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Overview of Fossil Barracudas (Sphyraenidae) from the Cenozoic Strata in Japan, and Associated Global Climate Events

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Abstract

This study provides an overview of "barracuda" (sphyraenid teleost) remains recovered from the Cenozoic strata of Japan, and explores their potential linkages to global climatic events. Fossil evidence of barracudas has been reported from multiple stratigraphic units on Honshu Island, including the Middle and Late Miocene, Early Pleistocene, and Holocene. The stratigraphic ages of these fossil occurrences correspond closely with the timing of major global climatic events. The distributional shifts and persistence of barracuda through multiple climatic episodes provide valuable insights into their ecological plasticity under changing environmental conditions. Incorporating scientific data from non-English-language sources significantly enhances our understanding of biodiversity patterns, not only in extant organisms but also in extinct organisms. Such historical perspectives are essential for constructing the evolutionary and biogeographic responses of epipelagic fishes and marine megafauna to climate-driven oceanographic changes.

Keywords

Barracuda, *Sphyraena*, Cenozoic Strata, Japan, Global Climate Event

1. Introduction

Large sphyraenid teleosts, commonly referred to as "barracudas" are epipelagic piscivorous fishes that are primarily distributed throughout tropical marine regions worldwide [1] [2]. In the waters surrounding the Japanese Archipelago, extant species of barracudas migrate in subtropical areas, particularly from the Ogasawara Islands to the southwestern coasts of Kyushu. Additionally, rare occurrences of barracudas have been recorded along the temperate coastal waters of

Honshu Island, especially off the Kanto region [3]. These northernmost records are generally interpreted as instances of abortive migration, whereby individuals are advected poleward by warm ocean currents beyond their viable thermal range, but are unable to survive the cooler winter temperatures, and thus do not establish reproductive resident populations. The teeth of piscivorous barracuda exhibit distinctive morphologies that allow them to be readily distinguished from those of most other teleost fishes. Consequently, fossils—particularly isolated teeth—of barracudas are commonly found in Cenozoic strata worldwide and serve as valuable components of the geological record [4]-[6]. The teeth of the barracuda are characterized by fang-like front teeth with hooked edges, and thick jaw teeth that taper toward their tips and possess finely serrated cutting edges.

The waters surrounding the Japanese Archipelago constitute a marine biodiversity hotspot, shaped by a variety of factors including the complex configuration of coastlines and seafloor topography as well as the confluence of warm and cold oceanic currents [7]. Fossil evidence, as part of the geological archive, can substantially contribute to a deeper understanding of this marine biodiversity through a chronosequential perspective. However, the limited awareness and accessibility of such fossil data may hinder the full recognition and appreciation of this fact. The fact that fossil records of barracuda from Cenozoic strata in Japan are not widely recognized internationally may serve as a representative example of this issue [6]. This limited recognition is partly attributable to the fact that publications describing these barracuda fossils have predominantly appeared in regionally focused journals and in languages that are not widely accessible to the global scientific community.

This study provides an overview of fossil barracuda teeth found in Miocene and Pleistocene epochs on Honshu Island, Japan [8]-[11], along with a barracuda jawbone found from the Holocene archaeological site [12], and discusses the potential relationships between their occurrences and global climatic events.

2. Occurrences of Barracuda Fossils in Japan

Localities of barracuda remains reported from Japan are shown in **Figure 1**. The following sections provide a review of barracuda remains arranged in chronological order.

2.1. Middle Miocene

The Middle Miocene Mizunami Group is distributed in Gifu Prefecture, located in central Honshu Island. Several tens of fossil teeth identified as *Sphyraena* cf. *S. barracuda* have been described from the Yamanouchi Formation, Hida Formation, Shukunohora Formation, and Nataki Formation that constitute this group (location 1 in **Figure 1**) [8]. All found teeth are isolated teeth consisting of tooth crowns, and they include both front teeth and jaw teeth (**Figure 2(a)**, **Figure 2(b)**). The Mizunami Group has been dated to approximately 17 - 16 Ma based on fission track dating (FT method) [13] [14], and evidence such as the presence

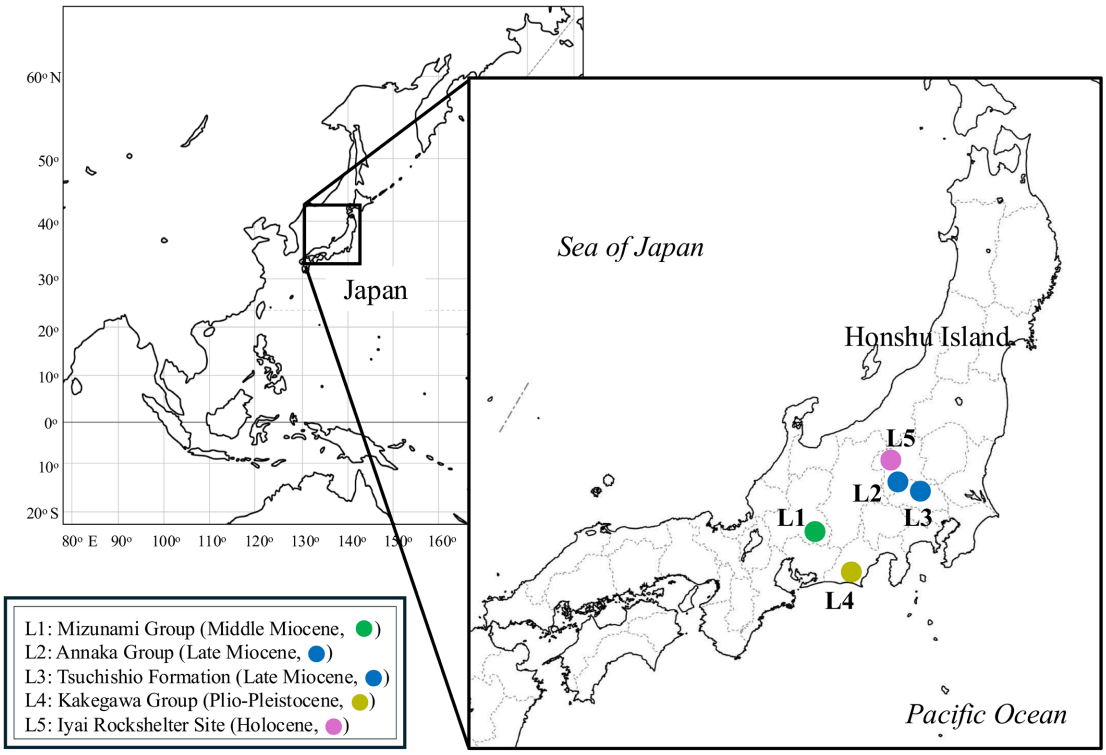

Figure 1. The map shows the localities of barracuda fossils in Japan's main island (Honshu).

of mangrove forests indicates that it developed under a tropical climate [15]. Associated megafaunal remains recovered from these formations include paleoparadoxiids and a diverse assemblage of elasmobranchs [16] [17].

2.2. Late Miocene

The Lower Miocene Annaka Group is distributed in Gunma Prefecture, located in the Kanto region of Honshu Island. Seventeen fossil teeth of *Sphyraena* sp. (cf. *Sphyraena barracuda*) from the Itahana Formation that constitute this group have been described (location 2 in **Figure 1**) [9]. All found teeth are isolated teeth consisting of tooth crowns, and they include both front teeth and jaw teeth (**Figure 2(c)**, **Figure 2(d)**). Based on $^{40}Ar/^{39}Ar$ dating of the tuff layer at the corresponding stratigraphic horizon and the estimated sedimentation rate of the Itahana Formation, the age of the formation is inferred to range from approximately 11.0 - 10.5 Ma [18] [19]. Associated megafaunal remains recovered from this formation include sirenia and *Otodus megalodon* [20] [21].

The Lower Miocene Tsuchishio Formation is distributed in Saitama Prefecture, located in the Kanto region of Honshu Island. An isolated jaw tooth of *Sphyraena* cf. *barracuda* from the Tsuchishio Formation has been described (location 3 in **Figure 1**, **Figure 2(e)**) [10]. The age of the formation has been constrained to 10.1 - 10.0 Ma based on diatom biostratigraphic analysis [22]. Associated megafaunal remains recovered from this formation include *Otodus megalodon* and *Carcharhinus* sp [23] [24].

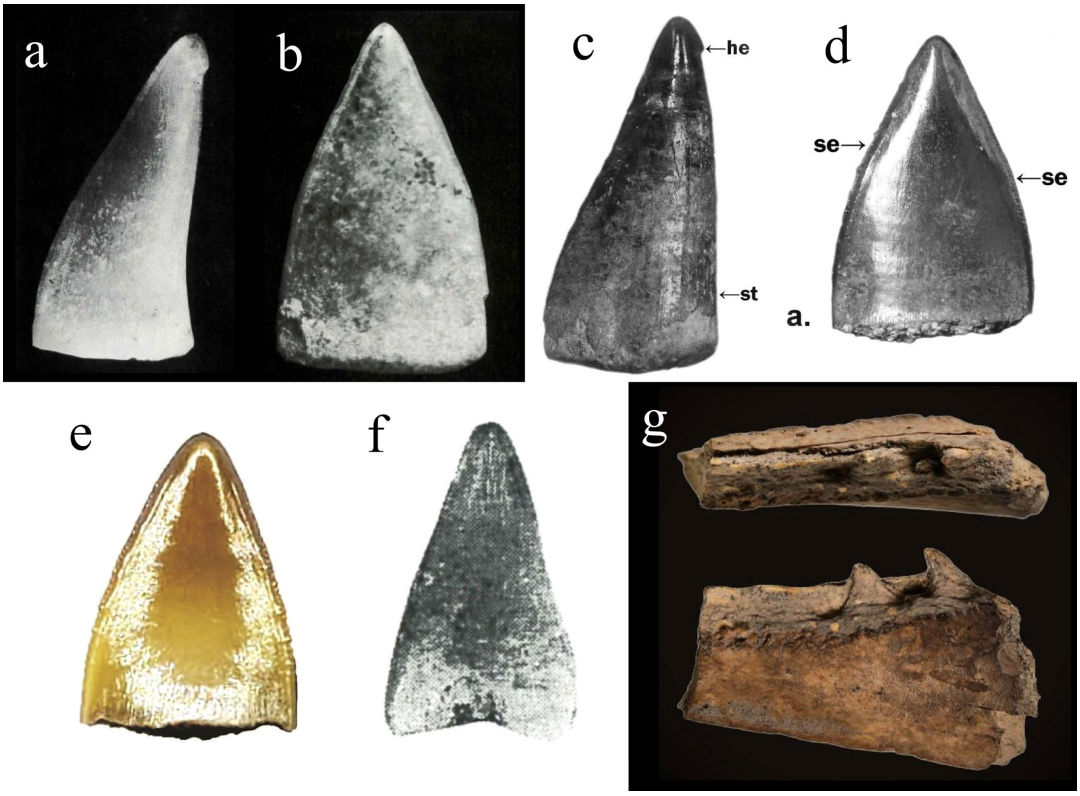

Figure 2. (a) Front tooth of *Sphyraena* cf. *S. barracuda* from the Middle Miocene Mizunami Group, Gifu Prefecture (crown height length 8.6 mm, Nishimoto and Ohe, 1982, Plate 25 [8]). (b) Jaw tooth of *Sphyraena* cf. *S. barracuda* from the Middle Miocene Mizunami Group, Gifu Prefecture (crown height 10.1 mm, Nishimoto and Ohe, 1982, Plate 26 [8]). (c) Front tooth of *Sphyraena* sp. (cf. *Sphyraena barracuda*) from the Late Miocene Annaka Group, Gunma Prefecture (crown height 14.58 mm, Takakuwa, 2025, Fig. 3 [9]). (d) Jow tooth of *Sphyraena* sp. (cf. *Sphyraena barracuda*) from the Late Miocene Annaka Group, Gunma Prefecture (crown height 10.2 mm, Takakuwa, 2025, Fig. 3 [9]). (e) Jaw tooth of *Sphyraena* cf. *barracuda* from the Late Miocene Tsuchishio Formation, Saitama Prefecture (crown height 5.9 mm, Furukuma and Isoda, 2023, Fig. 1 [10]). (f) Jow tooth of *Sphyraena* sp. from the Upper Pleistocene, Dainichi Formation, Kakegawa Group, Shizuoka Prefecture (crown height 4.5 mm, Tanaka, 1985, Plate II [11]). (g) Fragment of dentary of Sphyraenidae gen et sp. Indet. from the Iyai Rockshelter Site, Gunma Prefecture (upper part max. length 28.83 mm, Iyai Rockshelter Site Excavation Team, 2024, Plate 1 [12]).

2.3. Pleistocene

The Kakegawa Group, which represents the Pliocene to Pleistocene, is distributed in Shizuoka Prefecture, located along the Pacific coast in central Honshu Island. An isolated jow tooth of *Sphyraena* sp. from the Dainichi Formation of the Kakegawa Group has been described, and it is identified as a tooth of the species of Barracudas (location 4 in **Figure 1**, **Figure 2(f)**) [11]. Based on FT dating of the intercalated volcanic ash layers, the Dainichi Formation is estimated to be 2 Ma [25]. The Kakegawa Group is characterized by the occurrence of the warm current molluscan assemblage known as the "Kakegawa fauna" [26] [27]. Associated megafaunal remains recovered from this formation include cetaceans and a diverse assemblage of elasmobranchs, notably including *Parotodus benedeni* and *Carcharodon carcharias* [11] [28] [29].

2.4. Holocene

A fragment of a left dentary from an exceptionally large member of the Sphyraenidae (Sphyraenidae gen et sp. Indet.) has been found from the Iyai Rockshelter Site, an Early Jomon period (ca. 10,000 cal BP) archaeological site locates in Gunma Prefecture, Kanto region of Honshu Island (location 5 in **Figure 1**, **Figure 2(g)**) [12]. The remainder is from Layer II in the rock shelter and is thought to be from an individual over 1m in length, possibly a barracuda. Radiocarbon dating has indicated that most of the human skeletal remains from Layer II in the rock shelter date to 8600 - 8000 cal BP, with a subset dating to 6900 - 5900 cal BP [30]. Marine shellfish and a tooth of the elasmobranch *Galeocerdo cuvier* have been excavated from the site [12] [31].

3. Discussion

In the field of biodiversity research, it has been suggested that the lack of geographic and linguistic diversity among researchers, along with a strong English-language bias, has hindered both scientific progress and conservation efforts [32]. A similar issue may affect our understanding of paleobiodiversity, where research findings from non-English-speaking regions are often underrepresented, potentially limiting the development of the field and its contributions to society. As an illustrative case, this study focuses on barracuda remains from Japan, thereby helping to fill this informational gap. In addition to linguistic barriers, it should also be mentioned here that researchers in the study of natural objects exhibit diversity. In paleontology, where fossils serve as the research material, the diversity of researchers involved has often been a subject of considerable debate [33]-[35]. Nevertheless, some of the references reviewed here are based on specimens held in private collections. While such use of privately curated material is not uncommon in specimen-based research, it highlights a broader structural bias: within highly institutionalized academia, there is often an implicit assumption that information produced within formal organizations is inherently more reliable, leading to the marginalization—or even erasure—of data originating outside these institutions. Consequently, valuable information, especially when published in localized languages and in diverse journals, may be overlooked by specialists—whether intentionally or unintentionally—regardless of whether those publications have undergone peer review. Although this may seem like a digression, it is worth considering that an implicit power dynamic—one that initiative should always rest with a small group of specialists—may be hindering our understanding of biodiversity, not only in extant organisms but also in extinct organisms.

A chronosequential overview of the occurrences of barracuda remains in Japan reveals that, similar to other faunal groups, their distribution appears to have been closely associated with global climatic events (**Table 1**). Most of the reported fossil barracudas have been described as comparative taxa to the extant species *Sphyraena barracuda* (e.g., *Sphyraena* cf. *S. barracuda*). Although several species of large sphyraenid teleosts, both fossil and extant, have been reported, all living

Table 1. Records of fossil barracudas in Japan and contemporary global climate events.

Record [Reference]	Relative age	Numerical age	Formation	Group	Global climate event
Nishimoto and Ohe, 1982 [8]	Middle Miocene	17 - 16 Ma	Yamanouchi Fm., Hida Fm., Shukunohora Fm., Nataki Fm.	Mizunami G.	Middle Miocene Climatic Optimum [36] [37]
Takakuwa, 2025 [9]	Late Miocene	11.0 - 10.5 Ma	Itahana Fm.	Annaka G.	Warm climate in the Late Miocene [38]
Furukuma and Isoda, 2023 [10]		10.1 - 10.0 Ma	Tsuchishio Fm.	—	
Tanaka, 1985 [11]	Pleistocene	2 Ma	Dainichi Fm.	Kakegawa G.	Super interglacial period [40] [41] (glacial interglacial cycles climate)
Iyari Rockshelter Site Excavation Team, 2024 [12]	Holocene	8600 - 8000 cal BP or 6900 - 5900 cal BP	(Iyari Rockshelter Archaeological Site)		Jomon transgression [42] [43] (Holocene glacial retreat)

large sphyraenids are restricted to tropical regions. Therefore, the taxonomic uncertainty surrounding these fossil barracudas does not directly translate into uncertainty in paleoecological interpretations; in other words, it does not necessarily challenge the underlying assumption that large fossil barracudas inhabited tropical environments. The Mizunami Group, which dates to the Middle Miocene (17 - 16 Ma), corresponds to the Middle Miocene Climatic Optimum (MMCO; 17 - 15 Ma) [36] [37].

Fossil assemblages from the Mizunami Group indicate the prevalence of tropical climatic conditions during this interval, suggesting that the geographic range of barracudas extended into this region at that time. Subsequently, although a gradual global cooling trend is thought to have begun, the Itahana Formation (11.0 - 10.5 Ma) of the Annaka Group and the Tsuchishio Formation (10 Ma), both assigned to the Late Miocene, have been shown to correspond to a relatively warm interval on a global scale [38]. Around 10 Ma, sea surface temperatures along the Pacific coast of northern Japan are estimated—based on the diatom temperature index—to have been as high as those during the Middle Miocene [39]. This suggests that warm currents predominated in the Pacific region of Japan at that time, likely supporting the distribution or migration of barracudas in the region. The Dainichi Formation of the Kakegawa Group, dating to the Early Pleistocene (2 Ma) of the Quaternary glacial period, represents a transgressive depositional sequence. The molluscan assemblage found from this formation is recognized as the Kakegawa fauna, which indicates a warm current system. Moreover, this interglacial period around 2 Ma is thought to represent one of the so-called "super-interglacials" [40] [41]. Accordingly, the barracuda remains from this formation is inferred to reflect migration into the region during an interglacial interval characterized by the predominance of warm currents. The dentary fragment of barracuda found from the Holocene Iyai Rockshelter Site is temporally associated—based on the co-occurring human skeletal remains—with either 8600 - 8000 cal BP or 6900 - 5900 cal BP. This period corresponds to the Jomon transgression (Holocene glacial retreat) [42] [43], suggesting that barracudas migrated into the region during a period dominated by warm currents and were subsequently captured by ancient humans ("Jomon-jin").

Focusing on a certain large migratory fish species distributed in tropical re-

gions, a review of historical occurrence patterns in the waters around Honshu Island of Japan confirmed that they were strongly associated with global climate events. During the Quaternary, glacial-interglacial cycles are thought to have promoted genetic diversification but had only a limited impact on species-level diversity [44]. This suggests that species and populations primarily responded to glacial-interglacial cycles through range shifts rather than evolutionary changes [45]. In the Pacific region of the Japanese Archipelago, the confluence of the warm Kuroshio Current and the cold Oyashio Current drives substantial shifts in the assemblages of migratory fish. Although paleoceanographic studies have examined historical changes in the Kuroshio path and the influence of the Oyashio [46], the corresponding changes in fish assemblages associated with these oceanographic shifts also represent a topic of potential scientific significance. As climate change and global warming continue to progress, the responses of these fish communities—many of which constitute important fishery resources—to changing oceanographic conditions have been increasingly studied and discussed as critical climate-related risks with direct implications for global food security. This study examined the historical changes of barracudas, but further accumulation of historical records for such migratory species would contribute to a deeper understanding of the adaptive changes in the migratory and dispersal behaviors of epipelagic migratory fishes and marine megafauna under ongoing climate change—that is, their plasticity and adaptive strategies in response to shifting environmental conditions.

4. Conclusion

A review of barracudas remains found from the Neogene strata of Japan revealed their occurrences in the Middle Miocene, Late Miocene, Early Pleistocene, and Holocene. These occurrences were found to be closely associated with major global climate events, including the Middle Miocene Climatic Optimum, the warm of the Late Miocene, and interglacial periods during the glacial cycles. Incorporating various research findings from non-English-speaking regions can enhance our understanding of paleobiodiversity, and moreover, elucidating its historical changes can contribute to a deeper understanding of the adaptive responses of epipelagic migratory fishes and megafauna under ongoing climate change.

Conflicts of Interest

The author declares no conflict of interest.

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