle part where the acoustic canal is located. Asterisci are also very fragile due to the thinness of these structures.

Montoya-Márquez *et al.*(2013) reported for the striped marlin in the coasts of Jalisco and Colima, 10 age groups determined by growth ring on spines, and that could correspond to the samples analyzed in our study. Results were for age group 1 - 133.33 cm, age 2 - 145 cm, age 3 - 156.10 cm, age 4 - 163.88 cm, age 5 - 169.27 cm, age 6 - 171.79 cm, age 7 - 173.35 cm, age 8 - 174.77 cm, age 9 - 178.33 cm and age 10 - 179 cm. Parameters of the growth equation were $L_{\infty}$= 181.00 cm, k= 0.331 and to=-3;longevity = 12.1 years. However, in this study organisms of larger sizes were obtained, possibly more than 10 years (Table 1).

Recent studies carried out by several authors have resolved to combine analysis of daily growth increments in juvenile specimens of marlin and complete them with the analysis of growth rings identification in samples of cut spines of adult organisms. This is the case of Shimose *et al*. (2015) with *M. nigricans* in Western North Pacific and of Kopf *et al.*(2011)for *K. audax* in the southwest of the Pacific Ocean.

The analysis of the relationship between otolith length and that of the fish, revealed in all cases a negative allometric growth index, much lower than the unit, which establishes that otolith growth is not proportional to that of the fish, and cannot be used as structures to determine the age of organisms.

Morphometric differences between the right and left otoliths for the three pairs were not statistically significant. In the same way, differences in otolith sizes were not statistically significant between sexes.

## Conclusions

The otoliths of *Kajikia audax* are structures with which age cannot be determined in organisms, because the growth of the otolith is not proportional to the fish.

Growth rings were observed in asterisci of *K. audax*, but the periodicity was not determined.

No statistical significant morphometric differences were observed between the right and left otolith and between sexes.

Blue marlin *Makaira mazara* is a very scarce species in Central Mexican Pacific Ocean.

## Recommendations

It is very important to continue studies of the otoliths of striped marlin to increase the amount of information on the morphometry and morphology of these structures. These will also help understand the form and function, as its capacity to transmit impulses from the different cavities where they are included (sacculus, lagena y utriculus) in the brain, by the eight cranial nerve.

It is important to analyze the abundance of this species in the Mexican Pacific, with the objective to establish capture quotas for its commercial fishing as sport fishing.

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