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NOTE

FOSSIL TUNA VERTEBRAE PUNCTURED BY ISTIOPHORID BILLFISHES

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Extant billfishes of the family Istiophoridae (Teleostei: Perciformes: Scombroidei) often use their rostra to impale or slash prey (Gudger, 1940; Nakamura, 1983; Frazier et al., 1994). Although it is generally assumed that fossil and living representatives of the same species have similar behaviors and physiology (Fierstine, 2001), there is no documentation of a fossil istiophorid billfish using its rostrum for food capture. The Yorktown Formation (early Pliocene) at Lee Creek Mine, eastern North Carolina, USA, has yielded the world's largest collection of fossils of the family Istiophoridae (Fierstine, 2001), and an abundant number of vertebrae belonging to tunas of the genus *Thunnus* (Purdy et al., 2001). Most of the fossil istiophorids at Lee Creek Mine belong to four extant species. The genus *Thunnus*, although not identifiable to species at Lee Creek Mine (Purdy et al., 2001), has five extant species, all of which are prey of istiophorid billfishes (Nakamura, 1983). We offer evidence that punch marks in five tuna vertebrae collected at Lee Creek Mine were the result of impalement by istiophorids.

MATERIALS AND METHODS

We follow Robins et al. (1991) for scientific and common names for recent species of fish, institutional abbreviations of Leviton et al. (1985), and osteological terminology of Gregory and Conrad (1937) and Potthoff (1974). All material examined (Tables 1, 2) is housed in one of the following institutions: Los Angeles County Museum (LACM), North Carolina Museum of Natural Sciences (NCSM), or National Museum of Natural History (USNM). Over 3,000 fossil *Thunnus* vertebrae from the Lee Creek Mine, Beaufort County, North Carolina, were examined from the collections of NCSM and USNM for evidence of punctures. Fossil vertebrae were compared with those of extant *Thunnus* species to substantiate identification, determine position in the vertebral column, and to estimate sizes of fish. Linear measurements of vertebrae were made to the nearest 0.5 mm (Table 1). Fork length (FL) is the straight-line measurement from tip of snout to fork of caudal fin (*Thunnus*) and from tip of upper jaw to fork of caudal fin (Family Istiophoridae). All species of *Thunnus* have 18 or 19 precaudal vertebrae and 21 or 20 caudal vertebrae, for a total of 38 to 40 vertebrae (Gibbs and Collette, 1967). Rostra of various extant istiophorids were inserted into each puncture mark to determine if they fit into the hole. The rostrum with the "best" fit of the rostra tested was recorded as the approximate size of the istiophorid that made the puncture mark.

RESULTS

Five fossil tuna vertebrae (NCSM 12683, 12684, and 16990; USNM 49441, 49442) collected at Lee Creek Mine, North Carolina, have a single puncture mark in each of their centra. Each mark is round to oval in cross-section, has its largest diameter on the lateral surface of the centrum, and terminates by a bulge of bone in the coelous intercentral space (e.g., Fig. 1B). If these weren't fossil specimens, one might consider each hole to have been made by a fisherman's gaff. None of the five punctured vertebrae showed evidence of being ingested; there is no visible etching of the bone.

NCSM 12683 (Fig. 1A, B) is a posterior caudal vertebra similar in size and shape (Table 1) to vertebra number 34 or 35 (from the anterior part of the peduncular keel) of a bluefin tuna (*Thunnus thynnus*) of 1,670 mm FL (USNM 268985; Table 2). The puncture mark enters the right dorso-lateral fossa of the centrum and extends into the posterior coelous space. The tip of the rostrum of an 86 kg blue marlin (*Makaira nigricans;* LACM 25321) fits the hole in the centrum (Table 2).

NCSM 12684 (Fig. 1C, D) is a posterior caudal vertebra similar in size and shape (Table 1) to vertebra number 33 (from the anterior part of the peduncular keel) of a bluefin tuna of 1,793 mm FL (USNM 268982; Table 2). The puncture mark enters the left dorso-lateral fossa of the centrum and extends into the posterior coelous space. The tip of the rostrum of a 123 kg blue marlin (*Makaira nigricans*; LACM 25320) fits the hole in the centrum (Table 2).

NCSM 16990 (Fig. 1E, F) is a middle caudal vertebra similar in size and shape (Table 1) to vertebra number 27 or 28 (located just anterior to the peduncular keel) of a bluefin tuna of approximately 1,300 mm fork length (USNM 268980; Table 2). The puncture mark enters the right ventro-lateral fossa of the centrum and extends into the anterior coelous space. The tip of the rostrum of a 23 kg white marlin (*Tetrapturus albidus*; LACM 25504) fits the hole in the centrum (Table 2).

USNM 494441 (unfigured) is an anterior caudal vertebra similar in size and shape (Table 1) to vertebra number 22 or 23 (located in the middle of the body) of a bluefin tuna of approximately 1,300 mm FL (USNM 268980; Table 2). The puncture mark enters the left dorso-lateral fossa of the centrum and extends into the anterior coelous space. The tip of the rostrum of a 82 kg blue marlin (*Makaira nigricans*; LACM 25409) fits the hole in the centrum (Table 2).

USNM 494442 (unfigured) is an anterior caudal vertebra similar in size and shape (Table 1) to vertebra 19 or 20 (located in the middle of the body) of a bluefin tuna of approximately 1,300 mm FL (USNM 268980; Table 2). The puncture mark enters the right dorso-lateral fossa of the centrum and extends into the posterior coelous space. The tip of the rostrum of a 27 kg white marlin (*Tetrapterus albidus*; NCSM 31294) fits the hole in the centrum (Table 2).

DISCUSSION AND CONCLUSIONS

Various factors limited the scope of our study. Because each fossil vertebra was incomplete and missing many of its diagnostic features (e.g., spines, articular processes), we were unable to identify any of them beyond the generic level, and only able to estimate the size of the fish and the position of the vertebra in the vertebral column. We never made an exhaustive search for the perfect fit between istiophorid rostrum and puncture hole, because most species of istiophorid billfish of similar size have a similar-shaped rostral tip. Our curiosity was satisfied when we determined that an istiophorid billfish rostrum, regardless of species, fit the puncture mark. Although Fierstine (2001) identified *Istiophorus platypterus*, *Makaira indica*, *M. nigricans*, and *Tetrapterus albidus* among the extant istiophorid species present at Lee Creek Mine, of these four only *M. indica* and *M. nigricans* have been reported to feed on adult tunas (Koga, 1958; Strasburg, 1969; Ovchinnikov, 1970; Rivas, 1975; Nakamura, 1983; Brock, 1984).

Extant sharks (*Carcharhinus*, *Isurus*), swordfish (*Xiphias gladius*), and marine mammals (*Orca*, *Phocaena*, *Globicephalus*) also feed on tunas (Tiews, 1963; Alverson and Peterson, 1963; Compagno, 1984; Nakamura, 1985), and all have been identified at Lee Creek Mine (Purdy et al., 2001). Cross-sections of the puncture marks in the vertebrae are round-oval, unlike the flattened cross-section of a shark's tooth (Cigala-Fulgosi, 1990; Schwimmer et al., 1997) or of a swordfish rostrum (Scott and Tibbo, 1968). Therefore, the shape of the hole eliminates sharks and swordfish as responsible for the puncture marks in the tuna

TABLE 1. Measurements (mm) of vertebrae of the genus *Thunnus* from Lee Creek Mine, Yorktown Formation (Early Pliocene), North Carolina, U.S.A.

Museum Number	Centrum Length (measured Ventrally)	Anterior Surface of Centrum		Posterior Surface of Centrum	
		Height	Width	Height	Width
NCSM 12683	43.4	33.9	42.6	28.3	38.3
NCSM 12684	51.1	37.7	53.0	37.0	51.0
NCSM 16990	31.7	30.0	36.0	30.0	37.3
USNM 494441	29.9	27.5	31.7	27.3	32.3
USNM 494442	30.4	30.7	36.3	30.1	—

TABLE 2. Fork lengths and weights from five extant species used as comparative skeletal material.

Species	Museum Number	Fork Length (mm)	Weight (kg)
Thunnus atlanticus	LACM 37930-2	614	—
T. thynnus	LACM 3800-1	2450	—
*T. thynnus**	USNM 268980	1257–1314*	38–43*
T. thynnus	USNM 268982	1793	est. 112
T. thynnus	USNM 268985	1670	est. 92
Istiophorus platypterus	LACM 25341	1460	14
Makaira nigricans	LACM 25320	2362	123
M. nigricans	LACM 25321	2210	89
M. nigricans	LACM 25330	2223	85
M. nigricans	LACM 25409	2120	82
Tetrapterus albidus	LACM 25504	1643	23
T. albidus	NCSM 31294	1854	27

*Specimen was part of a lot and only length and weight ranges were provided.

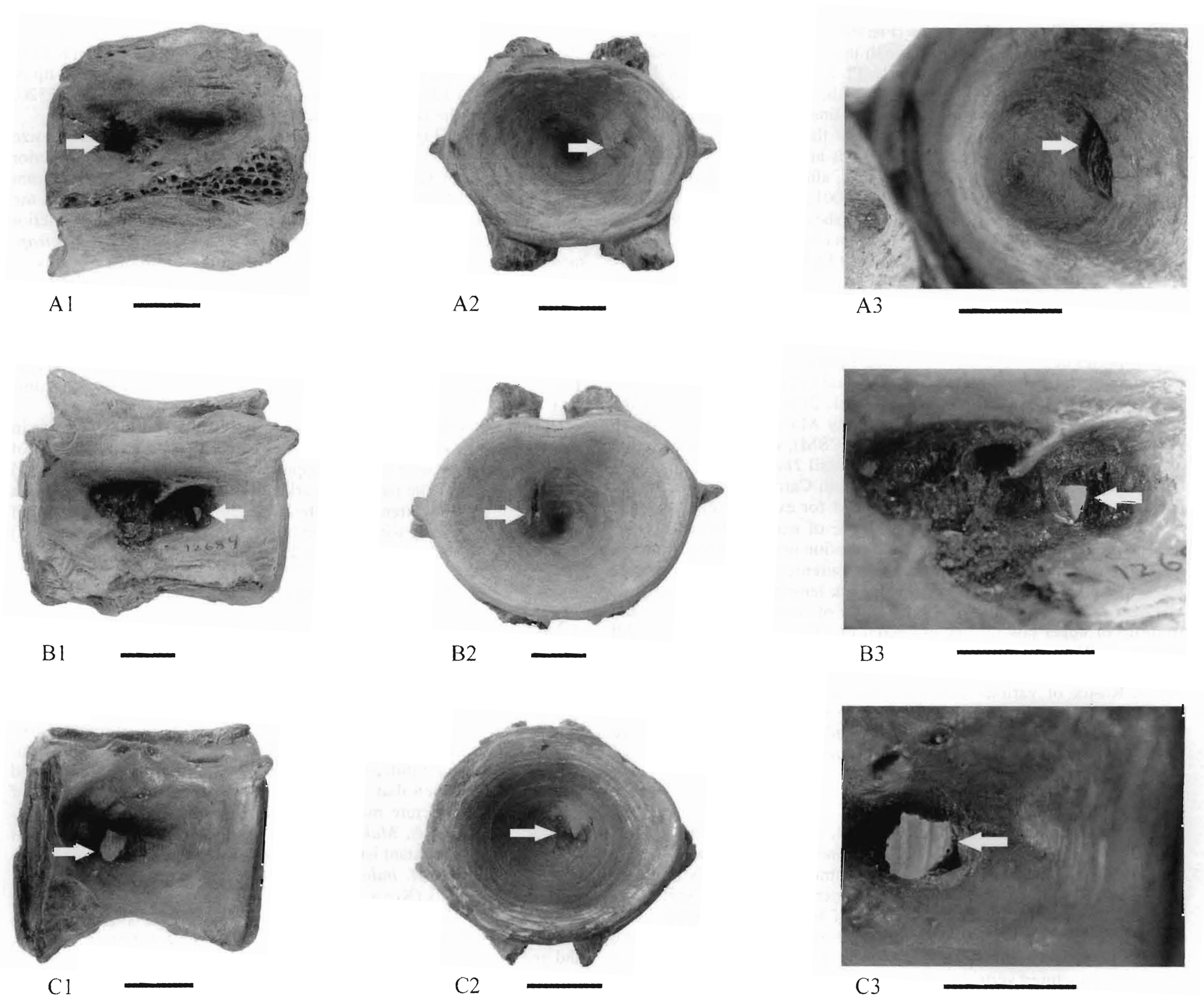

FIGURE 1. Three fossil caudal vertebrae of the genus *Thunnus* with puncture marks attributed to the rostrum of an istiophorid billfish, from the Yorktown Formation, early Pliocene, at Lee Creek Mine, North Carolina. NCSM 12683, right lateral view (**A1**), posterior view (**A2**), close-up of puncture from posterior view (**A3**); NCSM 12684, left lateral view (**B1**), posterior view (**B2**), close-up of puncture from left lateral view (**B3**); NCSM 16990, right lateral view (**C1**), anterior view (**C2**), close-up of puncture from right lateral view (**C3**). Arrows indicate puncture marks. Scale equals 10 mm.

vertebrae. We do not believe that marine mammals were responsible for the wounds because they have numerous teeth, one of which probably would have made an additional wound in at least one of the vertebrae examined. Also, the teeth of *Orca* and *Physeter*, which are spaced far enough apart to puncture a vertebrae only once, are much more robust than an istiophorid rostrum and would thus not make the narrow piercing hole found in the *Thunnus* vertebrae.

When marlin impale their food they usually spear it once or twice in the region of the body, then return to swallow the stunned prey (Wisner, 1958; Talbot and Penrith, 1962; Strasburg, 1969; Nakamura, 1983). Until now, stabbings have not been reported in the region of the caudal peduncle, from which our five vertebral samples originated, or to have pierced bone. There are, however, less than a dozen cited occurrence of extant istiophorids impaling *Thunnus*. The fact that none of these have occurred in the caudal peduncle, or have pierced the vertebral column, is not surprising. Most of the profile of a *Thunnus* is not over the vertebral column, but in the abdominal cavity. The caudal peduncle region of *Thunnus* is where the vertebral column is nearest to the surface in the fish and thus most vulnerable to piercing. We assume the attacks associated with these wounds in all five fish were fatal because none of the vertebrae show osteogenesis (healing). However, it appears that at least these vertebrae were not injested.

Frazier et al. (1994) reviewed the literature regarding the impaling of animate and inanimate objects by billfish and noted the capture of healthy billfish with shortened bills. They assumed that damage occurred when the fish failed to withdraw its bill successfully after impaling its target. Foreshortened bills found at Lee Creek Mine are evidence that spearing behavior was established during Yorktown times or earlier (Fierstine, 2001) and this evidence further supports our hypothesis that istiophorid billfish made the puncture marks in the fossil tuna vertebrae.

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