GROWTH OF DOLPHINS, *CORYPHAENA HIPPURUS* AND *C. EQUISELIS*, IN HAWAIIAN WATERS AS DETERMINED BY DAILY INCREMENTS ON OTOLITHS

The dolphin, *Coryphaena hippurus*, and pompano dolphin, *C. equiselis*, are widely distributed pelagic fishes in tropical and subtropical oceans (Beardsley 1967; Rose and Hassler 1968; Shcherbachev 1973). In Hawaiian waters *C. hippurus* is caught throughout the year, but its abundance fluctuates. Small fish (<2.3 kg) are plentiful in summer and large fish (13.6-18.1 kg) are more abundant from February to April (Squire and Smith 1977). *Coryphaena hippurus* is important to the commercial and recreational fisheries; *C. equiselis*, a smaller fish with a maximum length of 74 cm (Herald 1961), is occasionally caught by recreational fishermen. Although much is known about the life history of *C. hippurus* in the Atlantic (Palko et al. 1982), the biology of the Hawaiian population has been only sketchily investigated. Little is known about *C. equiselis*.

At least three age and growth studies on *C. hippurus* have been reported. Annual marks on scales have been used to age *C. hippurus* off Florida (Beardsley 1967) and North Carolina (Rose and Hassler 1968) in the western North Atlantic Ocean. Wang (1979) used monthly modal progression of length-frequency distributions to estimate the growth rate of *C. hippurus* off eastern Taiwan in the western Pacific Ocean. The estimated growth rates of *C. hippurus* off Florida and North Carolina differed slightly, but the growth rate of *C. hippurus* in the western Pacific Ocean was reported to be about twice as great as those in the western North Atlantic Ocean.

The purpose of this study was to validate estimates of age and growth of larval and juvenile *C. hippurus* and *C. equiselis* based on microstructure of otoliths (sagittae) from fish of known age reared in captivity. Otoliths from wild specimens captured in Hawaiian waters were also used as a source of age and growth information and these data were fitted to the von Bertalanffy growth model. Ages of cultured and captured wild specimens were estimated by enumerating presumed daily increments on the sagitta following Pannella (1971). The daily nature of the increments was validated by counts from sagittae of fish reared in captivity and whose age was known. Knowledge of growth rates of both species of dolphins are useful to mariculturists who would like to compare the growth rates of wild and cultured individuals. Information on the growth rate of *C. hippurus* can also be of use to managers of Hawaiian fishery resources.

Materials and Methods

Validation

Fertilized eggs of *C. hippurus* and *C. equiselis* were obtained between January 1982 and February 1983 from captive broodstock held at the University of Hawaii's Waikiki Aquarium (WA); the Kewalo Research Facility (KRF) of the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service; and The Oceanic Institute, Waimanalo, HI. Larvae of both species were reared at the WA in 4,000 L circular fiber glass tanks with flow-through water exchange and under shaded natural light condition. Water temperature ranged between 23° and 27°C. Both species were fed an unlimited supply (a density of 1-5/mL) of cultured copepod, *Euterpina acutifrons*, and *Artemia* sp. until they were large enough to accept chopped fish and squid (about 30 d after hatching), which were then provided several times during the day. These fish were fed to satiation. One 167-d-old and three 191-d-old *C. hippurus* were reared at the KRF under similar environmental conditions and feeding regime as at the WA.[1] These juvenile *C. hippurus* were transferred to 8 m diameter tanks when they were about 25 cm long.

One to three larvae of *C. equiselis* were sampled on the day of hatching (D-0), and each day thereafter (D-1, D-2, D-4, etc). However, after the fourth day, there were few survivors, so only a single specimen was taken at intervals of 4 d from D-19. Three larvae of *C. hippurus* were sampled on D-4 and single specimens were sampled at various intervals or obtained after accidental deaths for validating the growth increments. Other larvae were sampled from other batches on D-0, D-1, and D-2 for measurements. Specimens were sampled around noon. Total length of the larvae was measured under a microscope with an ocular micrometer while the specimen was alive or within an hour after death. To facilitate measurement, each larva was put on a glass slide, extended to its full length, and measured. For the examination of otoliths, the larva on the slide was immersed in 70% ethanol and allowed to fix for an hour. The larva was then removed from the ethanol bath, blotted, and mounted in Euparal,[2] a water soluble mounting medium, and covered with a cover slip.

Otoliths could be examined in the squashed whole mount without extracting them.

After measuring the fork length of juvenile and adult dolphins with a caliper to the nearest millimeter, otoliths were extracted, cleaned, and mounted whole. To extract the otoliths, the head was removed from the body, and the flesh removed from the head to expose the skull. With a saw or knife, most of the supraoccipital and roof of the skull were removed. After careful removal of the brain, the sagittae (largest of the three otoliths) could be found in the sacculi located anteriorly on the right and left sides of the first vertebra at the caudal end of the brain cavity. Under a dissecting microscope, the sagitta was teased out of the sacculus, and extraneous tissues were brushed away. The pair of sagittae was then placed on a clean glass slide, permitted to dry, and mounted in Euparal. Segments of monofilament line slightly thicker than the sagittae were placed on both sides of the sagittae to prevent the cover slip from crushing it.

After clearing for a month, presumed daily increments on a sagitta were enumerated using a compound binocular microscope with transmitted light at 600× magnification. Increments were counted starting from the core out to the edge of the postrostrum, or from the core to the tip of the rostrum. Usually, counts could not be made in a direct line from the core to the edge of the rostrum or postrostrum of the sagitta; rather, a somewhat circuitous route was taken from one area of the sagitta to another by following a prominent growth increment. Increments were also counted inward from the edge to the core. Two independent age estimations were made separately on the rostrum and postrostrum on a sagitta to verify the age of fish. In some samples, it was possible only to make a single age estimate since the sagitta was incomplete, having just a rostrum or postrostrum. The reader had no information such as specimen size or previous counts to prevent bias in the counting.

The arithmetic mean of 3-14 counts was used to estimate a fish's age. The number of counts from the rostrum and postrostrum varied from as few as 3 for a larva to 14 for a sagitta of a juvenile. The relationship between counts of otolith increments and days was assessed for both species by regression analysis.

Growth of Wild Specimens

Juveniles of both species were dip netted from Kaneohe Bay, HI. Large juveniles and adults of both species were obtained from private and chartered

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sport fishing boats in Honolulu, and *C. hippurus* specimens were also obtained from cruises of the NOAA ship *Townsend Cromwell* to the Northwestern Hawaiian Islands from October 1976 to September 1981. Fork lengths were measured to the nearest millimeter with calipers. The extraction and slide preparation of sagittae, and counting method were the same as described for the validation experiments above. But before reading the sagittae of fish caught in the wild, the sagitta of a known-age fish was re-examined to review the difference between known daily increments and subdaily increments. Concentric daily increments, which consist of an inner light band and an outer dark band, were distinguished from subdaily increments by carefully focusing to the plane of maximum clarity. The dark band of the subdaily increment appeared less defined than the dark band of daily increments. Misinterpretation and counting subdaily increments as daily increments could result in an overestimation of age. The mean of 10-20 counts was used as the age estimate of older fish.

Age estimates of wild fish were fitted to the von Bertalanffy growth model using NLIN Procedure, a nonlinear regression routine (SAS Institute 1982). The three juvenile *C. hippurus* whose sex was un-

determined were added to both the male and female groups when fitting the curves.

Results

Validation

Fertilized eggs of *C. equiselis* and *C. hippurus* began to hatch after 48-50 h at 24°-25°C and all hatched within 2 h. The larvae of both species were 4.0-4.6 mm TL and had two pairs of otoliths, the sagitta and lapillus, at time of hatching. Otoliths of *C. equiselis* and *C. hippurus* on D-0 ranged from 16 to 20 μm in diameter and consisted of the core and primordium. An hour after hatching, the larvae were from 5.2 to 5.4 mm TL but did not grow during the next 3 d and even shrank from 0.1 to 0.2 mm. Otoliths of both species on D-1 had a dark ring near the edge which the otoliths of D-0 larvae did not have and were 22-24 μm in diameter. The sagittae of both species on D-4 had four increments (Fig. 1) and were now slightly larger than the lapillus. Sagittal diameters were 29-36 μm for *C. equiselis* and 34-41 μm for *C. hippurus*.

Mean counts of growth increments on the sagittae of 10 *C. hippurus* (Table 1) and 13 *C. equiselis*
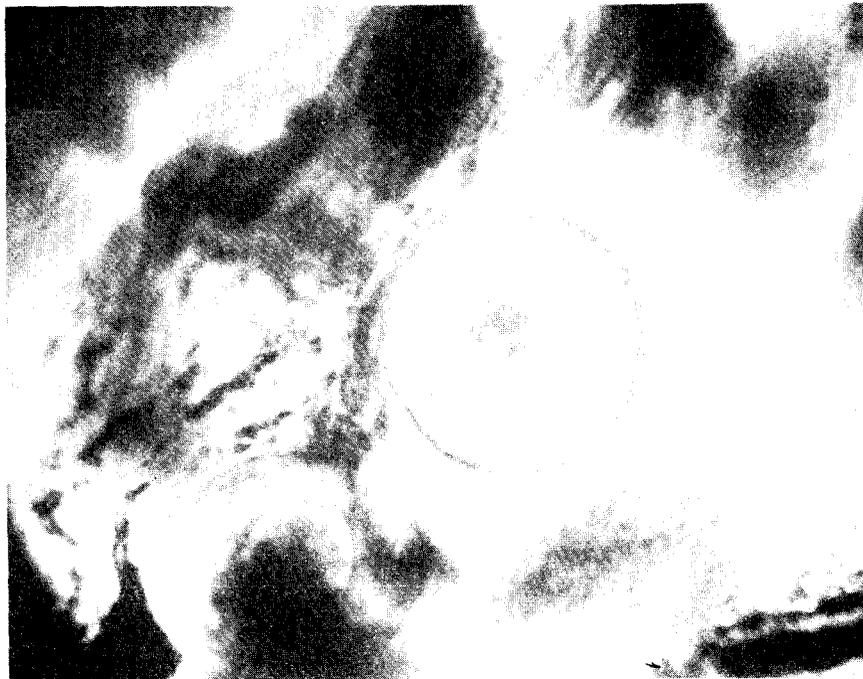
FIGURE 1.—Sagitta of a day-4 *Coryphaena hippurus* larva. Diameter of sagitta is 17 μm.

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TABLE 1.—Mean of counts on known age sagittae of *Coryphaena hippurus*.

Known age	Mean increment counts	SD	No. of counts	Total length (mm)	Fork length (mm)
0	0			5.3	
1	1			—	
4	4	0.00	3	6.7	
4	4	0.00	3	6.8	
4	4	0.00	3	6.8	
20	20.0	±1.26	5	—	
35	33.6	±2.06	9	—	—
47	45.2	±3.16	10	—	95.0
167	166.8	±7.14	11	—	383.0
191	190.3	±6.92	6	—	510.0
191	191.0	±0.71	4	—	554.0
191	192.8	±7.44	5	—	491.0

TABLE 2.—Mean counts on known age sagittae of *Coryphaena equiselis*.

Known age	Mean increment counts	SD	No. of counts	Total length (mm)	Fork length (mm)
0	0			4.0	
1	1	0.00	3	—	
1	1	0.00	3	. —	
4	3	0.00	3	4.6	
4	4	0.00	3	5.2	
19	19	0.00	3	14.2	
23	23.6	±2.23	8	23.0	
27	21.5	±1.59	14	25.2	
31	31.7	±1.38	7	—	29.5
36	35.3	±2.45	10	—	48.0
51	51.7	±2.13	13	—	82.0
52	53.6	±4.81	14	—	72.0
63	63.3	±3.19	14	—	89.0
63	63.4	±8.59	13	—	112.0

(Table 2) were plotted against corresponding known ages (Figs. 2, 3). The relationships of mean increment counts (Y) to known age (X) were $Y = -0.5295 + 1.0035X$ $(r = 0.999, P < 0.01)$ for 10 *C. hippurus* and $Y = -0.6986 + 1.0164X$ $(r = 0.997, P < 0.01)$ for 13 *C. equiselis*. These results demonstrated that growth increments are formed daily, and validated their use for aging wild fish up to 191 d for *C. hippurus* and 63 d for *C. equiselis*.

Growth of Wild Specimens

Because of sexual dimorphism, separate von Bertalanffy growth parameters were calculated for male and female *C. hippurus* (Table 3). The male and female von Bertalanffy growth curves and 18 age-length relationships of *C. hippurus* are shown in

TABLE 3.—Von Bertalanffy growth parameters calculated from captured wild specimens of *Coryphaena hippurus*.

Sex	Number	Parameter	Estimate	SE
Male	10	t_0	0.0790 yr	0.0305
		K	1.1871	0.5218
		L_∞	189.9301 cm FL	48.9702
Female	9	t_0	0.0731 yr	0.0126
		K	1.4110	0.2454
		L_∞	153.2676 cm FL	14.2168
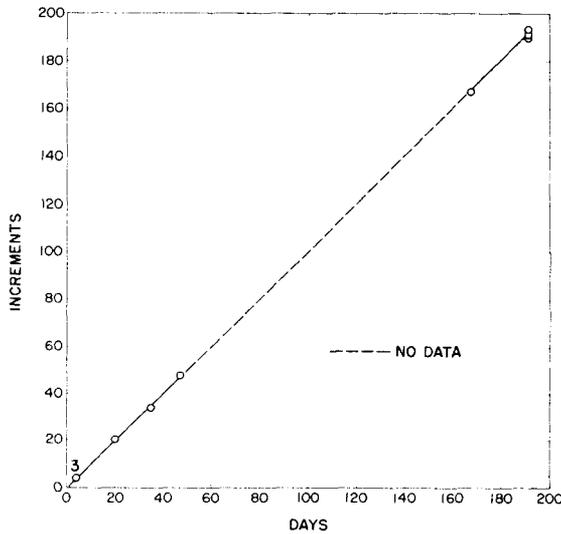
FIGURE 2.—Validation of daily increments on sagittae of *Coryphaena hippurus* by relationship of known age (X) to mean increment count (Y) up to 191 d $(r = 0.999)$.
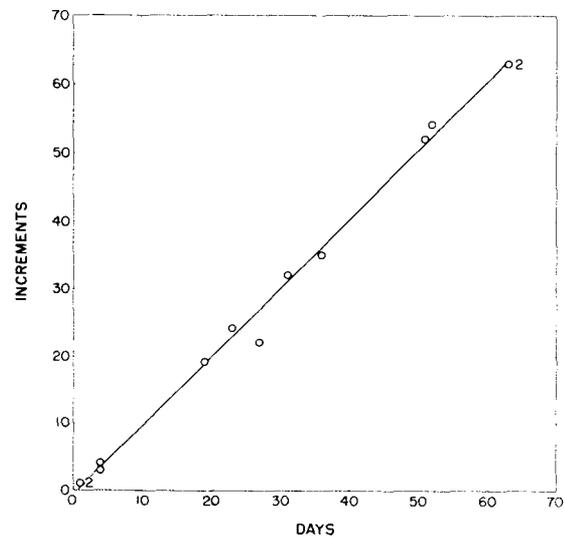
FIGURE 3.—Validation of daily increments on sagittae of *Coryphaena equiselis* by relationship of known age (X) to mean increment count (Y) up to 63 d $(r = 0.997)$.

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Figure 4. A single set of growth parameters (Table 4) was calculated for *C. equiselis* since the largest specimen in the sample had just reached sexual maturity, and the calculation of separate growth curves by sex was not warranted. The von Bertalanffy growth curve and 13 age-length relationships of *C. equiselis* are shown in Figure 5.

Discussion

Validation

A pair of otoliths was present at the time of hatching for both dolphins, and the first increment was formed on the otoliths on D-1, identical to *Katsuwonus pelamis*, another tropical pelagic species (Radtke 1983). The strong correlation of mean increment counts of sagittae to known age of fish validated the use of growth increments in the aging of *C. equiselis* up to 63 d and *C. hippurus* up to 191 d. Since regular incremental formation began on D-1, no adjustment is required to the incremental counts

of wild fish sagittae to estimate age. Ideally, validation of daily increments should cover 1) the time when the first daily increment is formed, 2) the regularity in the formation of increments in all stages of life, and 3) events such as spawning, migration, and periods of starvation which may affect the regularity of increment formation. Having achieved only part of these requirements, validation of daily increments on otoliths should continue as older known-age specimens become available, and the effects of spawning and starvation on increment formation should also be examined.

Growth of Wild Specimens

The plot of age-length relationships of male *C. hippurus* showed that there was at least one extreme variant. This 111.0 cm FL male greatly affected the growth curve, resulting in a lower estimated L_∞ and causing most of the male age estimates to fall below the growth curve (Fig. 4). Thus, age-length relations of wild *C. hippurus* should be examined further to shed light on the extent of variation in size at given ages. Additional age determinations might also improve the confidence intervals of the von Bertalanffy growth parameters.

Growth rates of *C. hippurus* to age 1 around Hawaii appeared to be greater than those reported from the western North Atlantic Ocean. Beardsley (1967) reported a mean length of 72.5 cm in age group 1 for *C. hippurus* off Florida. Rose and Hassler (1968) reported a mean length of 65.3 cm at the end of 1 yr for fish off North Carolina. Around Hawaii male *C. hippurus* were estimated to attain
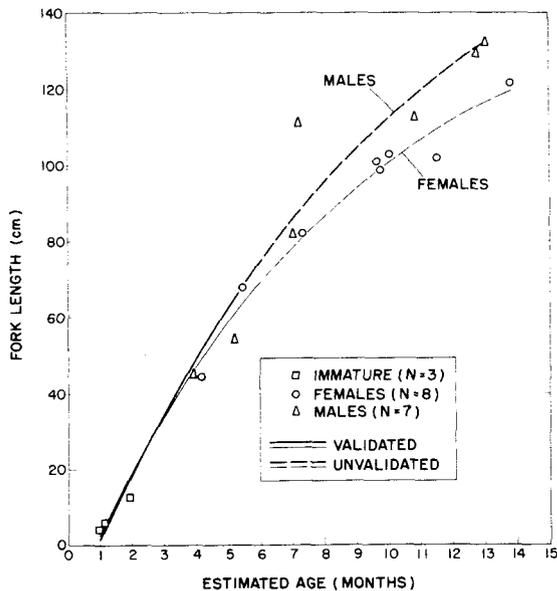
FIGURE 4.—Von Bertalanffy growth curves of male and female *Coryphaena hippurus* in Hawaiian waters.

TABLE 4.—Von Bertalanffy growth parameters calculated from captured wild specimens of *Coryphaena equiselis*.

Number	Parameter	Estimate	SE
13	t_0	0.0648 yr	0.0131
	K	2.1734	0.9750
	L_∞	61.3914 cm FL	17.8000
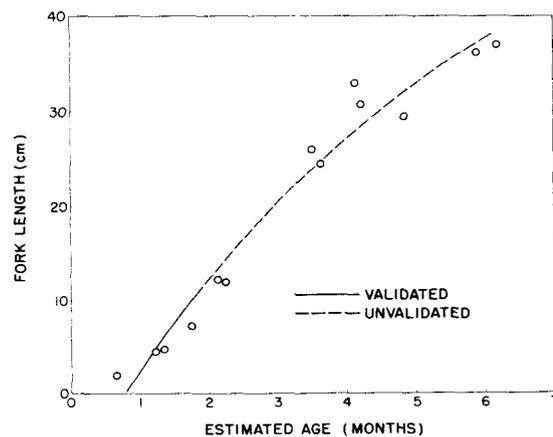
FIGURE 5.—Von Bertalanffy growth curve of *Coryphaena equiselis* in Hawaiian waters derived from 13 age estimates.

a length of about 126 cm at 1 yr and about 112 cm for females. The slower growth rate of *C. hippurus* in the western North Atlantic Ocean may be the result of a decrease in feeding rate when water temperature goes below 23.0°C and a cessation of feeding at 18.0°C (Hassler and Hogarth 1977). *Coryphaena hippurus* feed throughout the year in Hawaii and can be expected to grow continuously.

Wang (1979) used the monthly progression of modes in length-frequency distributions to estimate growth rates of about 10 cm/mo from February through June for *C. hippurus* between 50 and 100 cm FL. This growth rate is similar to that found for *C. hippurus* in Hawaiian waters.

Growth rates of captive *C. hippurus* were similar to those of wild fish in Hawaiian waters. Beardsley (1967) reported rapid growth rates of three captive *C. hippurus*. These fish grew from about 35 to 125 cm in 7 to 8 mo.[3] Soichi (1978) reported that 11 *C. hippurus* 35-50 cm TL grew to a mean 123 cm TL in 7-8 mo. Their observations also support our estimates of rapid growth for *C. hippurus* around Hawaii.

Coryphaena equiselis appeared to grow as rapidly as *C. hippurus* during the first 4 mo, then grew at a slower rate (Fig. 5). At about 4 mo, *C. equiselis* reached sexual maturity. *Coryphaena hippurus* also reached sexual maturity at 4-5 mo, but have been observed to mature as early as 3 mo in captivity.

The daily regularity of increment formation has been demonstrated from D-1 to D-191 for *C. hippurus* and from D-1 to D-63 for *C. equiselis*. So the use of daily increment counts on the sagitta of wild fish for estimating age has only been partially validated for these dolphins. The age-length relationships are valid for the first 6 mo for wild *C. hippurus* and the first 2 mo for wild *C. equiselis*. Thus, the von Bertalanffy growth curves calculated for wild *C. hippurus* in Hawaiian waters should be viewed with caution despite good agreement with several other growth observations in the literature.

Acknowledgments

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[3]A length-weight relationship (Gibbs and Collette 1959) was used to estimate lengths in centimeters from weights, given in pounds, by Beardsley (1967).

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