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Giantism and Delayed Maturation in Fossil Sharks: Evidence for Extreme Longevity?

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Abstract

The Bible's assertion that the Genesis patriarchs routinely experienced lifespans of hundreds of years is one of the claims in Scripture most ridiculed by skeptics. Hence, Biblical creationists should be interested in possible scientific corroboration of this claim. Whatever factor or factors were allowing extreme human longevity in the pre- and immediate post-Flood worlds were likely also affecting the animal kingdom, as well. Hence, it is reasonable to suspect that animal lifespans were also once much greater than they are today. In this light, we examine fossil shark data for possible evidence of extreme longevity. Paleontologists have used allometric relationships and growth rings within shark vertebrae to construct ontogenetic length-versus-age growth curves for both extinct and extant sharks. Growth curves for fossil sharks are generally too short to provide direct evidence that fossil sharks experienced much greater longevity than extant sharks, but they are sufficiently long to show that fossil sharks took longer to mature than comparable extant sharks. Longevity studies of extant animals have repeatedly shown that greater ages at skeletal and/or sexual maturity are positively correlated with greater longevity, as are larger adult body sizes. Hence, the apparent delayed maturation and large adult body sizes of these giant fossil sharks is indirect evidence that they had much greater lifespans than extant sharks. By extension, it is partial scientific corroboration of the extreme human lifespans recorded in the earliest chapters of Genesis.

Key Words: antediluvian, fossils, giantism, growth rings, longevity, ontogeny, pre-Flood, sharks, von Bertalanffy growth curves

Introduction

The recent movies *The Meg* and *Meg 2: The Trench* have done for megalodon what the movie *Jaws* did for great white sharks: they have brought the giant extinct shark *Otodus megalodon* into the public consciousness. The megalodon is thought to have been the largest shark—or fish—to have ever lived (Rafferty, 2023). The idea of a giant shark swimming the oceans and devouring prey (including humans!) with its enormous jaws (Figure 1) is admittedly terrifying.

The name *megalodon*, meaning 'big tooth,' is certainly appropriate, as megalodon teeth are much larger than

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teeth of the extant great white shark *Carcharodon carcharias* (Figure 2).

Maximum length estimates (Shimada, 2019; Perez et al., 2021) for a (presumably) fully-grown megalodon, based upon tooth sizes, range between approximately 14.2 meters (46.6 feet) to greater than 20.3 meters (66.6 feet). Pimiento and Balk (2015) cite a shorter length of 10.54 meters, but this is a modal value, with the longest estimated lengths in their study between 17.0 and 17.9 meters. A recent length estimate based on the reconstruction of a vertebral column was about 15.9 meters (Cooper et al., 2022). However, Sternes, et al. (2024) have argued that the megalodon was longer but less stocky than depicted in the reconstruction of Cooper et al. Sternes et al. suggested that previous maximum length estimates of 15 to 20 meters were probably too short, and that the ontogenetic growth model of Shimada et al. (2021), discussed later in this article, was probably an underestimate.

Figure 1. The megalodon has often been depicted as a giant great white shark, although there is debate among evolutionary scientists as to whether the two sharks were related. Image Credit: Karen Carr. CC BY 3.0. https://creativecommons.org/licenses/by/3.0/.

Popular depictions often show the megalodon as an oversized version of the great white shark *Carcharodon carcharias* (Figure 1). However, controversy abounds among paleontologists as to the megalodon's relationship to the great white. It seems that few, if any, evolutionary paleontologists believe that the great white is a descendant of the megalodon. However, some have argued that the great white is the closest living relative to the megalodon (Gottfried, Compagno, and Bowman, 1996, pp. 55–66). Such paleontologists think (Ehret et al., 2012) all large "megatooth" sharks with serrated teeth should be placed into the genus *Carcharodon*. In this thinking, the great white evolved alongside the megalodon, rather than descended from it. Hence, *Otodus megalodon* should be reclassified as *C. megalodon*.

Others think *C. carcharias* evolved from a group of broad-toothed mako sharks, which included *Carcharodon* (*Cosmopolitodus*) *hastalis*, formerly known as *Isurus hastalis*, formerly known as *Oxyrhina hastalis*. In this view, the megalodon has a separate lineage and should retain its designation as *O. megalodon*. Currently, this view seems to have the most support among evolutionary paleontologists.

However, this conclusion may have been driven in part by evolutionary circular reasoning. The claim that the great white descended from extinct mako sharks was ostensibly due to subtle differences in tooth morphology, and the strong, more obvious tooth similarities that were the original basis for considering great whites and megalodons related (Figure 2) are now generally attributed (Rafferty, 2023) to convergent evolution (!).

Ehret et al. (2012) argued that a new species *Carcharodon* (*Cosmopolitodus*) *hubbelli* sp. constituted a transitional form between *Carcharodon* (*Cosmopolitodus*) *hastalis* and *Carcharodon carcharias*. As is often the case in paleontology, a radiometric "recalibration" played a major role in this conclusion (Ehret et al., 2012, p. 1139):

> We also provide a recalibration of critical fossil horizons within the Pisco Formation, Peru using zircon U-Pb dating and strontium-ratio isotopic analysis. The recalibration of the absolute dates suggests that

> *Carcharodon hubbelli* sp. nov. is Late Miocene (6–8 Ma) in age. This research revises and elucidates lamnid shark evolution based on the calibration of the Neogene Pisco Formation.

Figure 2. Size of a megalodon tooth compared to two great white shark teeth. Image credit: Brocken Inaglory. CC A-SA 3.0 Unported. https://creativecommons.org/licenses/by-sa/3.0/deed.en.

Within a creationist framework, it seems entirely reasonable that the megalodon really *was* a giant version of the great white shark. Evolutionary scientists (Gottfried, Compagno, and Bowman 1996, p. 57) who think the megalodon should be placed into the *Carcharodon* genus have enumerated similarities between great white and megalodon teeth (Figure 2):

> (1) As *C. carcharias* [great white] teeth grow larger, they become increasingly similar in morphology to *C. megalodon* teeth, with increasingly finer and more numerous serrations and more robust proportions, including deeper roots and a broader neck. We suggest that a *C. megalodon*-type tooth would be the result of extrapolating the ontogenetic changes seen in *C. carcharias* teeth to a megatooth-sized shark.
>
> (2) Presumed subadult teeth of *C. megalodon*, described by Uyeno and Sakamoto (1984), are morphologically very similar to teeth of *C. carcharias*, including the size and nature of the serrations.

They also noted (pp. 58–59) similarities in the vertebrae of the sharks:

> The similar morphology of the teeth and vertebral centra in fossil and living species of *Carcharodon* lends credibility to this assumption [that megalodon morphology may be inferred from great white morphology].

On the other hand, Sternes, Wood, and Shimada (2022) argued that fossil data are currently insufficient to draw firm conclusions about megalodon body shape, and they may be correct.

In any case, can we learn something from the megalodon's large size? And is there a connection between this large size and the astonishing longevities that the Bible reports for the Genesis pre-Flood and immediate post-Flood patriarchs?

The Bible matter-of-factly asserts that humans in the antediluvian world routinely attained ages of more than 900 years (Genesis 5:3–32). Even some time after the Flood, humans were still experiencing centuries-long lifespans (Genesis 11:12–32). Such extreme longevity is far beyond our present-day experience. Hence, creationists should be interested in possible corroboration of the Bible's claim in this regard, either from historical or paleontological data. Previous creationist authors have discussed extrabiblical historical and cultural confirmations of the first eleven chapters of Genesis (Patten, 1982; Oestreicher, 1989; Cooper, 1995; Cooper, 2011; and Liguori, 2021), including the claims of greater past longevity (López, 1998). Others have discussed possible evidence of greater longevity in Neanderthal fossils (Cuozzo, 1998, 1999), as well as a possible connection between greater longevity and past giantism (Patten, 1982; Beasley, 1990; Nelson, 2017).

This paper discusses examples of giantism and delayed maturation in fossil sharks. Both fossil data and theoretical considerations suggest that these giant sharks took much longer to mature than comparable extant sharks. Because of the studies repeatedly correlating delayed maturation and larger adult body sizes with greater longevity, these observations constitute indirect evidence that fossil sharks were living much longer than comparable extant sharks.

Connections Between Longevity, Maturation, and Body Size

Studies (Sato, 1994; Miller et al., 2002; Genade et al., 2005; de Magalhães et al., 2007; Ricklefs, 2010a, 2010b; Ridgway et al., 2011; Lee et al., 2013; Moss et al., 2016) have shown that, in extant creatures, greater longevity is often positively correlated with greater ages at maturity. Generally speaking, the longer it takes an organism to attain to sexual or skeletal maturity, the longer its lifespan will be.

Here we are attempting to ascertain whether fossil representatives of the Genesis kinds were living longer than the modern-day representatives of those kinds. For this reason, longevity comparisons within a *baramin* or 'Biblical kind' are likely to be of greater interest to creationists than inter-baramin comparisons.

Creationists generally agree that creatures within a particular genus can usually safely be assumed to belong to a single baramin or 'Genesis kind,' even if the baramin itself actually corresponds to the family level or higher in the Linnaean taxonomic classification system (Wood-morappe, 1996). Most of the studies listed above were inter-genera comparisons, but a few (Sato, 1994; Genade et al., 2005; Lee et al., 2013), were intra-genus or intraspecies comparisons. The results by Sato (1994), however, did not include a test for statistical significance.

Likewise, studies (de Magalhães et al., 2007; Wasser and Sherman, 2010; Ricklefs, 2010a; Ridgway et al., 2011; Holm et al., 2016) have also shown a positive correlation between greater longevity and larger adult body sizes: larger creatures tend to live longer. Unfortunately, none of the above studies were confined to a single genus or species. Sato (1994) did find such a trend for a single species of bivalve, but as noted above, he did not perform a test for statistical significance.

Admittedly, there is evidence contrary to these conclusions (see Marchionni et al., 2020 for a summary). However, West et al. (2001) used the principle of energy conservation and a well-known allometric rule called Kleiber's Law (Brody et al., 1932; Kleiber, 1932, 1947, 1961; Brody, 1945) to show that adult body mass M should be proportional to the fourth power of the age at skeletal maturity t_{mature}:

$$M \propto t_{mature}^{4} \tag{1}$$

This result had been anticipated by others (Lindstedt, 1981; Calder, 1984; and Schmidt-Nielsen, 1986), who observed that biological timescales in general were proportional to body mass raised to the fourth power.

Likewise, fossil *Crassostrea* and *Magallana* oysters also provide evidence for both conclusions (Kirby, 2001; Kirby and Jackson, 2004; Harzhauser et al., 2016), provided that counts of annual growth rings within bivalve shells are reasonably accurate. A discussion is provided in Hebert, Overman, and Sherwin (2024).

In summary, greater longevity seems to be positively correlated with both larger adult body sizes and greater ages at maturity (Figure 3).

In this light, it is striking that the earliest age at which a Genesis 5 patriarch is listed as having a son is 65 (Genesis 5:15, 21). Given the strength of the human sex drive, it seems extremely unlikely that the Genesis patriarchs were becoming sexually mature at 15 or 16, but were all choosing to postpone marriage 50 years! Rather, it seems far more likely they were taking longer to reach adulthood than do extant humans. Thus, the greater ages at maturity recorded in Genesis 5 make sense in light of the results of these studies: one would expect very long-lived humans to take longer to mature than humans with much shorter lifespans. It also raises the question: were long-lived antediluvian humans larger than extant humans, as some creationists (Taylor, 1987) have suggested? A comparison of Genesis 6:4 and Numbers 13:33 shows that the Nephilim were giants, but were 'normal' humans before and just after the Flood *also* larger than extant humans? There is some circumstantial evidence that this may have been the case, at least in the post-Flood world (Hebert, 2023a), but a detailed discussion must await some other time.

In any case, whatever factor or factors were allowing humans to attain extreme longevity in the pre-Flood and immediate post-Flood worlds (more pristine genomes, better nutrition, higher atmospheric oxygen concentration, etc.) would almost certainly have also affected the animal kingdom. Hence, we should not be surprised if animal fossils also show evidence of much greater size and/or longevity. Hebert (2023b) included a preliminary discussion of possible examples of this, and this paper is one in a series that attempts to flesh out the argument (see also Hebert, 2024, and Hebert, Overman, and Sherwin, 2024).

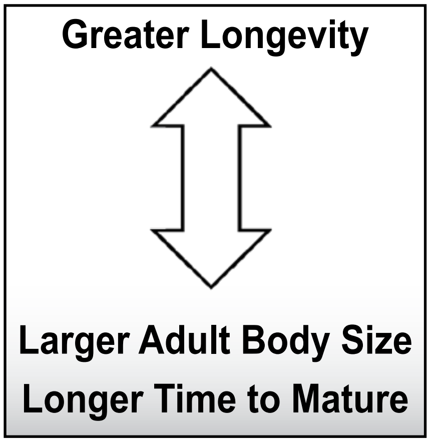

Figure 3. Studies of extant animals have shown that larger adult body sizes and longer maturation times are positively correlated with greater longevity.

Background: Growth and Growth Curves

Many animals exhibit asymptotic growth: as they mature, their total body length L either reaches or asymptotically approaches a maximum value that we designate as L_∞ (Figure 4). This asymptotic growth is described mathematically by the von Bertalanffy (1938) growth equation:

$$L(t) = L_\infty\left(1-e^{-k(t-t_0)}\right) \tag{2}$$

In Equation (2), t is the time since birth (measured in years) and k is a parameter (with units of years^{-1}) that governs the relative speed at which an organism approaches adulthood. The parameter k is not a growth rate *per se*, but it is a proxy for growth rate, with high k values representing faster growth and lower k values representing slower growth. Other similar growth equations do exist, but the von Bertalanffy equation is thought to provide the best fit to data for slow-growing, long-lived species (Amalfitano et al., 2022).

The value t_0 is the (theoretical) time at which the organism's length is zero. If the creature has a positive, non-zero size at birth, t_0 is a negative number, indicating that the creature had zero size at the beginning of its gestation, $-t_0$ years before birth. The parameter t_0 will be zero if the organism has a size of zero at birth.

Equation (2) is usually obtained from length-versus-age data for a popula-

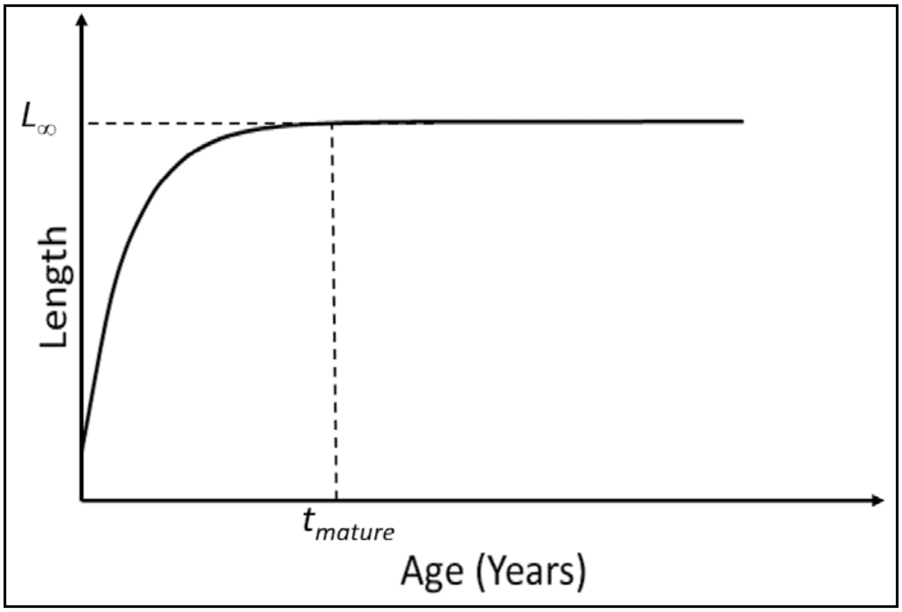

Figure 4. The von Bertalanffy growth curve, showing an organism's length or height as a function of time since birth or hatching. Note that growth effectively, if not completely, stops when the organism reaches skeletal maturity at time t_{mature}.

tion of organisms. L_∞ is thus the average adult body size for the population. Since this is a population average, individual specimens in the population will be characterized by L_∞ values that are both longer and shorter than this. Naturally, organisms with larger values of L_∞ will also have higher adult body masses M.

Given enough time, the growth rate of an organism with *determinate* growth will become vanishingly small when it reaches skeletal maturity at time $t \approx t_{mature}$. Some organisms undergo *indeterminate* growth, meaning that they continue to grow, albeit slowly, for as long as they live. If an organism's growth has not yet "levelled off" at some time t, the organism has not yet attained its full potential size. For an organism exhibiting determinate growth, once the slope of the curve in Figure 4 becomes vanishingly small at time t_{mature}, the organism has effectively reached skeletal maturity. Note that t_{mature} is not necessarily the same as the age at sexual maturity, t_{sex}. In many organisms, the age at sexual maturity does not necessarily coincide with the age at skeletal maturity; some organisms become sexually mature long before attaining skeletal maturity. Nevertheless, one might expect organisms that take longer to reach skeletal maturity to also take longer to reach sexual maturity.

Inferring Size and Growth Data from Shark Vertebrae

Since shark vertebrae are made of cartilage rather than bone, preserved fossil shark vertebrae are rare, and the vast majority of shark fossils consist of teeth. However, some calcified fossil vertebrae have been found, and paleontologists have used growth rings in the vertebrae to infer growth rates and size estimates of fossil sharks. In fact, vertebral growth bands are virtually the only means that paleontologists and marine biologists have to infer this information regarding extinct elasmobranchs (Shimada et al., 2021).

Alternating translucent and opaque concentric bands are evident in the cross-sections of shark vertebrae centra. These couplets are alternately referred to as rings, band pairs, or vertebral growth increments. Paleontologists have traditionally assumed that each band pair is formed annually, and studies seemed to vindicate this assumption for multiple shark species (Smith, 1984; Killam and Parsons, 1989; Ribot-Carballal et al., 2005; Joung et al., 2008; Barreto et al., 2011; Kotas et al., 2011; Hall et al., 2012; and Liu et al., 2018). However, some studies (Chen et al., 1990; Anislado-Tolentino et al., 2008) suggested biannual deposition in the scalloped hammerhead *Sphyrna lewini*. Also, Wells et al. (2013) showed that ring formation occurred twice per year in the case of the juvenile blue shark, *Prionace glauca*.

A difficulty in the ring-counting process noted by several researchers is that the outermost rings become thinner and harder to count in older sharks (Francis, Campana, and Jones, 2007; Harry, 2017), resulting in systematic underestimation of true age. For instance, Hamady et al. (2014) seemed to confirm that ring deposition was annual in white sharks but that thinning of bands in older great whites would complicate attempts to infer age from vertebrate data.

However, a study of seven shark species by Natanson et al. (2018) has called these simple assumptions into serious question. Their study showed that different vertebrae on the same shark can have different numbers of rings! Ring growth is apparently more closely related to the need for vertebrae to support body girth and length than to time *per se*. This conclusion was supported by the fact that the greatest intrashark differences in ring counts occurred for the five species whose girth varied the most along the length of their respective vertebral columns (Atlantic angel sharks, white sharks, porbeagle sharks, shortfin makos, and common thresher sharks). For sharks whose girths were much more uniform along the vertebral column (blue and dusky sharks), counts were much more consistent.

Figure 5. Artist conception of *Ptychodus mortoni*, one particular species in the extinct genus *Ptychodus*. Image credit: Dmitry Bogdanov. CCA 3.0 Unported. https://creativecommons.org/licenses/by/3.0/deed.en.

Natanson et al. all suggested that shark species could be subdivided into three general categories: (1) those whose band pairs were validated as annual throughout their lives, (2) those whose band pairs were validated as annual for only a portion of their lives, and (3) those for whom band pairs simply could not be used for ageing studies. They noted that their results necessitated a re-evaluation of previous age estimates based on ring or band counts. However, they argued (p. 1450) that this did not necessarily invalidate all previous results:

> If band pairs are structural and related to growth, can they still be used for ageing? One cannot refute the few well-conducted direct studies indicating that band pair deposition occurs annually or biannually during some portion of the lifespan of the shortfin mako, porbeagle and leopard sharks (*Triakis semifasciata*), such as reported by Natanson *et al*. (2002), Smith *et al*. (2003), Wells *et al*. (2013), and Kinney *et al*. (2016), among others. However, this relationship to time must be considered loosely correlated over the span of these studies because we have shown that both the shortfin mako and the porbeagle have varying band pair counts along the vertebral column and ontogenetic changes in band pair deposition. For example, in the juvenile phase, vertebral centra are of similar size and band pair counts are similar along the column because these fish are generally growing faster than adults with a more uniform girth while increasing in length. Thus, band pair counts are similar along the vertebral column of juveniles, as shown herein. On average, the growth rate at this size relates to wider band pairs, which may be deposited annually, as has been validated in several species…. The results of the present study do not refute the validated ages previously published, but rather they explain the discrepancies observed in the literature (summarized in Harry 2018).

Although paleontologists are generally aware of the issues raised by Natanson et al. (2018), they will often assume as a first approximation that band pairs in fossil shark vertebrae are annual. Geochemical variations in the bandings within the centra of an Eocene lamnoid *Otodus obliquus* shark (MacFadden et al., 2004) were consistent with the assumption that the bands are seasonal or annual. However, this shark was apparently only 19 years old when it died, so this confirmation was only valid, at best, for juvenile *O. obliquus* sharks.

Allometric relationships are used to convert vertebrae centrum diameters into estimated total body lengths. Under the assumption that the bands are deposited at regular, periodic intervals, ontogenetic growth curves may be constructed.

An "Old" Adolescent *Ptychodus* Shark

Ptychodus (Figure 5) is an extinct genus of shark thought to have exhibited durophagous behavior (i.e., the eating of organisms with hard shells). Based upon its body type (and also upon an assumed evolutionary phylogenetic affinity), the *Ptychodus* genus is thought to have been similar to the extant genera *Heterodontus* and *Ginglymostoma* (Shimada et al., 2010). The genus *Heterodontus* consists of the bullhead sharks, of which there are nine extant species. These are relatively small bottom-feeders that are harmless to humans. Most adults are only about a meter in length, though some species can grow as large as 1.65 to 1.7 meters (Rafferty et al., 2023). The

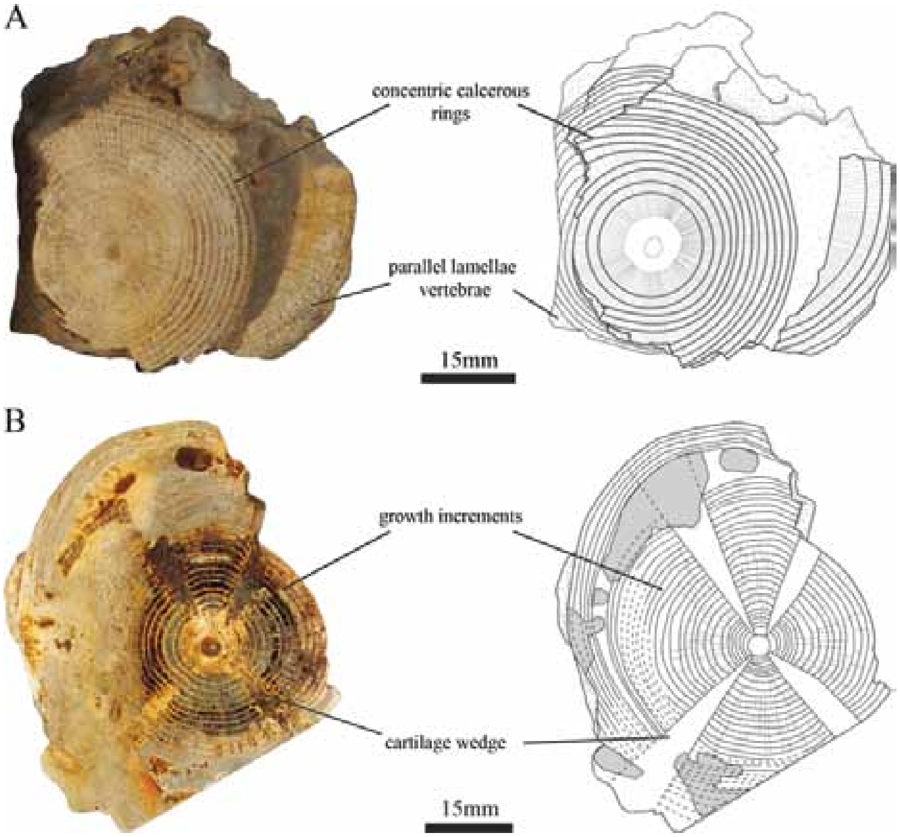

Figure 6. Figure 3 from Jambura and Kriwet (2020), showing vertebral growth bands within two calcified shark vertebrae. Image credit: P. L. Jambura and J. Kriwet. CCA 4.0 International. https://creativecommons.org/licenses/by/4.0/deed.en.

genus *Ginglymostoma* consists of two extant species of nurse shark, the Atlantic *Ginglymostoma cirratum* (Smithsonian Tropical Research Institute, biogeodb.stri.si.edu, accessed September 21, 2023) and the Pacific *Ginglymostoma unami* (Murch, no date). Atlantic nurse sharks are typically between 2.10 and 2.40 meters long (French et al., 2018). The Pacific nurse shark has a maximum length of about 2.8 meters (Murch, no date).

Jambura and Kriwet (2020) describe two large ptychodontid shark vertebrae centra (Figure 6) obtained from Upper Cretaceous limestone rocks in northern Spain, from a coastal outcrop near the village of Soto de la Marina. These vertebrae centra are housed in the vertebrate collection of the University of Vienna's Department of Paleontology (collection number EMRG-Chond-SK-1), and are publicly accessible.

They used the larger vertebra centrum (EMRG-Chond-1b), labelled as "B" in Figure 6, to estimate vertebra radius as a function of age. This centrum is 70 mm in diameter, as measured along the dorsal-ventral line. Dorsal, ventral, and mediolateral radius estimates all yielded similar radial growth patterns. Because of the fragmentary nature of the centrum near its edges, they measured radius rather than the diameter. Centrum diameters were obtained by multiplying the radius measurements by two.

Jambura and Kriwet were not able to determine precisely where this particular centrum belonged in the overall shark vertebral column, so they assumed it to be the largest vertebrae, in order to yield the most conservative estimates of body size. The relative constancy of the spacing between bands indicated that the shark's growth had not yet started to slow down, implying that it was still a juvenile.

Jambura and Kriwet estimated this shark's total length by extrapolating from length and centrum data for the known fossil species *Ptychodus occidentalis*. They also used allometric relationships between centrum diameter and total body length for great white, tiger, and whale sharks to obtain a range of estimates for total body length as a function of time.

The first method yielded an estimated length for this subadult specimen of 8.87 to 11.83 meters. The second method yielded a more conservative length estimate of 4.30 to 7.07 meters long. It should be noted that the upper limit of this conservative length range (7.07 meters) is longer than that of Deep Blue, the largest known extant great white shark (Biswas, 2018), whose estimated length is no more than 6.1 meters (20 feet)! Tooth, jaw, and vertebrae fossil material indicated that the *Ptychodus mortoni* (Figure 5) body length could be between 10 and 11 meters, yet *Ptychodus* fossil teeth exist that are even larger than those upon which the 10-meter-length estimate was based (Shimada et al., 2010)! Jambura and Kriwet (2020) also cited estimated lengths of 13 to 14.4 meters for *P. rugosus*, although they cautioned that these estimates were quite uncertain as they were based on very limited fossil data.

Jambura and Kriwet concluded that the shark was 30 years old when it died, under the assumption that band deposition was annual. Jambura (Anonymous a, 2020) expressed amazement at this fact:

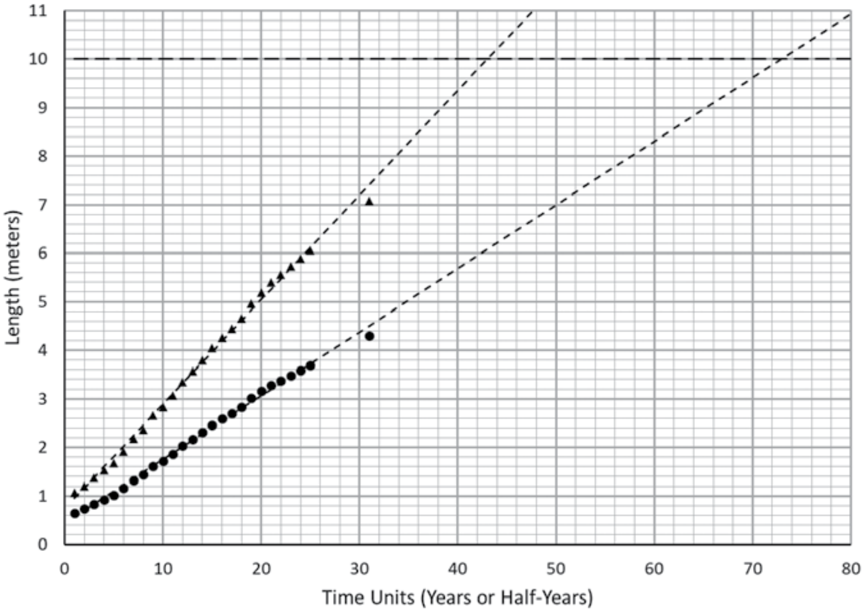

Figure 7. Estimated minimum time range for a *Ptychodus* shark to attain to a total body length of 10 meters, based upon linear extrapolation of Jambura and Kriwet's (2020) range of estimated growth trajectories. Triangles indicate length estimates based upon a body type similar to that of a whale shark, and circles indicate length estimates based upon a body type similar to that of a great white shark.

> We calculated a size of 4–7 meters and an age of 30 years for the examined shark. It's astonishing that this shark was not yet mature when it died despite its rather old age.… [T]his shark doesn't show any signs of flattenings or inflections in the growth profile, meaning that it was not mature—a teenager, if you want. This suggests that these sharks even grew much larger and older.

Jambura and Kriwet (2020, p. 9) stated: "Given that our specimen most likely has not yet reached maturity and therefore represents a subadult, previous size estimations of around 10 m [17] seem possible for this group. Although more accurate maximum size estimations need to wait until a complete specimen can be analyzed, our study agrees with previous work that †*Ptychodus* was one of the largest durophagous vertebrates ever to have lived [footnote, brackets, and dagger symbol, indicating an extinct genus, in original]."

Jambura and Kriwet (2020, p. 11) also stated: "Under the assumption of an annual growth band deposition, †*Ptychodus* matured very late (after more than 25 years) and showed great longevity, similar to the giant filter-feeding sharks that live today.… " Basking and whale sharks are thought to have lifespans, respectively, of up to 50 years (Johnston and Hendry, no date) and 80–130 years (Hsu et al., 2014; Perry et al., 2018).

However, it is possible to obtain tighter constraints on the age at maturity, under the assumption of an adult body length of 10 meters. Using Jambura and Kriwet's data, we can estimate the minimum time for a *Ptychodus* specimen to become fully-grown. Jambura and Kriwet's estimated maximum and minimum growth trajectories are shown in Figure 7. While the downward deflection of the rightmost data point in each trajectory *could* be indicative of a slow-down in growth, these downward deflections could also be due to random scatter in the data. Also, when they attempted to fit von Bertalanffy curves to their data, Jambura and Kriwet obtained a hard-to-believe adult body length of more than 20 meters. Hence, the most conservative approach is to fit straight lines to the two trajectories, rather than attempting to fit von Bertalanffy curves to them, even though we know the true growth trajectories *should* be similar to von Bertalanffy growth curves. From Figure 4, note that the slope of a von Bertalanffy growth curve can only decrease over time. But *any* decrease in slope that might occur after the age of 31 in Figure 7 will *increase* the amount of time for the shark to reach its adult body length. Thus, linear extrapolation of the data in Figure 7 yields the absolute *minimum* time range for this *Ptychodus* specimen to attain to a length of 10 meters. *At least* 43 to 73 years would be needed to attain to a 10-meter body length, under the assumptions of one growth band per year. Even under the assumption of two growth bands per year, the time to maturity would still have been about 21 to 36 years. As noted earlier, in extant animals, large adult body sizes and greater maturation times are consistent with increased longevity.

To put this in perspective, the horn shark (*Heterodontus francisci*) is a species of bullhead shark and an extant durophagous shark. Its maximum length is 1.20 meters (Buch and Bowling, 2019). In captivity, it can live for 12 years (Herstein, 2000), although there is an unconfirmed report of one living to an age of 25 (Anonymous c, no date). Likewise, the Bonnethead Shark (*Sphyrna tiburo*) is an extant durophagous shark, with average length at maturity of less than a meter. Maximum observed ages are between 12.1 and 17.9 years (Frazier et al., 2014; Frazier et al., 2023). Yet under the assumption of an adult body size of 10 meters, just the growth interval of this fossil durophagous *Ptychodus* shark was probably longer than the entire lifetimes of these extant durophagous sharks, even under the assumption of two growth bands per year!

Jambura and Kriwet stated (p. 1), "Our results indicate that ptychodontid sharks were large viviparous animals, with slow growth rates, matured very late and, therefore, show typical traits for K-selected species." The phrases "K-selection" and "K-selected species" occur frequently in evolutionary writings, reflecting an evolutionary, selectionist framework. As the quote above shows, "K-selected" species are characterized by slow growth, late maturity, and large body size. Hence, when reading the evolutionary literature, creation researchers should be especially alert to occurrences of "K-selection" terminology, as it is associated with characteristics (delayed maturation and larger body sizes) that have repeatedly been linked to greater longevity. Thus papers in the mainstream evolutionary paleontology literature discussing "K-selection" or "K-selected organisms" could inadvertently be highlighting indirect evidence for extreme pre-Flood longevity!

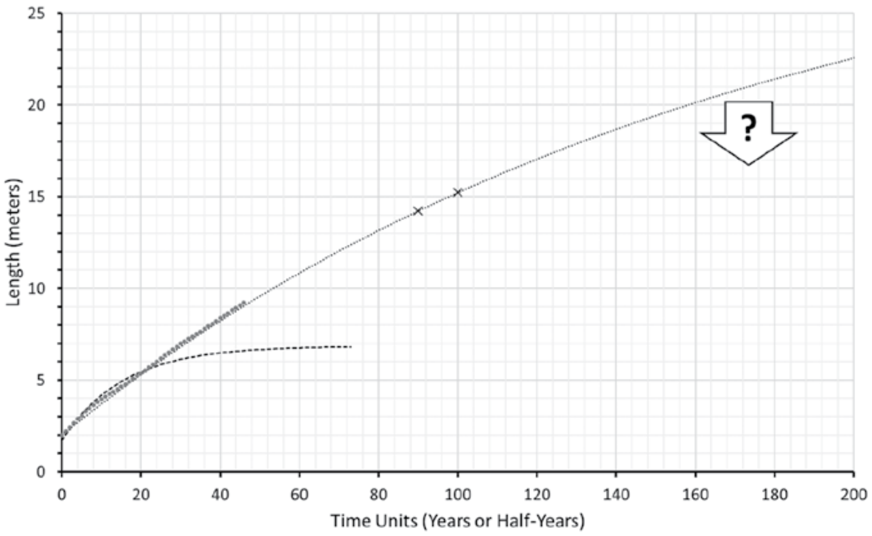

Figure 8. Length-versus-time data (gray dots) inferred from *Otodus megalodon* vertebrae, as well as an extrapolated von Bertalanffy growth curve (dashed line). The data points indicated by the two black crosses were not independent and were not used in the construction of the smoothed curve. After Figure 2a in Shimada (2021). Wintner and Cliff's (1999) inferred great white shark growth curve (short-dashed line) is included for comparison.

An "Old" Adolescent Megalodon

Shimada et al. (2021) counted 46 growth rings in three megalodon vertebrae centra, taken from the disarticulated Miocene megalodon specimen IRSNB P 9893 (formerly IRSNB 3121), housed at the Royal Belgian Institute of Natural Sciences. All three vertebrae showed 46 growth band pairs. They estimated the shark's total length to be 9.21 meters, and they used the assumption that, at any time, total body length was proportional to the (current) vertebrae radius in order to estimate how this total length varied in time. This allowed them to construct a tentative von Bertalanffy growth curve (Figure 8), even though such curves are usually constructed from data obtained from a population of organisms, rather than data from a single individual. The relatively constant spacing between the bands (gray dots in Figure 8) indicates that, at death, this specimen was still a juvenile whose growth had not yet started to slow down.

While recognizing the difficulties in vertebral ring-counting pointed out by Natanson et al. (2018), they assumed that each of the 46 band pairs represented a year (p. 3256):

> In the absence of compelling evidence to the contrary, and given that all three vertebrae we sampled had the same number of regularly spaced bands, we assumed that these bands represent annual growth markers in *Otodus megalodon*.

As acknowledged by Natanson et al. (2018), counting difficulties are likely to be less severe in younger, adolescent sharks, and the regular spacing of these 46 growth bands indicate that this was a young individual.

The great white shark growth curve of Wintner and Cliff (1999) is included in Figure 8 for comparison. The maximum number of growth bands in Wintner and Cliff's shark vertebrae samples was 13, but I have extrapolated their curve past 13 "time units" based on their inferred von Bertalanffy equation. It should be noted that both the implied great white pup length of 1.71 meters and asymptotic length of 6.86 meters are a little higher than expected. Great white sharks are typically 1.20 to 1.50 meters long at birth, and the asymptotic length is thought to be between 6.0 and 6.4 meters (Rigby et al., 2019).

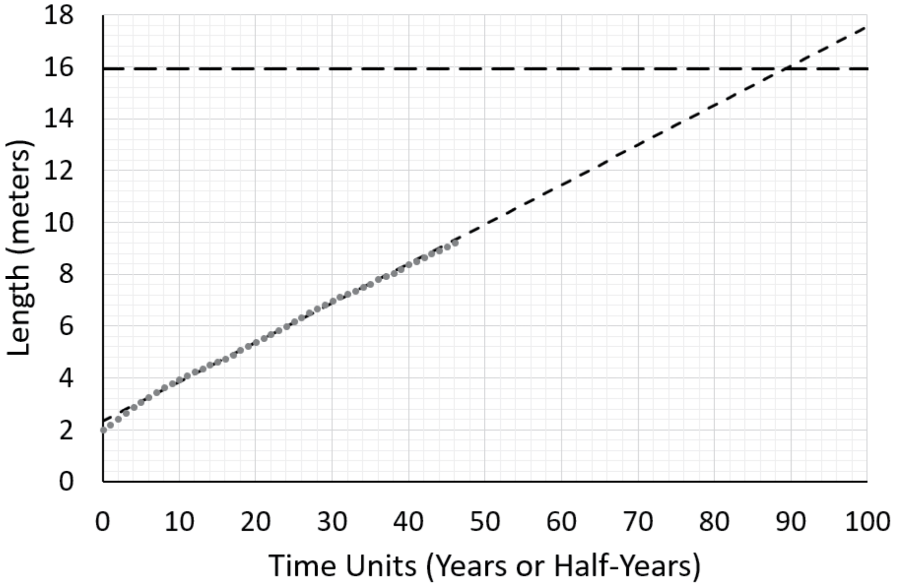

Figure 9. Estimated minimum time for a megalodon to attain the body length of 15.9 meters estimated by Cooper et al. (2022), based on linear extrapolation of Shimada's (2021) inferred megalodon length-versus-time values.

Their resulting growth curve in Figure 8 should be viewed as quite tentative, as it was obtained without any data at all in the 'plateau' part of the growth curve (compare Figures 3 and 8). Thus, their extrapolation beyond these 47 data points is highly uncertain (note the downward pointing arrow in Figure 8). Indeed, a face value interpretation of their growth curve implies an incredible body length of almost 32 meters, or 105 feet! Likewise, it would have taken 498 years to reach 95% of its total adult body length. Although this shark *was* large and long-lived, those numbers seem much too high.

Yet in hindsight, Sternes et al. (2024) suggested that this particular growth curve was an *underestimate*. It should be noted that K. Shimada and M. L. Griffiths were co-authors on this 2024 paper, as well as authors of Shimada et al. (2021), so presumably Shimada and Griffiths concur with this new assessment. Their phrasing is a little imprecise, so it is not exactly clear what they mean. It seems unlikely that they meant that the tentative adult length of 32 meters for megalodon was correct. More likely, they are implying that the allometric equations used to convert centrum diameter to body length underestimate body length.

Shimada et al. also obtained two body-length estimates from two large megalodon teeth. In Hebert (2023), I stated that Shimada et al. had used these teeth data, along with the vertebrae data, to obtain their growth curve. That was incorrect. Rather, they only used the 46 growth rings to obtain their growth curve. They then used allometric relationships and megalodon teeth data to infer estimated total body lengths of 14.17 and 15.33 meters. From their von Bertalanffy curve, Shimada et al. concluded that these body lengths would have occurred at ages of 88 and 100 years, as shown by the black crosses in Figure 8.

Again, these extrapolated numbers should be considered very tentative. What is of far greater interest is the *un*extrapolated portion of the growth curve. Fortunately for our purposes, this is the part of the growth curve subject to the least uncertainty. This megalodon, though still a juvenile, was likely already longer than even Deep Blue, the largest known great white shark, whose body length is thought not to exceed 6.1 meters (Biswas, 2018).

In Figure 9, I obtain a rough estimate of the minimum amount of time it would have taken a megalodon to become skeletally mature. As noted earlier, megalodon length estimates vary considerably, from 14.4 meters to more than 20.3 meters (Cooper et al., 2022). Here I take 15.9 meters to equal the adult body length, using the value provided by Cooper et al. (2022). This length was obtained via computer modeling and vertebral data from an "exceptionally well-preserved" megalodon fossil. However, we keep in mind that Sternes et al. (2024) have argued that this length is likely too short. I performed an informal linear regression (recognizing that the data points are not independent) to obtain the best-fit straight line equation to the data shown in Figure 8. Since the data implied L_0 = 2.0 meters, I forced the y-intercept to be 2. As shown in Figure 9, this extrapolated regression line intersects the line y = 15.9 meters after the passage of 89 time units. Again, the slope of a von Bertalanffy equation can *only decrease* over time. Any potential downward deviation of this regression trajectory will cause the regression line to intersect the line y = 15.9 meters at a time *greater than* 89 units. Hence, 89 years is the absolute *minimum* amount of time for a megalodon to become 15.9 meters long, under the assumption of one growth band per year. Under the assumption of *two* annual bands per year, this growth would still have taken more than 44 years. Both the megalodon's large size and prolonged period of maturation are indirect indications of great longevity.

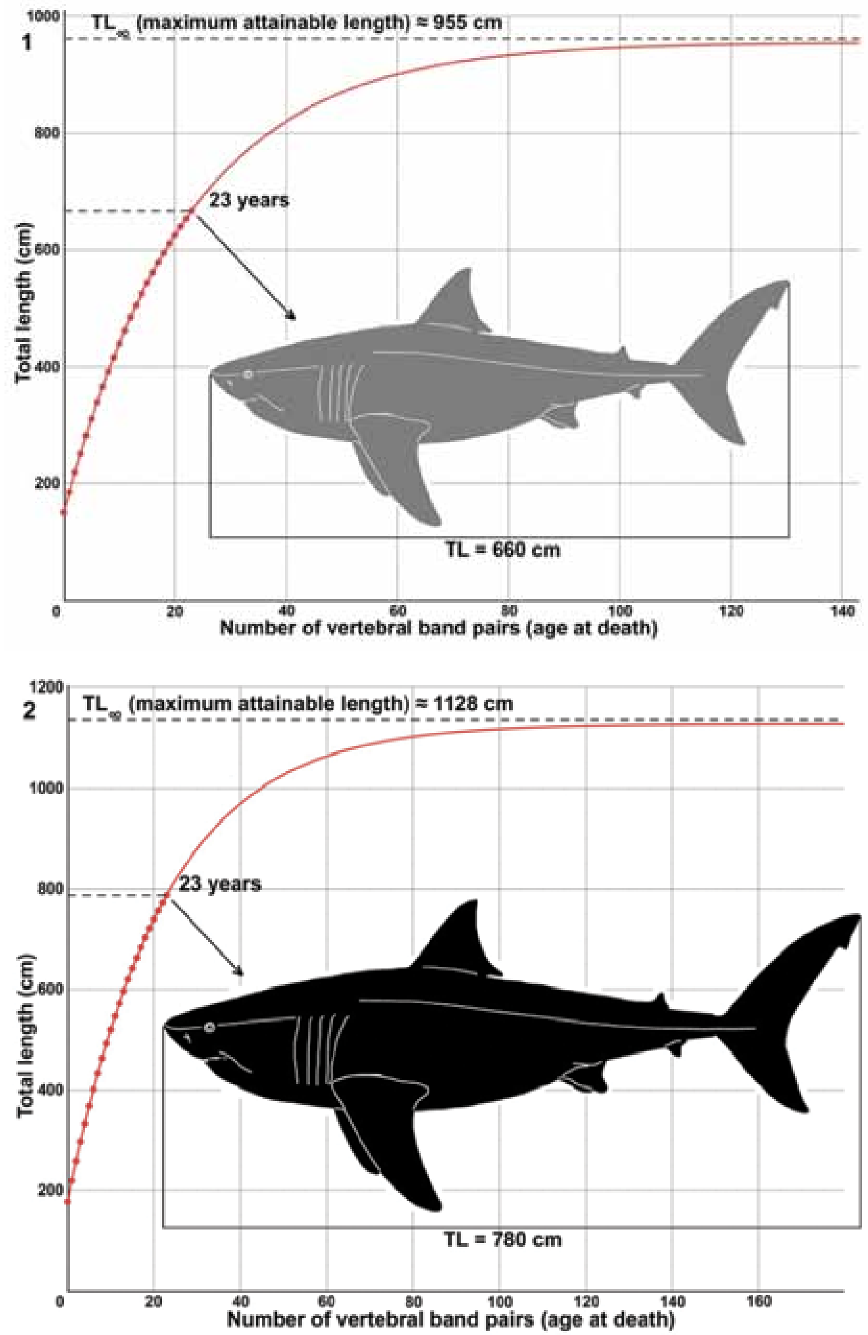

Figure 10. Figure 14 from Amalfitano et al. (2022), showing constructed von Bertalanffy growth curves for a *Cretodus crassidens* shark specimen (Late Cretaceous) from northern Italy. Amalfitano et al. reported that this shark specimen would have taken 64 years to reach 95% of its estimated body length. Image Credit: J. Amalfitano, F. M. D. Vecchia, G. Carnevale, E. Fornaciari, G. Roghi, and L. Giusberti. CC BY 4.0 International. https://creativecommons.org/licenses/by/4.0/.

Comparison with the Long-Lived Greenland Shark

The Greenland shark, *Somniosus microcephalus*, is very long-lived, with an estimated lifespan of between 250 and 500 years. In fact, it is the longest-lived of all extant vertebrate species. This shark's extreme longevity is generally attributed to a very slow metabolism resulting from the very cold waters in which it lives (Nielsen et al., 2016; O'Connor, 2017). The Greenland shark is also one of the largest extant sharks, with a length between 2.4 and 7 meters. It is believed to take about 150 years to reach maturity. Both its large size and stretched-out growth interval are consistent with the trends mentioned earlier linking greater longevity in extant animals to greater adult body sizes and longer growth periods.

However, cold temperatures can't be the explanation for the apparent longevity of the two fossil sharks discussed above. The *Ptychodus* fossil was found in Cretaceous strata, and evolutionary scientists think the Cretaceous climate was warm. Some creationists have long suggested that the pre-Flood world was warmer than today's world, with presumably warmer oceans (Whitcomb and Morris, 1991). Moreover, Cretaceous strata were deposited during the Flood, with likely much warmer oceans due to intense volcanism (Oard, 1990) and rapid production of new hot, seafloor (Baumgardner, 1990). So creationists and evolutionists both would agree that the ocean in which this *Ptychodus* shark swam was probably warm, but for different reasons. Moreover, evolutionists think megalodons lived in temperate-tropical waters (Shimada, 2021), and creationists (at least those holding to a "high" Flood/post-Flood boundary) would argue that Miocene strata were also deposited during the Flood. Hence Miocene oceans should have been fairly warm, as well. Yet despite living in temperate-to-warm waters, these fossil sharks demonstrate characteristics indicative of extreme longevity. Thus, their apparent longevity is truly exceptional.

Cretodus crassidens: A Giant Shark from Italy

Amalfitano et al. (2017) described a "virtually complete" (Amalfitano et al., 2022) large shark skeleton, catalogued as MPPSA IGVR 91032, found in Late Cretaceous rocks in northeastern Italy. They tentatively assigned it to the genus *Cretodus* but later narrowed the classification to the species *Cretodus crassidens* (Amalfitano et al., 2022). The shark's total body length at time of death was estimated to be between 6.60 meters and 9.55 meters. Although recognizing the difficulties in ring counting pointed out by Natanson et al. (2018), they used the assumption that each vertebral growth band represents a year to estimate its age at death to be 23 years. They also used this assumption to construct possible von Bertalanffy growth curves (Figure 10). These growth trajectories implied that the shark's total body length at age of maturity would have been between 9.55 meters and 11.28 meters. It should be acknowledged, given the lack of data in the "plateau" part of the growth curve, that there is considerable uncertainty in the estimated total lengths at maturity. However, since the data capture some of the curvature in the growth trajectory, the uncertainty is not as great as in the case of the megalodon growth trajectory inferred by Shimada et al. (2021). Under the assumption of one growth band per year, Amalfitano et al. estimated that this *C. crassidens* specimen had a longevity of about 64 years, with longevity defined (Taylor, 1958; Natanson et al., 2006) as the typical age for a species to attain to 95% of its adult length. Under the assumption of two growth bands per year, this age would have been 32 years. It seems more appropriate to call this the age at skeletal maturity, t_{mature}, rather than longevity *per se*. Again, a von Bertalanffy growth curve does not tell us *anything* about longevity, at least not directly. It only tells how long it takes for the organism to reach a certain size. Both large adult body sizes and prolonged maturation intervals are associated with greater longevity (Figure 3).

Giant Fossil Sharks Whose Diminutive Descendants May Still Be Extant

The shark examples discussed so far are presumably extinct, although perhaps the extant great white is a dwarfed version of the megalodon. Are there other possible examples of extant sharks whose fossilized relatives were much larger than the extant versions?

Yes. One possible example is the snaggletooth shark, *Hemipristis elongata*, a kind of weasel shark. It is the only extant representative of its genus and, according to the online *Encyclopedia of Life* (eol.org, Smithsonian National Museum of Natural History), it can grow to be 2.40 meters long, although a larger 3.81-meter-long specimen was reportedly caught in Mumbai in 2003 (Katkar and Josekutty, 2003). Yet the extinct snaggletooth *Hemipristis serra* was much larger, with an estimated total length of about six meters (Pimiento et al., 2019). *H. serra* fossil teeth are found in Miocene, Pliocene, and Indonesian Pleistocene deposits and are much larger than those of extant snaggletooth sharks: a large *H. elongata* might have teeth with slant heights of 2 to 2.5 cm, whereas, large fossil *H. serra* teeth from Florida are almost 7.5 cm long (Heim and Bourdon, 1997).

Another possible example are the thresher sharks, genus *Alopias*. There are three extant thresher sharks (Bourbon, 2006–2009), the largest of which is the common thresher, *Alopias vulpinas*, which can routinely be 2 to 5 meters long (Martin, no date), with a maximum length of 5.7 meters (Martinez, 2023). Teeth of the common thresher shark are relatively small, with two examples I saw advertised online (buriedtreasurefossils.com on September 14, 2023) having lengths of 1.4 and 1.59 centimeters. In an examination of eight modern *A. vulpinas* jaws, Shimada (2006) reported crown heights not exceeding 0.9 centimeters.

Fossil representatives of *Alopias* are known only from their teeth, which can be much larger than those from extant versions. Neogene fossil teeth from *A. palatasi* can be more than 4 centimeters long (Kent and Ward, 2018, pp. 157–160). It is a reasonable assumption that if the teeth of fossil *Alopias* sharks were much larger than those of extant *Alopias* sharks, then their total body lengths were probably much larger, as well. In fact, the extinct Neogene thresher sharks *A. grandis*, *A. palatasi*, and "*Alopias*" *Trigonotodus grandis* are commonly known as giant threshers. The teeth of "*Alopias*" *Trigonotodus grandis* have been described (Bourdon, 2006–2009) as "highly enlarged versions of thresher teeth."

Ward and Bonavia (2001, p. 133) note that larger versions of *Hexanchus griseus*, the bluntnose sixgill shark, existed in the past:

> For Neogene species of *Hexanchus*, the species *H. gigas* (Sismonda 1857) is usually employed. However, we have been unable to identify any convincing characters, *other than size* to separate Recent and Miocene specimens. [emphasis mine]

Of course, the name *gigas* is derived from the ancient Greek word for *giant*. Thus, the Neogene species of *Hexanchus* appears to have been a giant version of the extant bluntnose sixgill.

Summary, Conclusions, and Suggestions for Future Research

The large body sizes and apparent delayed maturation of fossil sharks are consistent with longevities greater than those of comparable extant sharks. This fits the Bible's account of early Earth history: whatever factors were enabling extreme human longevity would almost certainly have affected the animal kingdom, as well. Thus, these observations provide extra-Biblical confirmation of the extreme longevity of the antediluvian Genesis patriarchs.

Creation researchers should be alert to future additional growth curves for extinct sharks that might be published in the mainstream paleontological literature, especially if shark experts are able to reduce the current uncertainties in annual ring counts. In that case, such growth curves could provide additional evidence of delayed maturation and giantism, which in turn, are indirect arguments for greater longevity.

Creation researchers should also be alert to future findings of giant shark teeth that are otherwise identical to those of extant sharks, as this would constitute additional evidence that modern sharks are dwarfed versions of fossil sharks. Even evolutionary scientists have noticed that Recent and fossil teeth are often very similar. Ward and Bonavia (2001, p. 135) wrote: "[i]n the teeth of Miocene sharks, there is often little or no morphological difference between the fossil and Recent counterparts. In many cases a fossil name was used because the dentition of the Recent representative of the lineage was poorly known." For this reason, it is very likely that taxonomical names for extinct and extant sharks need to be "cleaned up" considerably. Very likely the true number of basic shark kinds is much less than that assumed by evolutionary paleontologists.

For example, a team led by David Cicimurri (South Carolina State Museum, Columbia, South Carolina) recently-discovered (Cicimurri, Ebersole, and Martin, 2020) the two shark species *Mennerotodus parmleyi* and *Mennerotodus mackayi*, which they acknowledge as being very similar to the modern-day sand tiger shark *Carcharias taurus*. As described in a 2020 press release (Anonymous b, 2020):

> Before naming these two species, the team of scientists spent months reconstructing the dentitions of these ancient sharks from hundreds of isolated teeth and comparing them to modern species. According to Cicimurri, "by piecing together and examining the dentitions of these new shark species, we were able to determine that they are closely related to modern Sandtiger Sharks, so close in fact, that we were able to use modern Sandtiger jaws to reconstruct them."
>
> "Like in modern Sandtiger Sharks, the front teeth in the mouths of the fossil species are very tall and fang-like" said [Jun] Ebersole [McWane Science Center, Birmingham, Alabama]. "These teeth often project out of the mouth, giving the shark a snaggle-toothed appearance, and were perfect for feeding on fishes, crabs, squids, and even other sharks"….

Given the great similarity in teeth shape, it is not hard to imagine that *Mennerotodus* and *Carcharias taurus* are actually the same Genesis kind. These *Mennerotodus* teeth were not exceptionally large, but they may have belonged to a juvenile sand tiger shark, rather than a full-grown adult.

Thus creationists should be "on the lookout" for published descriptions of any giant versions of such teeth, as well as *Mennerotodus* growth curves constructed from vertebrae fossil data. Should *Mennerotodus* be shown to be a giant, slow-growing version of the extant sand tiger shark, this would constitute still more evidence of giantism and greater longevity in sharks.

Also, creationists should be alert to "K-selected" or "K-selection" terminology in the mainstream paleontological literature, as these are used to describe organisms that are large and slow-growing. Hence, the appearance of such terminology in a paper may be a clue that the paper contains information which creationists might consider to be evidence of great longevity.

Nor is the giantism of these sharks a rare exception. Giantism is ubiquitous in the fossil record (Woetzel, 2013; Coppedge, 2023), which suggests that such longevity was widespread, if not universal.

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