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CLEANING SYMBIOSIS BETWEEN TOPSMELT, *ATHERINOPS AFFINIS*, AND GRAY WHALE, *ESCHRICHTIUS ROBUSTUS*, IN LAGUNA SAN IGNACIO, BAJA CALIFORNIA SUR, MEXICO

Many species of marine fishes are known to engage in various forms of cleaning symbiosis (Limbaugh 1961; Hobson 1969, 1971). The cleaners, generally small or juvenile fish, remove ectoparasites and necrotic tissue from larger host fish. This promotes the well-being of the host and provides food for the cleaner. Cleaning symbiosis between topsmelt, *Atherinops affinis*, cleaners and gray whale, *Eschrichtius robustus*, hosts was observed during the author's study of breeding gray whales in Laguna San Ignacio, Baja California Sur, Mexico, supported by the United States Marine Mammal Commission, the National Geographic Society, and the World Wildlife Fund-U.S. (Swartz and Jones[1]). Topsmelt are perennial residents of the lagoon and gray whales occupy the lagoon for 3 to 4 mo each winter. As we photographed gray whales from our skiff, schools of topsmelt were seen accompanying the whales and picking at clusters of parasitic barnacles, *Cryptolepas rhachianecti*, and whale lice, *Cyamus* sp., which incrust these cetaceans (Rice and Wolman 1971).

Topsmelt in association with gray whales were collected during the 1978-79 winter with a "mackerel rig" consisting of 1 m of monofilament line with four No. 6 brass hooks spaced 10 cm apart. The standard length (SL) of each fish was mea-

sured and its gut contents examined. A second series of topsmelt were collected during the same winter in the absence of gray whales.

The topsmelt ranged from 17 to 29 cm SL. All 38 specimens collected in association with gray whales contained bits of sloughed gray whale epidermis and whale lice appendages. No barnacle appendages or other material was found in these fish. None of 25 topsmelt collected in the absence of whales contained any gray whale epidermis or whale lice; rather they contained bits of filamentous brown algae, *Ectocarpus* sp., and gammarid amphipods.

Topsmelt are described as opportunistic feeders on marine plants, small crustaceans, bryozoans, and hydroids (Frey 1971). During the breeding season of the gray whale, topsmelt in Laguna San Ignacio supplement their diets by cleaning sloughing epidermal tissue and external parasites from gray whale hosts.

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MORPHOLOGICAL FEATURES OF THE OTOLITHS OF THE SAILFISH, *ISTIOPHORUS PLATYPTERUS*, USEFUL IN AGE DETERMINATION[1]

Because of its spectacular runs and leaps, sailfish, *Istiophorus platypterus*, is highly valued by sport fishermen, and the fishery contributes substantially to the economics of coastal regions (de Sylva 1969). However, information on the biology of sail-

fish, even though critical to resource management, is limited.

Age estimates and growth rates are necessary to prepare accurate stock statistics. Age determinations in fish are generally indirect measures and are made from length-frequency analyses (Petersen's method) or annual events in hard tissue (Bagenal 1974). The length-frequency method has been applied to sailfish (de Sylva 1957; Koto and Kodama 1962), but the results are inconclusive at best. Annual events recorded in hard tissues are a more accurate method of age determination, and Jolley (1974, 1977) counted the rings in dorsal fin spines to estimate the age of sailfish. The length-frequency data (de Sylva 1957; Koto and Kodama 1962) and proposals of Maksimov (1971) from length-frequency data indicated a rapid growth rate and relatively short lifespan of 3-5 yr for a sailfish. Jolley's (1974) analysis also indicated a rapid growth rate but a possible lifespan of about 10 yr, so at present, age determination in sailfish is unresolved.

Otoliths have been shown to be accurate indicators of age (Bagenal 1974; Six and Horton 1977) and are particularly useful on species of fish which lack scales or have minute scales such as those species in the family Istiophoridae. Otoliths are composed of calcium carbonate in the form of aragonite (Irie 1955; Degens et al. 1969) and are formed in the labyrinth of teleost fish. There are three otoliths (sagitta, lapillus, and asteriscus) on each side of the brain cavity in the inner ear (Lowenstein 1971) and the morphology of these calcified structures is species specific (Hecht 1978; Morrow 1979). The sagitta is usually the largest otolith and the one most often used for age determinations, but the other two otoliths have not been adequately studied and might also be of use. The otoliths of sailfish and other billfishes (families Istiophoridae and Xiphiidae) have been thought to be so small that they would not be useful in age determinations (Jolley 1974; Beckett 1974). Consequently, age and growth data are lacking for these important recreational and commercial species. In this study we analyzed 65 sailfish and described the morphology of the otoliths. A mathematical relationship between the wet weight of the fish and morphological features of the sagitta, enabled us to estimate the age of all but one specimen. Ages of very large fishes, previously difficult to measure, were readily amenable to otolith age analysis.

Methods

Otoliths were collected from sailfish at taxidermy facilities in Florida in fall 1978. Total lengths (TL) and wet weights were recorded from the tags placed on the fish at the dock and otoliths were extracted from 65 fish. The otoliths of sailfish were extremely small and required careful dissection. A saggital cut was made on the midline of the head and the semicircular canals dissected from the brain area. All three otoliths were removed from the semicircular canals and cleaned. Dried otoliths were attached to aluminum stubs; gold-coated otoliths were viewed in a Cambridge Stereroscan Mark 2A[2] scanning electron microscope (SEM).

The internal structure of the sagitta was observed by attaching the sagitta to a SEM stub with 5 min epoxy and fracturing it through the core region. The fractured otoliths were etched for 5 min in 7% ethylenediaminetetraacetic acid (pH 7.4) and then coated with gold before viewing. The lapilli of sailfish were viewed with reflected light microscopy to determine if this would be a viable alternative to SEM preparations.

Results

The morphological nomenclature we use to describe sagitta is that of Hecht (1978) and Morrow (1979). The otoliths are extremely small, from 0.75 to 1.5 mm long. The medial or concave surface (Figure 1) has a deep and well-defined sulcus and the depth of the sulcus increased with fish weight. The sagitta has no collum and lacks anterior and posterior cristae. The excisural notches are distinct and V-shaped and have two lobes which fold onto each other. The antirostrum is one-third as long as the rostrum and well separated from the rostrum. Consequently sagitta had a different configuration from most sagitta, as the rostrum is exaggerated. The surface of the concave portion of the sagitta is granular with crystalline palisade configurations.

There are distinct ridges on the side of the rostral lobe (Figure 2) which we interpret as annual events, as there is an increase in ridge number with weight (Figure 3). The sagitta of a sailfish
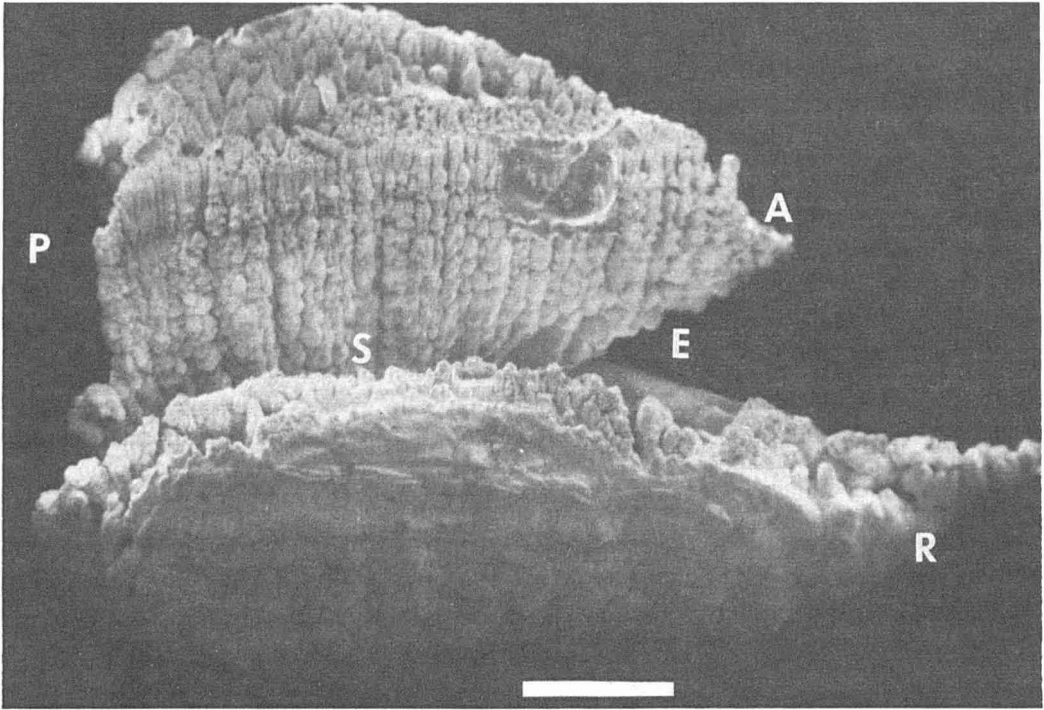
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FIGURE 1.—The concave medial surface of the left sagitta from a sailfish that weighed 27.7 kg (18 ×): A, Antirostrum; E, Excisural notch; S, Sulcus; P, Posterior. Bar = 0.5 mm.
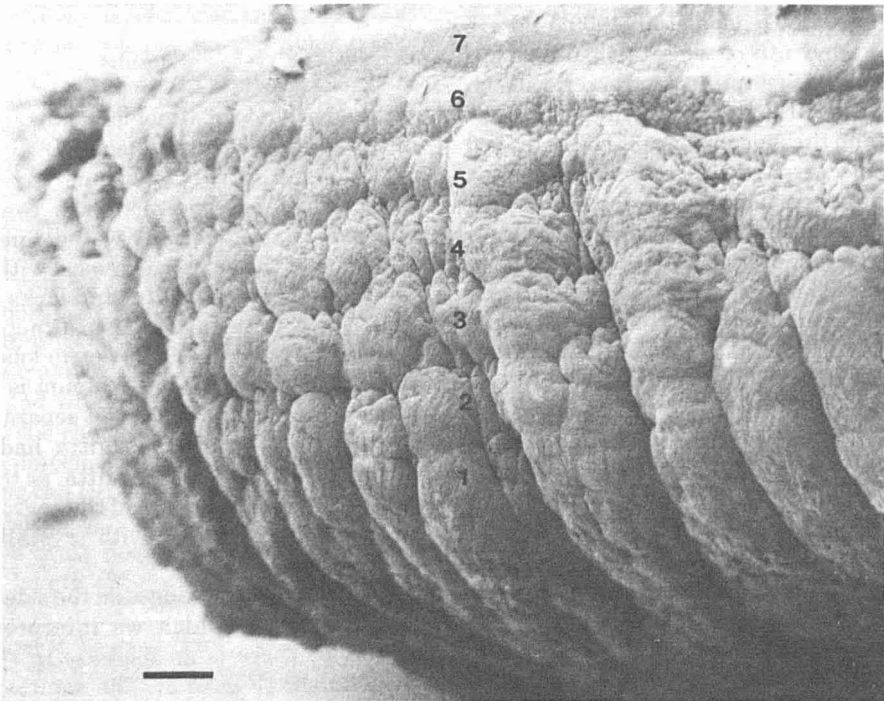

FIGURE 2.—Rostral lobe of the left sagitta of a 27.7 kg sailfish (60×). Numbers indicate ridges. Bar = 0.1 mm.

that weighed 27.7 kg and was 226 cm TL had 7 ridges (Figure 2), while the sagitta of a sailfish that weighed 12.7 kg and was 183 cm TL had 3 ridges (Figure 4). These ridges are distinctive and easily counted, and of a sample of 65 sailfish only 1 specimen had uncountable ridges on both sagittae.

The convex or lateral surface of the sagitta (Figure 5) was moderately smooth and the two lobes were joined in the core region. The convex surface did not have the distinctive configuration seen on the side of the rostral lobe. A medial section of the sagitta revealed internal structures which indicated incremental otolith growth and progressive deposition (Figure 6).

The asteriscus and lapillus (Figure 7) are much smaller than the sagitta and also show internal features that appear to have progressive deposition. The asteriscus is very fragile and was often broken during dissection, but its growth features support the sagittal ridge counts. The lapillus was much heavier in structure than the asteriscus and also showed internal growth features that appear to be age related (Figure 8). The lapillus showed layers that correspond to the number of ridges found on the sagitta when viewed under transmitted light (Figure 9). The lapilli age counts were identical to sagittal ridge counts 85% of the time and ±1 yr in the other counts. The possibility exists that age estimates could be obtained by light microscope techniques, although the sagittal

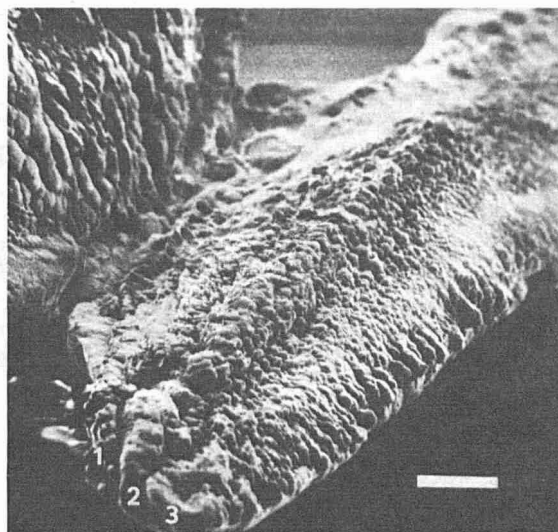FIGURE 4.—The rostral lobe of the left sagitta from a 12.7 kg sailfish with three ridges (85×). Numbers indicate ridges. Bar = 0.1 mm.

ridges were very distinct in SEM preparations which we feel would be more accurate.

The ridges on the sagitta of 64 sailfish were counted and compared with body weight and a strong correlation was found (Figure 3). The ridges appear to be annual events and fish with four ridges were the most numerous in our sample. We did a log transformation of the allometric growth curve equation or power curve fit of the data (Table 1) so we could compare our data directly with that of Jolley (1977) for which summary statistics only are available. The data used for statistical analysis were selected from the Jolley (1977) regressions. An F-test for difference between the regression coefficients gave $P > 0.05$, so there is no apparent difference between the slopes of Jolley's data and ours. The data indicate that the sailfish develop a large muscle mass in a short period of time (<4 yr), and our results are similar to Jolley's over the same time span.

TABLE 1.—Age-weight relationships ($Y = ax^b$) for the Atlantic sailfish as expressed by predictive power equations, $\log_{10}$ transformed for purposes of testing difference in regression coefficients between the data presented in this paper and those of Jolley (1977).

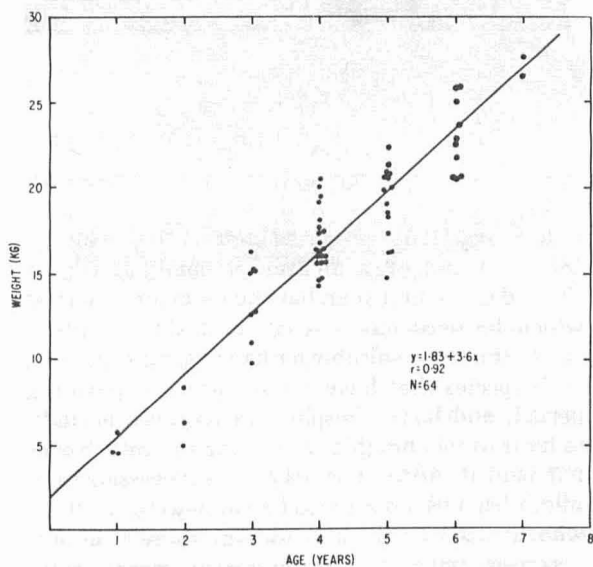| Source	N	Regression coefficient	Y-intercept	r	P (F-test)
Present study	64	0.883	4.64	0.86	>0.05
Jolley (1977):					
Males	74	.888	1.48	.85	>0.05
Females	73	1.048	1.33	.88	>0.05

FIGURE 3.—Relationship between the weight of the sailfish and the number of ridges (years) on the sagitta.

FIGURE 5.—The convex distal surface of the left sagitta of a 27.7 kg sailfish; N indicates nuclear (core) region (18×). Bar = 1 mm.
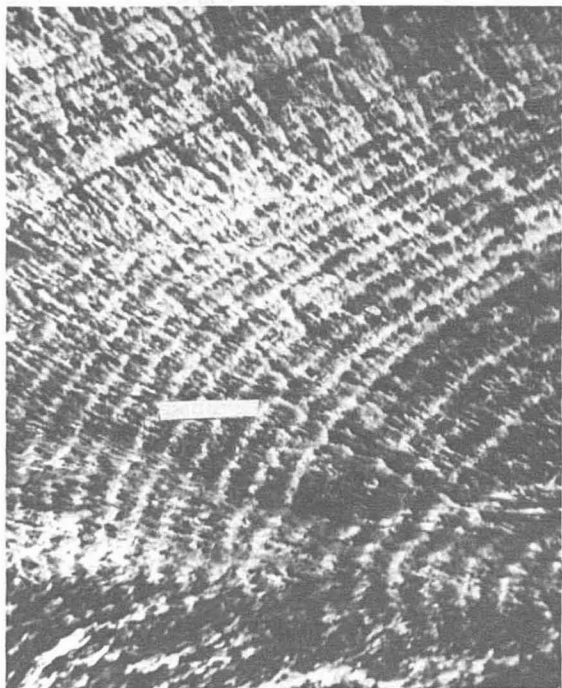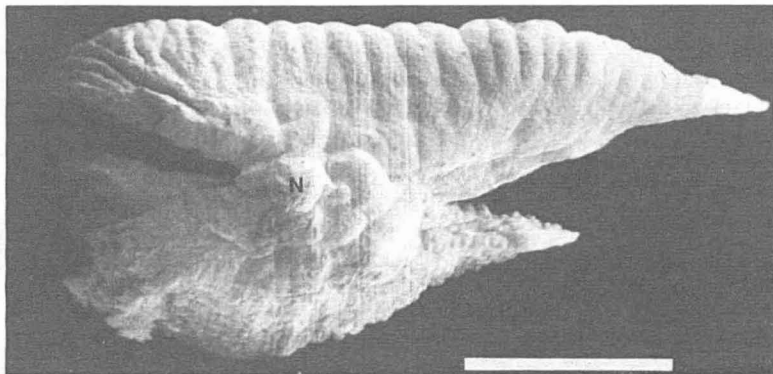

FIGURE 6.—Cross section of the rostral lobe of a sailfish sagitta that shows incremental growth in the internal structure (1,100×). Bar = 10 μm.

FIGURE 7.—The left lapillus (L) and asteriscus (A) of a 27.7 kg sailfish (18×). Bar = 0.5 mm.

Discussion

The otoliths from sailfish are very small in relation to the size of the fish and appear to be unique, as their prominent ridges on the rostral lobe are different from the morphology of other teleost otoliths. For comparison of morphological features, excellent surveys of otoliths from a broad range of families and geographic areas are found in Hecht (1978) and Morrow (1979). The external ridge feature makes it possible to use the sagitta of the sailfish for determination of age and growth rates.
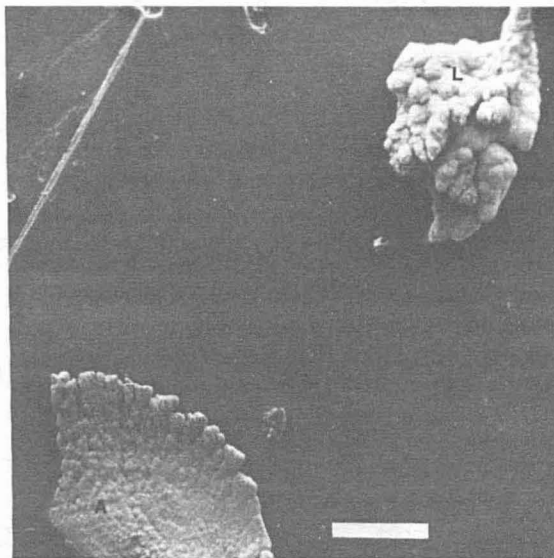
de Sylva (1957) proposed that sailfish average 183 cm TL and attain an average weight of 10 kg at the end of the first year, but the Petersen's method which he used has several limitations (Watson 1964). It is most suitable for fish in their early life, with species that have a short annual spawning period, and large samples are required as individuals cannot be aged. The biology of sailfish does not lend itself to analysis by the Petersen technique. This was recognized by Jolley (1974, 1977), who utilized hard parts (dorsal spines) for age determinations. Our estimates of growth rates and age estimates are similar to his. However, Jolley (1977) found that only 24% of the samples
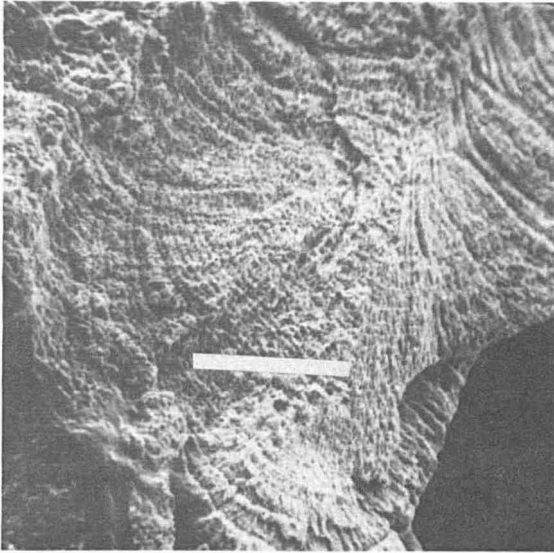
FIGURE 8.—The internal structure of the lapillus of a 20.5 kg
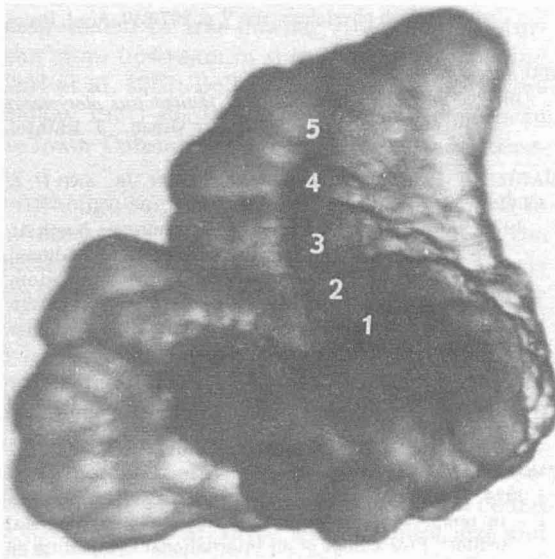sailfish (400×). Bar = 50 μm.

FIGURE 9.—The lapillus of a 20.5 kg sailfish viewed under
transmitted light. Five layers are shown (40×).

FIGURE 10.—Comparison of relationships between the mean
weight of sailfish and estimated age. Bars represent ranges.

he examined could be aged by the spine analysis,
and it was particularly difficult for him to age
larger specimens, while we read 64 of 65, or 98%,
of the otoliths. Our percentage might be lower for a
larger sample or older fish, but an age estimate
was usually possible from one of the two sagitta
present in the fish. We did not find it difficult to
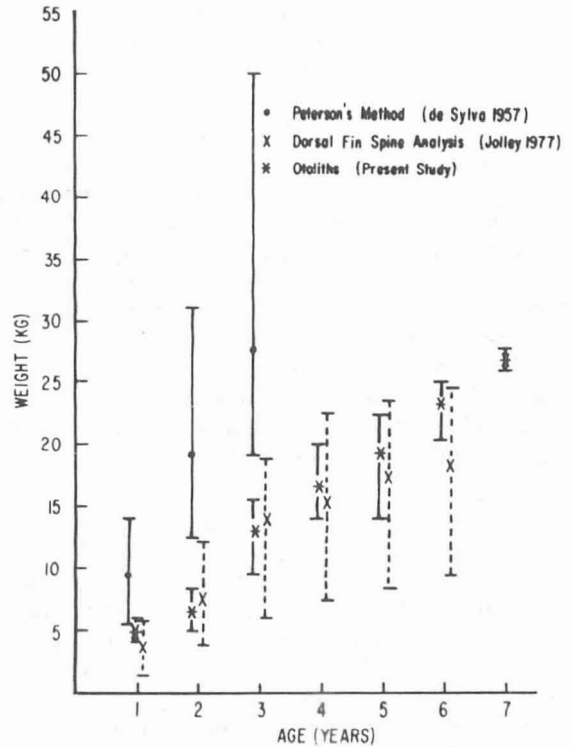resolve the age of our largest specimens.

The age-weight relationship developed in our
study from otoliths, and by Jolley (1977) from
analysis of dorsal fin spines (Figure 10) indicates
that weight attained at ages 1 through 3 are about
50% less than those estimated by de Sylva (1957)
and Koto and Kodama (1962). Tag data (Mather et
al. 1974) are inconclusive due to the small number
of returns. Our two largest specimens (estimated
age 7) weighed 26.4 and 27.7 kg and were 228.6
and 226.1 cm TL. This is similar to Jolley's largest
fish of 26 kg at our equivalent age 6, but his larger
fish could not be aged with the fin spine method.

Sailfish are multiple spawners (Jolley 1977),
which could account for the range of weights in the
different age-groups. A study of internal patterns
in otoliths might make it possible to determine
when an individual fish spawned. The internal
microstructure could be a permanent calendar of
the physiological history of the fish. Further study
on the micromorphology and internal structure of
the otolith should reveal valuable information.
The internal increments occurred at a frequency
of 13 or 14 increments in each major assemblage
which could be evidence of a lunar periodicity.

Hence, we had additional confidence in our interpretation of the ridges as annual events and since ridges were easier to count, we used them in our age determinations. Further analysis might show daily increments (Pannella 1974) within the lunar increments.

In conclusion, we have been able to collect the otoliths of sailfish, and all three otoliths showed morphological features that can be readily observed. The internal and external otolith structures, viewed with SEM, appeared to show an annual periodicity and provided data that are not available by other means. With this data it is possible to determine a growth rate and age estimate for all sizes of the sailfish sampled, including larger fish that were difficult to age in the past.

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DIEL AND SEASONAL MOVEMENTS OF WHITE STURGEON, *ACIPENSER TRANSMONTANUS*, IN THE MID-COLUMBIA RIVER

The white sturgeon, *Acipenser transmontanus*, is a commercial and sport fish common to major river systems of the Pacific Coast from Monterey, Calif., to Alaska (Scott and Crossman 1973). However, there is considerable confusion concerning migration habits or seasonal movements of the species. Early workers (Jordan and Evermann 1908; Craig and Hacker 1940) considered white sturgeon anadromous. In free-flowing rivers, white sturgeon move upstream in spring prior to spawning (Carl et al. 1967; Bell 1973). Other investigators (Bajkov 1951) suggested seasonal movements in the lower Columbia River may be related to feeding.

Although some white sturgeon can be found in the ocean and may ascend rivers to spawn, the species is not truly anadromous. Many individuals remain in freshwater, and those found in the upper Columbia River and its tributaries are landlocked by a system of hydroelectric dams. However, permanent freshwater residents also show seasonal movements. Studies in 1975 and 1976, involving radio-tagged white sturgeon in the mid-Columbia River, indicated sturgeon movements >2 km occurred when river temperatures exceeded 13° C (Haynes et al. 1978). Furthermore, size and possibly sexual maturity influenced direction of movement in the river. Smaller white sturgeon moved downstream in summer, larger sturgeon moved upstream in summer and fall, and inter-mediate-sized sturgeon remained near release points. Although seasonal movements may be related to water temperature, no quantitative data exist on diel activity patterns of the species. To further evaluate seasonal movements in the free-flowing Hanford reach of the Columbia River, we fitted additional white sturgeon with radio trans-mitters in spring and early summer 1977 and con-tinued monitoring fish which had been tagged in 1975 and 1976.

Methods

Radio-telemetry equipment was developed by the University of Minnesota, Bioelectronics Laboratory (Tester and Siniff[1]). Nineteen white sturgeon ranging from 98 to 236 cm total length were captured with trammel nets and angling gear at White Bluffs Pool (Figure 1), about 48 km upstream from Richland, Wash. Transmitters were selected so as not to exceed 2% of estimated sturgeon body weight and were attached dorsally (Haynes et al. 1978). Twelve transmitters had temperature sensors (precision ±0.2° C, Kuechle[2]). An automatic, channel-scanning receiver and recording station, capable of sequentially monitoring 16 channels, was established at White Bluffs Pool to record environmental temperatures and sturgeon movements in and out of the pool. Receivers operated on a carrier frequency of 53 MHz

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[1]Tester, J. R., and D. B. Siniff. 1976. Vertebrate behavior and ecology progress report for period July 1, 1975-June 30, 1976. COO-1332-123. Prepared for U.S. Energy Research and Development Administration. Contract No. E(11-1)-1332 by Univ. Minn., Minneapolis, 63 p.
[2]V. B. Kuechle, Bioelectronics Laboratory at Cedar Creek, University of Minnesota, Minneapolis, pers. commun. 1977.
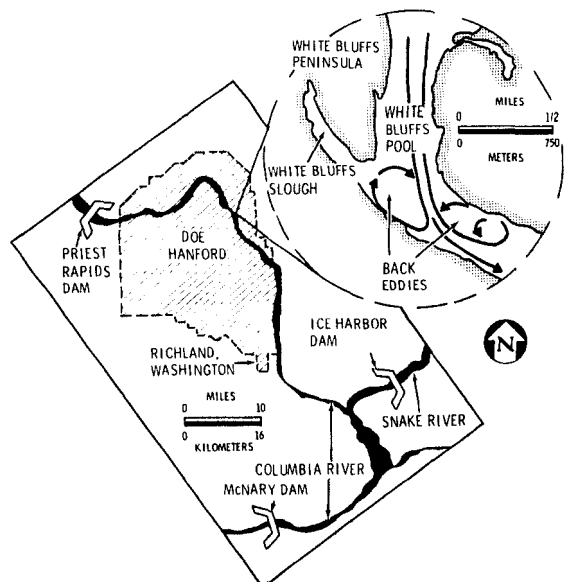
FIGURE 1.—White Bluffs monitoring area for white sturgeon movements in the Columbia River.