**ABSTRACT**—An anterior (distal) rostrum (MMNS 2957) from the Moodys Branch Formation (late middle Eocene), Tesheva Creek, Yazoo County, Mississippi, U.S.A., is described and identified as *Xiphiorhynchus cf. X. eocaenicus.* The specimen is compared to various species of *Xiphiorhynchus,* especially the holotype of *X. eocaenicus* (BMNH 25744), Bracklesham Group, early middle Eocene, England. This represents the first record of a species of *Xiphiorhynchus* in deposits on both sides of the North Atlantic Ocean. *Xiphiorhynchus eocaenicus* is thought to have had similar environmental preferences and habits as the extant swordfish, *Xiphias gladius.* Since the swordfish prefers oceanic water and makes transatlantic movements, then distribution of a *Xiphiorhynchus* on both sides of the Atlantic is not unexpected. The environment at Tesheva Creek and the type locality in England were both shallow, nearshore, tropical to subtropical habitats. The holotype was probably transported into shallow water either as stomach contents or by ocean currents, whereas the Tesheva Creek specimen was either the remains of a stranded individual or of an animal that died in shallow water after being impaled.

**INTRODUCTION**

In 1901, Woodward described a new species of billfish, *Histophorus eocaenicus,* based on an anterior (distal) rostrum, from the early middle Eocene Bracklesham beds, England. No additional specimens are known and very few authors have discussed the specimen since its original brief description. Fierstine (1978) noted that *Histophorus* is an invalid spelling of the extant sailfish genus *Istiophorus* Lacépède, 1801, and suggested that *I. eocaenicus* may be a *Xiphiorhynchus* because the rostrum contained a distinctive *Xiphiorhynchus*-like canal system (two pairs of lateral canals and a single central canal). Schultz (1987) placed the Bracklesham specimen in *Xiphiorhynchus* van Beneden, 1871, and suggested that it should be synonymized with *X. priscus* (Agassiz, 1834), a fairly well-known xiphiorhynchin from the lower Eocene, London Clay, England. Monch (2000) disagreed with Schultz’s decision of synonymy because the rostrum of *X. priscus* has a round cross-section, whereas the rostrum of *X. eocaenicus* has a much flatter cross-section. Thus, *X. eocaenicus* remains a valid, although relatively unknown species (Monch, unpublished).

The genus *Xiphiorhynchus* is composed of approximately ten species that have been found in Eocene deposits of Belgium, Egypt, England, Morocco, and U.S.A., and in Oligocene deposits of Belgium, Hungary, and the U.S.A. (Schultz, 1987; Monch et al., unpublished). With the exception of *X. priscus,* no species of *Xiphiorhynchus* has ever been recorded outside the geographic region and stratigraphic level of its original discovery.

One fairly complete and two poorly preserved distal rostra were collected in the Moodys Branch Formation (late middle Eocene), Mississippi, U.S.A. The better preserved specimen is identified as *Xiphiorhynchus cf. X. eocaenicus.* We compare the Moodys Branch specimens to other species of *Xiphiorhynchus,* especially *X. eocaenicus* and *X. kimbaloulii* Fierstine and Applegate, 1974 (upper Eocene, Yacoo Formation, Mississippi), and discuss the paleoecology of the Moodys Branch Formation as it relates to the specimen of *Xiphiorhynchus cf. X. eocaenicus* and its taphonomy.

**MATERIALS AND METHODS**

**Comparative Materials**


**Institutional Abbreviations**—AMNH, American Museum of Natural History, New York, New York; BMNH, The Natural
Methods

We follow the methodology of Fierstine (2001a, b) for identifying fossil billfish using rostral characters, with the exception that we added additional characters to analyze the position and size of the central and lateral canals (Fig. 1). Ratios (proportions) were used as variables and were compared to ratios of other species of Xiphiorhynchus. Measurements were taken directly from the specimen where possible, otherwise they were taken from computer tomography (CT) images. Because the oysters that encrust MMNS 2957 have paleoecological significance and were not removed, most of its measurements were made from CT images. To estimate how rapidly the rostrum tapers to a distal point, we drew a line along the right and along the left side of a photograph or drawing of a rostrum in dorsal or ventral view, and measured the angle where the two lines intersected distally. The resulting value (in degrees) was defined as the angle of taper (a).

The systematics presented herein are based on two recent clades analyses: Recent and fossil scatrophine fishes (Mosch, 2000) and Recent and fossil billfishes (Fierstine and Monsch, 2002). We follow the Eocene time scale of Berggren et al. (1995). We use the spelling, Tesheva Creek, as found on the Zeiglerville, Mississippi Quadrangle (U. S. Geological Survey) rather than the more widely published spelling, Techeva Creek (e.g., Dockery, 1977; Breda, 1993).

SYSTEMATIC PALEONTOLOGY

Class ACTINOPTERYGII sensu Nelson, 1994
Order PERCIFORMES Bleeker, 1859
Suborder SCOMBROIDEI Bleeker, 1859
Family XIPHIIDAE Swainson, 1839
Subfamily XIPHIORHYNCHINAE Regan, 1909
Genus XIPHIORHYNCHUS van Beneden, 1871

Type Species—Xiphiorhynchus elegans van Beneden, 1871

Diagnosis—In cross-section, the rostrum contains two types of longitudinal canals, an unpaired central canal and two pairs of lateral nutrient canals, and both types vary as to how far they extend distally. The dorsal pair of lateral nutrient canals is positioned closer to the mid-line than the ventral pair of lateral nutrient canals.

XIPHIORHYNCHUS CF. X. EOCAENICUS
(WOODWARD, 1901)
(Fig. 2; Tables 1, 2)

Reflected Specimen—MMNS 2957 (Fig. 2), a distal rostrum partially encrusted with the marine oyster, Pycnodonte trigonalis.

Locality and Age—MGS Locality 11, Moodys Branch Formation, late middle Eocene, along Tesheva Creek, Yazoo County, Mississippi, U.S.A.; Section 9, T.12N, R.1E, Zeigleerville, Mississippi Quadrangle, 7.5 minute Series, U.S. Geological Survey, 1964 (Fig. 3). Specimen MMNS 2957 was collected in situ in the Glycymeris idonea (a taxodont clam) bed as defined by Dockery (1977). The Glycymeris bed contains Ophiura (a sand-dollar) burrow fillings (trace fossils of a callianassid ghost shrimp) and has a 30-60 cm-thick coquina-like concentration of Glycymeris shells that form the middle of the bed.

The Moodys Branch Formation of the basal Jackson Group was deposited as the transgressive systems tract of the late Eocene sequence cycle TE3.2 of Mancini and Tew (1991), who placed the Moodys Branch Formation in the Bartonian planktonic foraminifer zone P14 and calcareous nannoplankton zone NP17. According to Berggren et al. (1995), NP 17 is late middle Eocene (37.0-40.3 Ma).

Dockery (1977) recognized three facies in the Moodys Branch Formation, one of which, the northern terrigenous facies, is based on the presence of nearshore marine sands that were deposited in Yazoo County, Mississippi. Dockery (1977) divided the northern terrigenous facies that is exposed along 3.2 km of Tesheva Creek into three beds: a lower 1.2 m-thick basal clay, a middle 1.8-m thick Glycymeris bed (source of the study specimen), and an upper 1.8 m Periarchus伊利 (a sand-dollar) bed (Fig. 3). The Periarchus bed grades upward into the basal Yazoo Formation (late Eocene). The Glycymeris bed has produced remains of other marine vertebrates including a primitive whale and abundant shark, ray, and bony fish teeth (Breda, 1993). In
FIGURE 2. Xiphiorhynchus cf. X. eocaenicus, MMNS 2957, late middle Eocene, Moodys Branch Formation, Mississippi, U.S.A. Posterior half of rostrum is encrusted with oysters (Pycnodonte trigonalis). A, dorsal view; B, ventral view; C, cross-section (computer tomography image) of the rostrum taken 200 mm from the distal tip; D, same as C, but taken 165 mm from the distal tip. Abbreviations listed in text. Scale bar equals 20 mm (A, B) and 10 mm (C, D).

addition, Green and Stringer (2002) have reported an otolith fauna of 14 species of teleosts from the underlying clay bed.

Description—MMNS 2957 is 295 mm long, and 58 mm wide and 31.1 mm deep at its proximal end (Table 1). It tapers relatively rapidly to a complete distal tip (α = 17°). The posterior half of the dorsal and right lateral surfaces is encrusted with six different sizes of the oyster, *P. trigonalis* (the largest oyster is incomplete and measures 80 mm in length). The exposed (non-
from the distal tip (Fig. 2D) has a morphology similar to the MGSll from test hole (MMRI-LTH #83-06, file map of Yazoo County, Mississippi, U.S.A.; have a longitudinally oriented fibrous texture. The ascending at the posterior end of the specimen. The anterior two-thirds of canals on the left side are less distinct. The dorsal surface is more chus 2C) shows a mid-line suture dorsally, a groove at the ventral mid-line, a central canal (cc), a right dorsolateral nutrient canal (led) and a right ventrolateral nutrient canal (lev). The nutrient canals on the left side are less distinct. The dorsal surface is more rounded than the flatter ventral surface. A CT image 165 mm from the distal tip (Fig. 2D) has a morphology similar to the proximal cross-section. The right led and lev, and the left lev are distinctly visible; however, the cc and left led are too indistinct on the CT image to determine if they are present.

Discussion—What little we know about Xiphiorhynchus is based on fragmentary and often poorly preserved specimens, most of which are partial rostra. Of the ten putative species, seven are known only by the holotype, six are known only by a single rostral fragment, and one, X. rupelianus (Leriche, 1909) is known only by several isolated vertebrae and an articual. Two holotypes have been lost or misplaced [X. homalorhamphus (Cope, 1869) and X. hungaricus Weiler, 1943]; thus, only seven species have rostra that can be compared with MMNS 2957 (Table 2). Casier (1966) identified five rostra as belonging to X. priscus, and it is the only xiphiorhynchin other than X. eocaenicus known by more than one rostrum. With so few rostra identified for any one species, we have very little data on intraspecific variation. In addition, we lack measurements of the internal canal system of all xiphiorhynchins except MMNS 2957, X. aegyp- ticus and X. kimblaloeki (Table 2). With these limitations in mind, we make the following morphological comparisons.

Table: Various measurements (in mm) of the rostrum of MMNS 2957, Xiphiorhynchus cf. X. eocaenicus (Woodward, 1901), Moodys Branch Formation, late middle Eocene, Mississippi. Proximal measurements taken at 0.67 L or 200 mm from distal tip and distal measurements from 0.57 L or 165 mm from distal tip. Abbreviations are defined in the Materials and Methods section of the text and in Fig. 1. Characters with an asterisk (*) were measured from computer tomography (CT) images.

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The combination of two variables (D/W and α) separates MMNS 2957 from rostra of all other xiphiorhynchins, except X. eocaenicus (Table 2). Xiphiorhynchus aegyp- ticus has a more depressed rostrum (D/W = 0.45) and X. kimblaloeki, X. parvis, X. priscus, and X. rotundus have more round rostra (D/W varies between 0.69-1.02) than MMNS 2957. The rostra of X. eocaenicus and X. elegans have an intermediate cross-sectional shape (D/W = 0.62 and 0.63, respectively) that is probably not significantly different from the shape (D/W = 0.56) of MMNS 2957. The rostrum of MMNS 2957 has a taper that is nearly identical to that of X. eocaenicus and X. rotundus, and a more rapid taper (higher α value) than the rostra of X. aegyp- ticus, X. elegans, X. kimblaloeki, and X. priscus (Table 2). A specimen of X. priscus (BMNH 36133a ) is a middle segment of a rostrum with almost parallel sides (α ~ 3°); the reduced taper is evidence that the specimen is probably misidentified when compared with others that Casier (1966) identified as X. priscus (Table 2). Thus, based on the variables D/W and α, rostrum MMNS 2957 is most similar to X. eocaenicus.

Variables associated with the size and position of the canal system as seen in cross-section are known for only two species of Xiphiorhynchus and MMNS 2957 (Table 2). With the exception of one measurement, the lateral canals of MMNS 2957 are closer to the mid-line (DMlcv/W, DDi,cv/W) and dorsal surface (DDi,c/D, DDlcv/D) than in X. aegyp- ticus and X. kimblaloeki. In a cross-section of the holotype of X. eocaenicus (BMNH 25744) at 150 mm from the distal tip (Fig. 4B), Fierstine (1978) and Mousch (unpubl.) noted two pairs of very small (unmeasured) lateral nutrient canals (led and lev) and one or two small foramina (canals) in the center of the cross-section that are prob-
ably remnants of the cc. Unfortunately, the ventrolateral canals (lecv) are not visible in Figure 4B. None of these canals were mentioned in the type description (Woodward, 1901). This morphology contrasts with the larger lateral nutrient canals of MMNS 2957 observed in a cross-section at 165 mm from the distal tip (compare Figs. 2C, D with Fig. 4B).

The exterior surface of the holotype of *X. eocaenicus* is very smooth (Fig. 4B), whereas the exterior surface of MMNS 2957 has a longitudinally oriented fibrous texture. Most likely, the difference in texture is related to different states of preservation (see discussion below). Because of the differences in the canal system between MMNS 2957 and *X. eocaenicus*, we think there is enough taxonomic uncertainty to warrant identification of MMNS 2957 as *Xiphiorhynchus cf. X. eocaenicus*.

**PALEOECOLOGICAL AND PALEOGEOGRAPHICAL IMPLICATIONS**

In this section we compare the environment and age of the Moodys Branch Formation at Tesheva Creek, west-central Mississippi, to the environment and age of the type locality of *X. eocaenicus* at Bracklesham Bay, southern England. In addition, we discuss the presence of *X. eocaenicus* in shallow, nearshore waters of both the western and eastern North Atlantic Ocean.

Bread (1991) concluded that the fossil invertebrate and vertebrate fauna of the *Glycymeris* bed of the Moodys Branch Formation inhabited a shallow, nearshore marine environment. He also noted *Glycymeris* prefers current-swept bottoms and that the bed suggested a high energy setting. Based on the presence of several of the shark species, he hypothesized that an open, deeper marine environment was nearby. The latter point was emphasized by Manning (2003), who noted that two of the taxa listed by Bread (1991), the mako shark *Isurus paucus* and the lesser billyfish *Cylindracanthus rectus* (Dixon, 1850) and to a lesser extent the great white shark *Carcharodon carcharias* (Blainville, 1815) were indicative of a deep-water habitat. Green and Stringer (2002) concluded that the telescop fishes (primarily congrid, haemulid, and sciainid) they identified based on otoliths from the clay bed at Tesheva Creek dwelled mainly on the bottom and favored water depths less than 40 m in a tropical to subtropical climate. Foraminiferan studies from the clay bed at Tesheva Creek also indicated a shallow marine (inner shelf) environment with tropical to subtropical conditions (Green, 2002). As noted above, the Moodys Branch Formation is in the biostratigraphic zones P14 and NP 17 (Mancini and Tew, 1991) or late middle Eocene (37.0-40.3 Ma).

The exact locality where the holotype of *X. eocaenicus* was collected is unknown, except that it was in the Bracklesham Group (Beck) at Bracklesham Bay (Woodward, 1901; Monsch, 2000). Four formations comprise the Bracklesham Group, each with several transgressive and regressive phases that have diverse ecological conditions ranging from estuarine lagoonal to offshore shelf (Daley, 1999). Since the Selsey Formation of the upper Bracklesham Group is the only one of the four formations that contains both *Glycomeris* sp. and *Ophiomorpha* burrows (Curry et al., 1977; Tracey et al., 1996; Daley, 1999), we think it is probably the ecological equivalent of the Moodys Branch Formation at Tesheva Creek. Daley (1999) believed the Selsey Formation in the Isle of Wight was deposited in shallow, nearshore waters between 49-40.5 Ma (early middle to late middle Eocene) based on calcareous nanoplankton. Taylor (1978) hypothesized that the seawater temperature was around 18°C during the de-
position of the Bracklesham Group, and that the abundant remains of sharks, rays, teleosts, and cuttlefish indicated a diverse nektic community that preyed on benthic invertebrates. Thus, the Selsey Formation is slightly older, but probably represents an environment similar to the Moodys Branch Formation at Tesheva Creek.

Fierstine and Monsch (2002) and Fierstine and Pfeil (2002) concluded that xiphiorhynchins belong to the same clade (Family Xiphiidae) as the extant swordfish, *Xiphias gladius*. If their preliminary analyses are correct, then the ecological preferences of *X. eocaenicus* might be similar to the preferences of *X. gladius*. According to Robins et al. (1986), swordfish are distributed worldwide in tropical and temperate oceanic waters. They primarily inhabit midwaters from 300-600 m in depth, but come to the surface in temperate climates. Normally an offshore pelagic species, an individual swordfish may occasionally wander into shallow water to become stranded (Robins et al., 1986). Swordfish in the North Atlantic Ocean favor waters of 18° C or higher (Beckett, 1974). These giant fishes can travel long distances. A swordfish tagged off the Grand Banks in the western North Atlantic Ocean was captured nearly three years later off Morocco, a total distance of 3,715 km (The Southwest Fisheries Science Center's [National Marine Fisheries Service] 1998 Billfish Newsletter, unpubl.).

During the Middle Eocene, the distance across the North Atlantic Ocean was much shorter than it is today (Smith et al., 1994) and the Tethys Seaway was open (Prothero, 1994; Smith et al., 1994). During the Eocene the circulation pattern in the North Atlantic Ocean flowed southwest from the Tethys Seaway, across the middle Atlantic into the Caribbean Sea and Gulf of Mexico, then developed into a Gulf Stream-like pattern. On the return trip it flowed northeast along the eastern shore of North America, then curved across the Atlantic Ocean to Europe, where it turned southward to join the westward flow from the Tethys Seaway (Prothero, 1994:fig. 1.12; Feldmann et al., 1998:fig. 30). If *X. eocaenicus* and *Xiphias gladius* had similar travel patterns, then *X. eocaenicus* would have had no trouble crossing the narrow North Atlantic Ocean, either with or against the Gulf Stream-like current during the middle Eocene. Thus, its presence at both Tesheva Creek and Bracklesham Bay is not surprising.

If the Selsey Formation and Moodys Branch Formation at Tesheva Creek are nearshore shallow habitats, how do we explain the presence of a supposed oceanic fish like *X. eocaenicus*? Several possibilities provide plausible explanations:

1. The rostra were transported into shallow water as stomach contents of a predator. Based on bones of juvenile billfish in the stomach contents of the black marlin, *Makaira indica* (Fierstine, unpubl.) and on a few eroded istiophorid rostra collected at Lee Creek Mine (early Pliocene) (Fierstine, 2001a), stomach acid dissolves the outer surface of the rostrum to a smooth finish and can cause some shallow and deep pits. The surface of the holotype of *X. eocaenicus* is smooth with a few shallow pits (Fig. 4A), a condition that is consistent with erosion by stomach acid. Speci-
men MMNS 2957 is slightly etched on its outer surface, but not worn smooth. Since it was encrusted with oysters and exposed to the elements, the etching most likely was due to chemical and physical erosion of the environment, not by stomach acid. Neither of the two rostra contained bite marks, a pathology one might expect when predaceous sharks consume large food items (Schwimmer et al., 1997).

(2) The rostra were remnants of stranded individuals. We cannot discount this hypothesis; however, no other parts of the skeleton have been positively identified at either Bracklesham Bay or Tesseha Creek.

(3) The rostra were from xiphiorhynchins that inhabited shallow water. We doubt that X. eocaenicus normally inhabited shallow water. The holotype and specimen MMNS 2957 are bill fragments from large fish, perhaps three to four meters in length, based on the size of a nearly complete specimen collected in the Austrian Oligocene (Fierstine and Pflieger, 2002). Since xiphiorhynchins lacked large teeth and structures to crush invertebrates, X. eocaenicus probably fed like a swordfish, that is, by injuring prey with its rostrum, then returning to consume it (Scott and Tibbo, 1968). This action must be accomplished at a water depth in which the billfish can maneuver.

(4) The rostra were embedded in a large oceanic animal that moved into shallow water and died. Distal tips of swordfish bills have been found impaled in a variety of animate and inanimate objects, including marine turtles, sharks and whales (see discussions in Gudger, 1940; Frazier et al., 1994). Remains of laminid sharks and primitive whales have been collected at Tesseha Creek; therefore, it is possible that one or more of the rostra were impaled and broken off in a large animal that died in shallow water.

(5) The rostra were transported by currents from deeper water. Deep water has been postulated in proximity to the collection sites at both Tesseha Creek (Braeard, 1991) and Bracklesham Bay (Taylor, 1978d:fig. r; Daley, 1999:19). However, the distal tip of MMNS 2957 tapers to a sharp point, an unexpected morphology for a specimen that was mechanically transported very far. The holotype of X. eocaenicus has a broken tip and a very smooth outer surface, conditions that are consistent with transport by ocean currents.

In summary, we believe Xiphiorhynchus favored oceanic waters and reject the hypothesis that xiphiorhynchins normally inhabited shallow water. The holotype of X. eocaenicus was probably transported into Bracklesham Bay either as stomach contents of a predator or by ocean currents from deeper water. Rostrum MMNS 2957 was probably deposited at Tesseha Creek either as the remains of a stranded individual or the remains of an animal that had been impaled previously in deeper water.

ACKNOWLEDGMENTS

We are indebted to D. Dockery (Mississippi Office of Geology) for the loan of the Tesseha Creek specimens and for advice, encouragement, and invaluable information throughout the project. K. Munsch (University of Wrocław, Poland) unsolicitedly allowed us to use his unpublished photograph of X. eocaenicus. D. Dockery, E. Manning (Tulane University, New Orleans, Louisiana) and G. Strangier (The University of Louisiana at Monroe) made important comments on an earlier draft of this paper. H. Thomas (LACM) and F. Vernecia (San Luis Diagnostic Center) provided computer tomography (CT) scans. A. Garcia (Cal Poly, San Luis Obispo, California) assisted in specimen preparation, and R. Bowker (Cal Poly) and J. McLaughlin (Cal Poly) helped with data retrieval. A. Fierstine provided support and encouragement throughout the study.

LITERATURE CITED


