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An analysis of the feasibility of using caudal vertebrae for ageing the spinetail devilray, *Mobula japanica* (Müller and Henle, 1841)

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Abstract Age assessment of *Mobula japanica* may be possible using the caudal vertebrae, below the origin of the dorsal fin. This is supported by the significant linear relationship found between disc width (DW) and centrum radius (CR, n=55), the continuous record of growth bands in the vertebrae, the clarity to distinguish and count growth bands, and the precision of the band counts. Assuming an annual band formation, the preliminary assessment of the age suggests that *M. japanica* lives at least 14 years and has a low growth rate (K=0.28 year^{-1}). The minimum number of growth bands was one for spinetail devilrays with a 1,210–1,390 mm DW, while the maximum was 14 for a 2,300 mm DW devilray. While age validation is still required, results indicate the feasibility of the use of caudal vertebrae for age estimation. To provide robust estimates of validated age and growth for the spinetail devilray, the sampling coverage needed might imply an international cooperation.

Keywords Batoid · Life history · Growth parameters · Age assessment

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Introduction

The spinetail devilray *Mobula japanica* (Müller and Henle) is a pelagic and migratory batoid, occurring in oceanic and coastal waters (Notarbartolo-di-Sciara 1987a). The life history of this mobulid is poorly known, and few studies have provided information on its distribution, food habits and reproduction (Notarbartolo-di-Sciara 1987a, b, 1988; White et al. 2006b; Sampson et al. 2010).

There is no information on the age and growth of *M. japanica*, or for any mobulid species. This lack of knowledge is due to the difficulty in obtaining sufficient biological samples of this species that is caught by a limited number of fisheries (White et al. 2006b). The reproductive mode of *M. japanica* is aplacental viviparity, with a size at birth range of 700–850 mm disc width (DW) (Notarbartolo-di-Sciara 1987b) and a maximum size of 3,100 mm DW (Notarbartolo-di-Sciara 1987a). Devilrays are particularly susceptible to overfishing because their fecundity is the lowest among elasmobranchs (White et al. 2006b).

Mobula japanica is commonly present in the southern Gulf of California, mainly during the summer months, and according to Notarbartolo-di-Sciara (1988) the species uses the area for feeding and mating. Traditionally, mobulids have been targeted seasonally by a small-scale fleet in the southwest Gulf of California, where *M. japanica* is the second most important species among mobulid species after the bentfin devilray *Mobula thurstoni* (Bizzarro et al. 2007, 2009). Nowadays, fishing for mobulids is prohibited by the Mexican Official Standards, NOM-029-PESC-2006 (Poder Ejecutivo Federal 2007), that regulate the fishery. Nevertheless, they are still captured and incidental catches of these species in other fisheries of the region are still happening. Thus to support the conservations measures, life history information for spinetail devilray is needed.

The spinetail devilray has been assessed as Near Threatened by the IUCN Red List for Threatened Species (2006) due to its low reproductive potential and productivity, and the general increase of its catches in different regions of the world (White et al. 2006a).

Accurate knowledge of age and growth is important to assess the current fish population status and predict its changes in time (Cailliet and Goldman 2004). The majority of the elasmobranch age and growth studies have used vertebral centra from the thoracic region, which are relatively homogeneous and possess a larger radius and clear growth bands, compared with the caudal portion (Cailliet et al. 1983).

In batoids, the vertebral column becomes less flexible and quite rigid anteriorly to support the greatly expanded pectoral fins. The monospondylous precaudal vertebrae of batoids, just posterior to the neurocranium, are fused into a rigid tube or cervicothoracic synarcual and centra are absent (Compagno 1999). This is a homologous structure to the first thoracic shark vertebrae (Montes-Domínguez and González-Isáis 2007). However, in myliobatoids, in which the family Mobulidae resides, there is a second synarcual in the monospondylous vertebrae named the thoracolumbar synarcual that may have a dozen or more vertebrae and abuts the cervicothoracic synarcual (Compagno 1999). Because of this complex vertebral column, previous attempts to assess the age of mobulids have been jeopardized because of the difficulty to find centra which were of adequate size for sectioning and band counting.

The first aim of this study was to explore the feasibility for ageing *M. japanica* using vertebrae from the caudal portion. The second aim was to estimate preliminary results of age at size of the sampled specimens, based on the hypothesis that one band pair represents one year. Due to the seasonality in the access to samples (only summer), no age validation analysis could be performed.

Methods

Sample collection and laboratory processing

Vertebral samples were collected from the spinetail devilrays (*Mobula japanica*) caught on the landing operations at the artisanal fishing camp of Punta Arenas de la Ventana (24°03′N, 109°49′W), located in the southeastern Baja California Peninsula, Mexico, during the summer of 2002, 2004 and 2005. Each specimen was sexed and measured to the nearest disc width (DW, mm). During the first field sample collection, a general examination of whole vertebral columns was conducted, noticing that larger vertebral centra were located in the caudal section of the column, below the dorsal fin. For further analysis, the whole vertebral column of two specimens and the caudal portion of vertebral column of 55 specimens were collected.

A X radiography of the whole vertebral column and the cranial region was obtained and processed with a Fuji FCR.XG-1 digitalizer as Dicom images. The skeleton was mounted in ventral position and steel pins were inserted in the origin of the thoracic portion and in the origin of the dorsal fin to locate external features. Transverse cuts in different sections of the vertebral column were made to determine the presences, size and shape of the vertebral centra. For the description of the vertebral column we followed Compagno (1999).

From each specimen, three diplospondylous precaudal vertebrae from below the origin of the dorsal fin were removed, cleaned by hand of excess tissue and left at room temperature. Sagittal vertebral sections 0.35 mm in thickness including the focus were cut using a Buhler Isomet low speed saw. The sections were stained with a 0.01 % crystal violet solution (Schwartz 1983) for 24 h. Each section was mounted on a glass microscope slide with clear resin and examined using a dissecting microscope under transmitted light. Centrum radius (CR) was measured (mm) as a straight line from the central focus to the outer margin of the corpus calcareum. The relationship between centrum radius (CR) and disc width (DW) was represented by a linear regression model to assess the suitability of using vertebrae as an ageing structure.

Age assessment

A band pair count was defined as an opaque band (OB) and a translucent band (TB) that were observed across the intermedalia (I) and clearly extends to the corpus calcareum (CC) (Cailliet et al. 2006) (Fig. 1). The birth mark (BM) was defined as the first distinct change in the angle of the corpus calcareum (Neer and Thompson 2005).

Two nonconsecutive band counts were made independently by two readers for each specimen, in blind, randomized trials without knowledge of each specimen's disc width (Goldman 2005). The translucent bands were counted for age determination, and the narrow "false bands" occasionally observed in the corpus calcareum were not considered in the count. We estimated precision following Goldman (2005) by: a) calculating the percent reader agreement ($PA = [No.agreed/No.read]*100$) within and between readers for all samples; b) calculating the percent agreement plus or minus one year (PA ± 1 year) within and between readers for all samples, and c) calculating the percent agreement within and between readers, with individuals of both sexes divided into disc width groups (10 cm disc width size classes). Also, in order to test for systematic differences within and between readers, Chi-square tests of symmetry were used following Hoenig et al. (1995).

Growth description

No validation analysis was possible due to the lack of samples during an entire year cycle. To have a preliminary growth description of the spinetail devilray, we therefore assumed that a growth band pair was deposited annually, like in many other elasmobranchs (Cailliet and Goldman 2004). Only the von Bertalanffy (1938) growth model was fitted to the observed size-at-age data as: $DW_t = DW_\infty \left[1 - e_0^{-K(t-t)}\right]$, where DW_t was the mean disk width at time t, DW_∞ was the theoretical asymptotic disc width, K was the growth coefficient, and t_0 was the theoretical age at zero length. Due to sample size sexes were combined for the analysis.

Results

Size and shape of vertebra centra

In the thoracic portion of the vertebral column, in the anterior section of the thoracolumbar synarcual (TS),

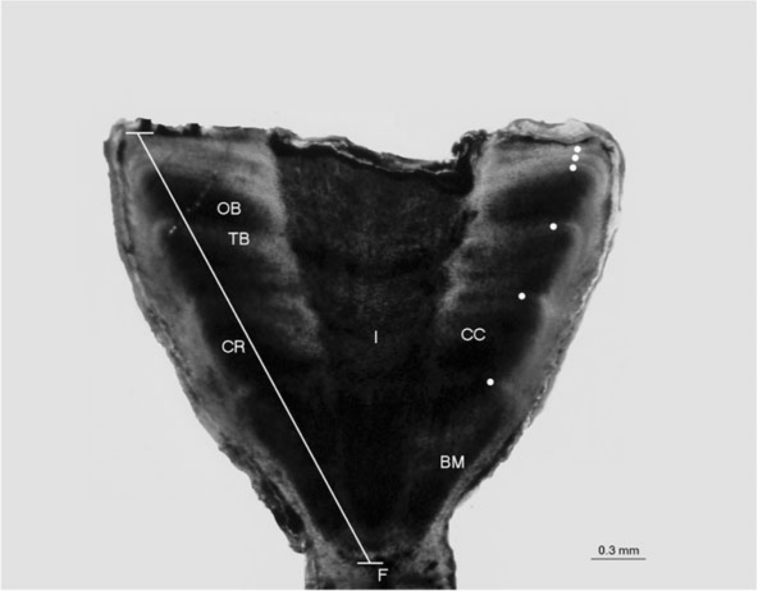

Fig. 1 Vertebral section of a *Mobula japanica* female 2,260 mm DW. Six growth bands (represented with *white lines*) were observed for this specimen. *F* focus; *BM* birth mark; *CC* corpus calcareum; *CR* centrum radius; *TB* translucent band; *OB* opaque band; *I* intermedialia

no vertebral centra were observed (Fig. 2a–b). Toward the middle part of this portion, small vertebrae were observed, and the size of the vertebrae increased as they approach the caudal portion (Fig. 2a–b). In the caudal portion, below the origin of the dorsal fin, where diplospondylous precaudal vertebrae (DPV) are located, the largest and most round shaped vertebrae were found; therefore, these were assumed to be potentially useful to assess the age of *M. japanica*.

Age assessment and growth description

In total 55 specimens (1,095–2,400 mm DW) were examined: the 24 males ranged in size from 1,390 to 2,400 mm DW, while the 31 females ranged from 1,095 to 2,300 mm DW. A significant linear relationship occurred between disc width (DW) and centrum radius (CR) ($y=509.87x+602.70$, $r^2=0.80$, $P<0.001$) (Fig. 3). This relationship showed that the vertebrae growth was proportional to the growth of the devilray.

Growth bands were very distinctive in the corpus calcareum and the intermedialia, and they were frequently associated with a defined angle change in the corpus calcareum (Fig. 1). A banding pattern was readily distinguishable in sectioned centra, with wide translucent bands separated by distinct narrow opaque bands. This pattern occurred on both arms of the corpus calcareum and the band pairs extended across the intermedialia. The band formation in the vertebrae of *M. japanica* provides a continuous record of growth and was suitable for use in age assessment (Fig. 1). Band counts in larger specimens were slightly difficult, because the bands were more tightly grouped at the outer edge of the vertebrae.

The preliminary estimated age of *M. japanica* ranged from one (female 1,210 mm and a male 1,390 DW) to 14 (female 2,300 mm DW) bands. The specimens with 4–8 bands (1,620–2,240 mm DW) account for the 66.66 % of the total sample.

The Percent Agreement (PA) resulted of 63 % for the reader one, 40.7 % for the reader two, and 25.9 % between readers. The PA plus or minus one band resulted of 24.1 % for the reader one, 31.5 % for the reader two, and 27.7 % between readers. This means that the PA with a precision of ±1 band was 87.1 % for the reader one, 72.2 % for the reader two, and 53.6 % between readers.

The PA was highly variable among the size classes (Table 1). Although, the PA for readers was higher in small size classes than in large size classes, it is difficult to observe a pattern due to the low sample size for small size classes. The PA for medium to large individuals varies from 37.5 % to 75 % for the reader one, and from 25 % to 87.5 % for the reader two; however, there was no

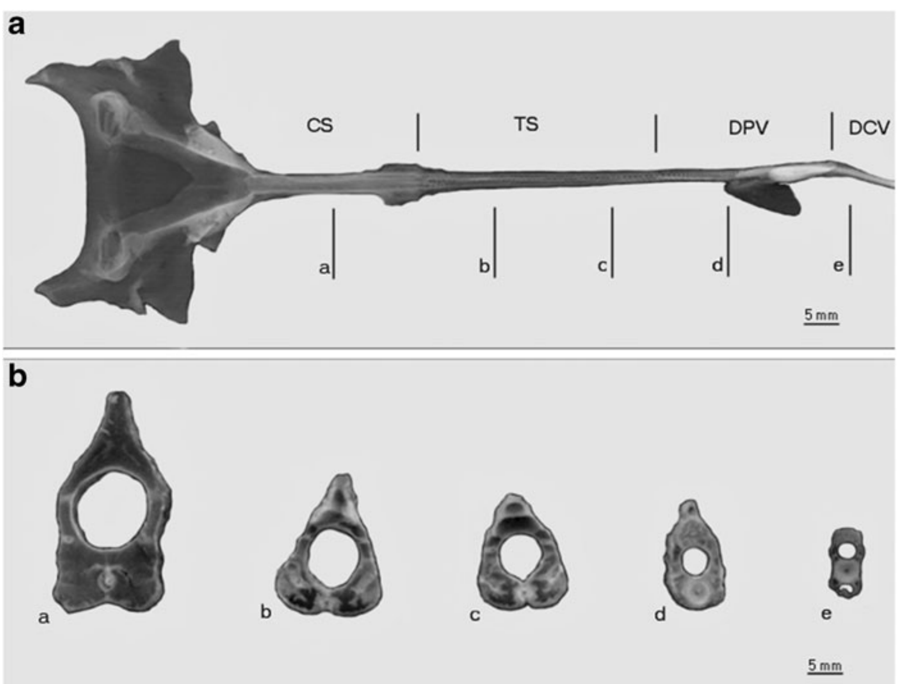

Fig. 2 **a** Vertebral column of a *Mobula japanica* female 1,280 mm DW showing the Anterior portion: CS Cervicothoracic synarcual; Thoracic portion: TS Thoracolumbar synarcual; Caudal portion: DPV Diplospondylous precaudal vertebrae and DCV Diplospondylous caudal vertebrae. The *lowercase letters* shows the place where the transversal cuts were made. **b** Transversal cuts from the vertebral column. The transversal cut d) shows the vertebrae below the origin of the dorsal fin

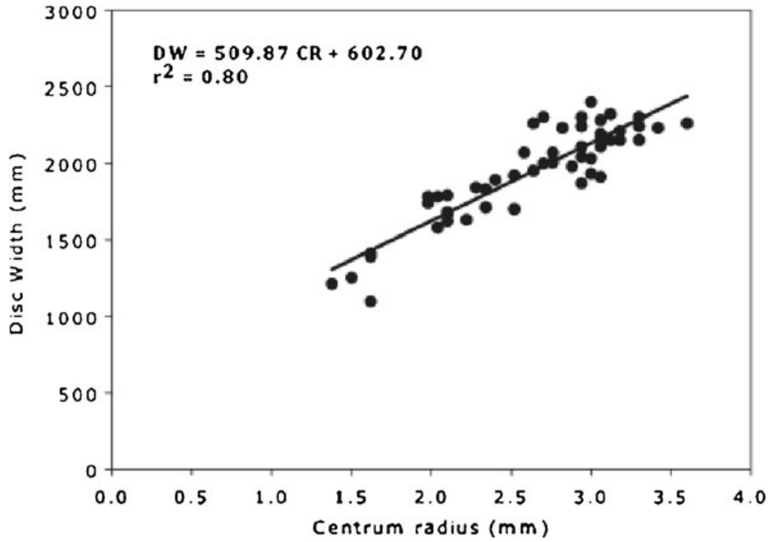

Fig. 3 Relationship between centrum radius (CR) and disc width (DW) for *Mobula japanica*

trend of decrease of PA from medium to large individuals for both readers. The PA between readers was low, being cero in the lowest size classes and from 14 % to 75 % for some medium to large individuals, however, without a trend of decrease of PA towards large size classes.

The hypothesis of symmetry was not rejected for the reader one (X2=17.3, df=12, P=0.14) and the reader two (X2=21.5, df=17, P=0.20), however, the hypothesis was rejected in the comparison between readers (X2=31, df=19, P=0.04), which means that there were systematic differences between readers (with a PA of 25.9 %), and that differences were not due to random error.

The von Bertalanffy growth model for sex combined predicted a DW_∞ of 2338.07 mm DW, a K value of 0.28 year^{-1} and a t_0 of −1.68 years. Therefore, the preliminary growth equation estimated was $DW_t = 2338.07\left[1 - e^{-0.28(t+1.68)}\right]$ (Fig. 4).

Table 1 Percent agreement by size classes within and between readers

Size class	Number of samples	PA between readers	PA reader 1	PA reader 2
1000-1100	1	0	100	100
1100-1200	0			
1200-1300	2	0	100	100
1300-1400	1	0	100	100
1400-1500	1	0	0	0
1500-1600	1	0	100	0
1600-1700	4	75	75	0
1700-1800	6	33.3	66.6	0
1800-1900	4	0	75	25
1900-2000	5	20	40	60
2000-2100	7	14	71	42.8
2100-2200	8	50	62.5	37.5
2200-2300	8	37.5	37.5	87.5
2300-2400	4	0	75	25
2400-2500	2	0	50	0

Discussion

Before this study, there were no age assessments for *M. japanica*, or for any other mobulid species for this matter. Therefore, this is the only information available on this mobulid species, and White and Sommerville (2010) include a first version of this study as part of the 7.5 % of the 465 tropical elasmobranch species having age and growth assessment.

According to Officer et al. (1996), the locations from which vertebral samples are taken for ageing have statistically significant effects on the increment counts of some species. Therefore, for age studies on elasmobranchs it is important to use the larger, more anterior (thoracic) centra, because centra from the caudal region are smaller and may lack some bands (Cailliet et al. 1983). This emphasizes the importance of standardizing the vertebral sampling region for all aging studies, allowing for precise, valid comparisons among individuals within a population and for more accurate comparisons between populations (Cailliet and Goldman 2004).

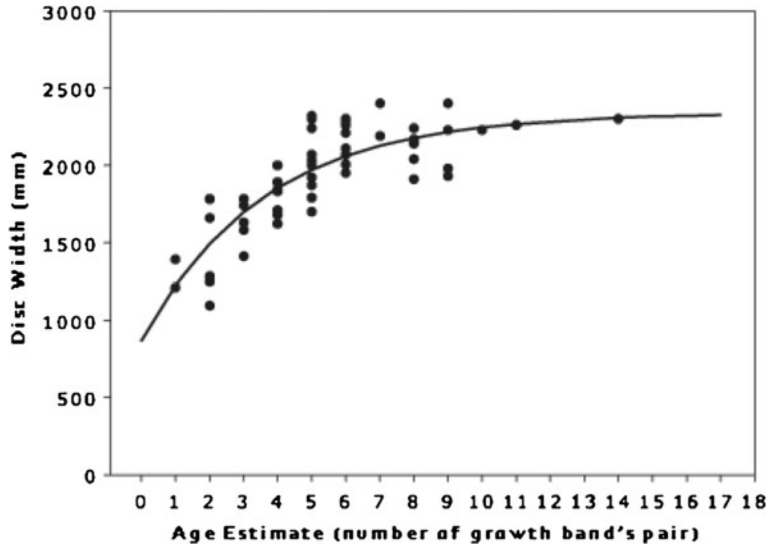

Fig. 4 The preliminary von Bertalanffy growth model ($DW_t = 2338.07[1 - e^{0.28}(t + 1.68)]$) for *Mobula japonica*

The majority of age studies on sharks have utilized vertebrae from the thoracic region, taken below the first dorsal fin (Piercy et al. 2006). Several published age studies for batoids have also used vertebral centra from the thoracic portion of the column (e.g. Neer and Cailliet 2001; Neer and Thompson 2005; Sulikowski et al. 2005; Hale and Lowe 2008). However, our results show that useful vertebrae for aging *M. japanica* were located in the caudal portion of the vertebral column, where diplospondylous precaudal vertebrae (DPV) are located, below the origin of the dorsal fin. Due to the presence of the cervicothoracic and thoracolumbar synarcuals in the vertebral column of *M. japanica*, the thoracic vertebrae were absent or smaller in size compared to the caudal region.

The use of the vertebrae below the origin of the dorsal fin for age assessment of *M. japanica* is supported by the significant relationship between disc width (DW) and centrum radius (CR), the observed continuous record of growth bands in the vertebrae, and the precision of the estimated ages.

In vertebral sections of elasmobranchs, each pair of wide and narrow bands is often assumed to represent a year. However, the validity of this assumption must be tested (Campana 2001; Cailliet and Goldman 2004). As in the present study, some authors assume an annual band formation for other species of batoids, such as the blue stingray *Dasyatis chrysonota chrysonota* (Cowley 1997), the cownose ray *Rhinoptera bonasus* (Neer and Thompson 2005), the round stingray *Urobatis halleri* (Hale and Lowe 2008), the bat ray *Myliobatis californica* (Martin and Cailliet 1988) and the winter skate *Leucoraja ocellata* (Sulikowski et al. 2003). The lack of age validation can jeopardize further analysis of population dynamics in which age and growth information are utilized. Age validation analysis is needed to verify the annual band formation in *M. japanica* vertebral centra used in this study and to assess the true age for the specimens and should be pursued. Validation was not possible in this study because of the limited access to specimen samples due to the seasonality of the fishery (only summer). Other methods like mark-recapture procedures or keeping them in captivity (Cailliet and Goldman 2004) might be tried in the future.

The preliminary assessment of the age suggests that *M. japanica* lives at least 14 years. However, the largest observed *Mobula japanica* during this study, i.e. 2,400 mm DW, is smaller than the 2,483 mm DW reported by Notarbartolo-di-Sciara (1987b) in the same region of this study, and even smaller than the recorded in Indonesia, i.e. 2,840 mm, (White et al. 2006b) and in New Zealand, i.e. 3,100 mm WD (Paulin et al. 1982). The lack of larger organisms in the sample suggests that the species might reach a higher longevity. High longevities have been estimated for other batoid species: 24 years for *M. californica* (Martin and Cailliet 1988), 28 years for the southern stingray *Dasyatis americana* (Cailliet and Goldman 2004), 26 years for the cownose ray *Rhinoptera bonasus* (Neer and Thompson 2005), 14 years for *Dasyatis chrysonota chrysonota* (Cowley 1997) and 28 years for females and 19 years for males of *Dasyatis dipterura* (Smith et al. 2007).

Preliminary growth analyses suggest that *M. japanica* has relatively slow growth and late age at maturity. The value of the growth coefficient (K) obtained for *M. japanica* (0.28 year-1) is among the values for batoids (0.07 to 0.45) reported by Cowley (1997). According to Notarbartolo-di-Sciara (1988), males and females of *M. japanica* began to mature at 2,100 and 2,070 mm DW, respectively, which correspond to an age between 5 and 6 years. However, the obtained DW_{∞} value of 2338.07 mm is smaller than the largest organism recorded for the region, i.e. 2,483 mm DW (Notarbartolo-di-Sciara 1987b) and from other regions (Paulin et al. 1982; White et al. 2006b), suggesting that this growth parameter might be inaccurate. All the parameters of the von Bertalanffy growth equation are poorly estimated when inadequate samples of large and/ or small individuals are used for their estimation (Cailliet and Tanaka 1990).

The results of this study show the feasibility of the use of caudal vertebrae sections for the age estimation of *M. japanica*. However, results obtained this far make it clear the need for a validation analysis based in any of the methods available (Cailliet et al. 2006). Also, in order to provide robust estimates of age and growth for the spinetail devilray, an adequate sample has to be obtained, which might be based on an international cooperative effort across the *M. japonica* distribution in order to avoid the high seasonality observed in this study, and to accomplish the necessary sampling coverage (Goldman 2005).

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