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Otolith description and age-and-growth of *Kurtus gulliveri* from northern Australia

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The sagitta of *Kurtus gulliveri* was ovate, moderately thick with the following attributes: lateral surface convex, mesial surface flat; dorsal margin sinuate, posterior margin rounded ventrally, ventral margin rounded and irregular; sulcus divided into ostium and cauda by constriction of dorsal and ventral margins, heterosulcoid, colliculum heteromorph; dorsal depression large and distinct, ventral groove close to margin in larger otoliths; rostrum broad and antirostrum small, separated by wide, shallow excisural notch. Otolith size was moderate, average 4·6% standard length (L_S), typical for a perciform. Annuli on 78 whole sagittae were read, and 15% of these were transversely sectioned for verification of the annuli. Males ranged from 94 to 235 mm L_S and females from 95 to 284 mm L_S. There was little difference in size distribution of the sample between the sexes, perhaps due to a 6 month spawning season over which young were continually added to the population. Some sexual dimorphism was noted, however, as age 2 year females were significantly larger than males of the same age. The largest fish aged was a 284 mm L_S, 3 year-old female, and the oldest age reached was 4 years by two males. It appears likely that most spawning females are ≥2 years old, but some larger 1 year old fish may attain sexual maturity.

Key words: age and growth; *Kurtus gulliveri*; nurseryfish; otolith; sagitta.

INTRODUCTION

The nurseryfish *Kurtus gulliveri* Castelnau is an unusual species found in fresh and brackish waters of coastal rivers in northern Australia and southern New Guinea (Berra, 2001). Along with *Kurtus indicus* Bloch from southern Asia, it comprises the family Kurtidae that is placed in the monotypic perciform suborder, Kurtoidei (Nelson, 1994). *Kurtus gulliveri* is remarkable for its bizarre method of parental care in which the male carries the egg mass on a supraoccipital hook [Figs 1 and 2(a)] (Berra & Humphrey, 2002; Berra & Neira, 2003). Another notable feature of this strange fish is the lobed swimbladder, and its relationship to the ribs and lateral line nerve as a peripheral acoustic apparatus (Berra, 2003; Carpenter *et al.*, 2004). This species has not been studied for the past 90 years, but

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FIG. 1. Male nurseryfish photographed alive in the aquarium at the Territory Wildlife Park outside of Darwin, Northern Territory. Note the supraoccipital hook.

recently, aspects of its life history have been described (Berra & Wedd, 2001; Berra, 2003). The purpose of this study was to describe the sagitta and to use it to determine aspects of the biology of this species including age and growth.

A detailed description of the fish ear and hearing was presented by Popper & Coombs (1982) and Popper *et al.* (1988). Popper & Fay (1993) reviewed the extensive literature on fish hearing. The inner ear of teleosts contains a left and right membranous labyrinth enclosed in bony otic capsules at the rear of the neurocranium [Fig. 2(a), (b)]. The labyrinth includes three semicircular canals oriented in different planes and three compartments: the utriculus, sacculus and lagena. Each compartment contains an ear stone or otolith: the lapillus, sagitta and asteriscus, respectively. In most teleosts the sagitta is the largest otolith, however, in the otophysan fishes (Cypriniformes, Siluriformes, Characiformes and Gymnotiformes), the asteriscus is largest. Otoliths are composed of aragonite layered with up to 10% of the protein otolin, which is similar to keratin (Degens *et al.*, 1969). Sollner *et al.* (2003) suggested that the shape of otoliths is controlled by the expression levels of the newly discovered *starmaker* gene. The inner ear functions in sound reception and balance. Just as the bony fishes (Osteichthyes) come in an immense variety of shapes and sizes, so do their ears. This variation, however, is primarily associated with the auditory function rather than the vestibular and is especially apparent in hair cell orientation patterns (Popper *et al.*, 1988). The sensory hair cells and their ciliary bundles respond to displacement by the otolith within the labyrinth's endolymph. Details of this complex process can be found in Popper & Coombs (1982) and Popper *et al.* (1988).

Otoliths have been used for taxonomy and age-and-growth and population studies (Härkönen, 1986; Secor *et al.*, 1995; Smale *et al.*, 1995). In addition, isotopic analysis of ancient otoliths has been used to characterize ontogenetic histories and to describe ambient life conditions (Carpenter *et al.*, 2003). Otolith derived age-and-growth data can be used in combination with ecological data to illuminate important life history variables.

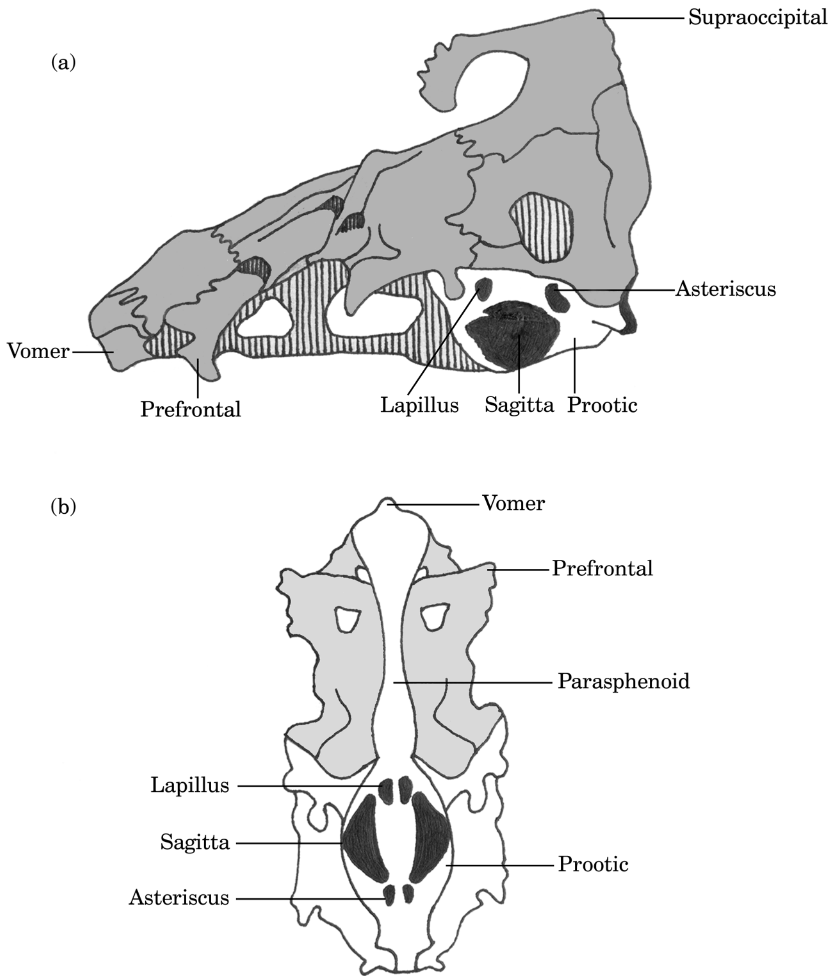

FIG. 2. (a). Lateral view of male *Kurtus gulliveri* skull showing the location of the three otoliths based on a computed tomography (CT) scan. (b). Ventral view of the skull showing location of the three otoliths. Drawing modified from de Beaufort (1914).

MATERIALS AND METHODS

Nurseryfish were collected by gillnet from Marrakai Creek (12°40′ S; 131°20′ E), a freshwater tributary of the Adelaide River 65 km south-east of Darwin, Northern Territory during the dry season on 35 field trips from May to November 2001 when water temperatures ranged from 20·6 to 31·3° C (Berra & Wedd, 2001; Berra, 2003). Fish were collected approximately weekly from April to November. The specimens were fixed in 10% non-buffered formalin for a week, then washed and stored in 70% ethanol. Skeletal preparations (Berra & Humphrey, 2002) and high resolution X-ray tomography (Carpenter *et al.*, 2004) of *K. gulliveri* were used to visualize the exact location of the sagitta. The sagitta was removed by lifting the right opercle and opening the otic capsule with the tip of a scalpel. The scalpel blade was used to pry the otolith free. After removal with forceps, the otolith was washed in alcohol and placed in a vial that was labelled with the collection number, sex and standard length (L_S) of the specimen. This dissection did little or no damage to the outside of the specimen. Eighty sagittae were removed from fish ranging from 24 to 284 mm L_S. The length, width and depth of each otolith were measured with digital calipers. All fish specimens and otoliths are in the fish collection at the Ohio State University at Mansfield. The collection numbers are: TMB 01–4, 12, 14, 15, 16, 18, 20, 22, 23, 24, 26, 27, 29, 31, 32, 33.

Otoliths were examined under a dissection microscope and described using the terminology of Smale *et al.* (1995). Otoliths were submerged in 40% ethanol, placed against a black background and aged in whole view by reflected light (Fig. 3) (Hoxmeier *et al.*, 2001). Age of fishes can be reliably determined through the identification of annual bands on otoliths aged in whole view or sectioned (Hoxmeier *et al.*, 2001). Because of variation in length-at-age within particular species, this is an important method for age estimation. Because annuli were easily identified, only a sub-sample (*c.* 15%) of otoliths was sectioned for verification of ages determined in whole view. Otoliths were sectioned transversely (DeVries & Frie, 1996), cemented to a microscope slide, and examined through transmitted light with a dissection microscope (Fig. 4). There was good agreement between ages derived from whole view and sectioned otoliths except for one otolith (the sectioned otolith was read to be 1 year older than the otolith aged in whole view, and the sectioned otolith age was taken to be correct).

Length-at-age plots for male and female nurseryfish were examined, and tested by ANOVA for sex-specific differences in length at ages 1 and 2 years. Comparisons were not possible at ages 3 and 4 years due to small sample size. The relationship between otolith size (length, mm) and fish size (L_S, mm) was also examined through correlation analysis.

RESULTS

OTOLITH DESCRIPTION

The sagitta is ovate and moderately thick (Fig. 5). The lateral surface is convex, and the mesial surface is flat. The dorsal margin is sinuate (rounded with regular wave-like curves) and meets the posterior margin in a rounded right angle. The posterior margin is rounded ventrally and may have a flattened dorsal part in larger otoliths. It is slightly irregular to slightly lobed. The ventral margin is rounded and irregular. The sulcus (longitudinal groove on mesial surface) is divided into an anterior ostium and a posterior cauda by constriction

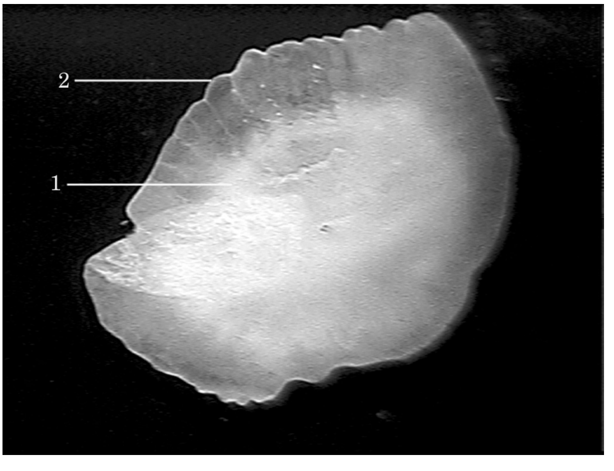

FIG. 3. Whole sagitta showing two annuli from a male *Kurtus gulliveri* (185 mm L_S). Numbers are annual growth rings.

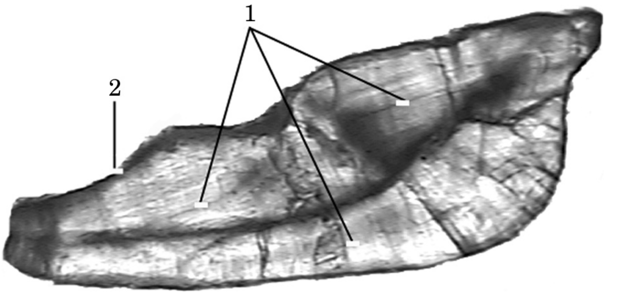

FIG. 4. Sectioned sagitta from a female *Kurtus gulliveri* (210 mm L_S). This otolith is $9{\cdot}3 \times 6{\cdot}4$ mm and 1·95 mm thick. Numbers are annual growth rings.

of the dorsal and ventral margins of the sulcus. The sulcus is ostial (opens onto the anterior-dorsal margin), and the cauda has a poorly defined tip. The ostium and cauda are distinct, and the ostium is bulbous ventrally and larger than the cauda, a condition known as heterosulcoid. The cauda flares dorsally towards its tip. The colliculum (raised part of sulcus floor) is heteromorph, slightly raised in the ostium and more developed than in the cauda. The crista superior (dorsal rim of sulcus) is well developed to ridge-like over the ostium and anterior cauda. The crista inferior (ventral rim) is well developed to ridge-like under the cauda. There is a distinct and large dorsal depression. There may be a distinct ventral groove close to the ventral margin in larger otoliths. The rostrum is broad and rounded and the antirostrum small and rounded. They are separated by a wide, shallow excisural notch.

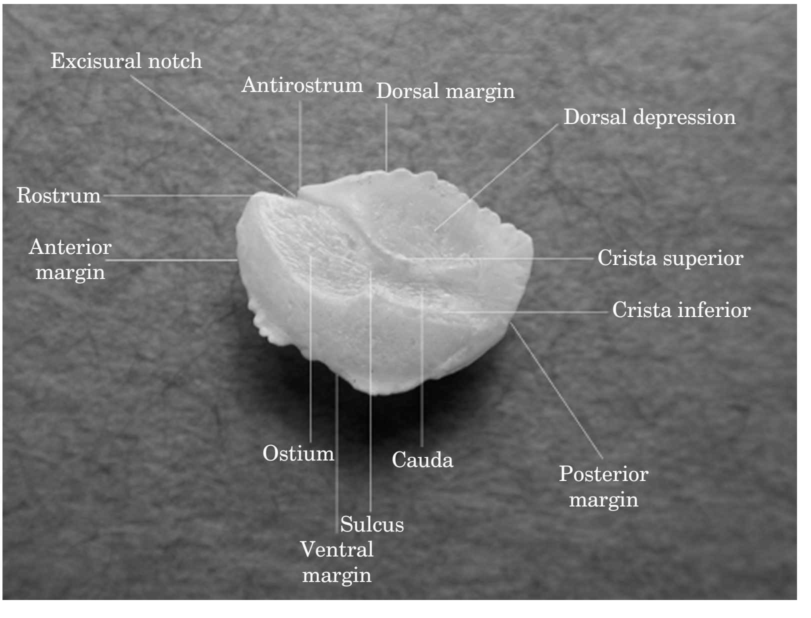

FIG. 5. Mesial view of right sagitta of a male *Kurtus gulliveri* (185 mm L_S). This otolith is $8{\cdot}4 \times 6{\cdot}3$ mm and 1·9 mm thick.

AGE AND GROWTH

Otolith size uniformly averaged 4·6% L_S and ranged narrowly from 3·9 to 5·1% L_S with the smallest ratio found in the largest females and the largest ratio found in the smallest males. As expected, there was a strong relationship (*F*-test, d.f. = 1 and 77, $P < 0.0001$, $r^2 = 0.97$) between otolith length and fish size (Fig. 6).

No annulus was present on the sagitta removed from the 24 mm L_S specimen that was collected with a plankton net. This individual was <6 months-old based, on a hatching size of 5·5 mm and a larval growth rate of *c.* 0·8 mm week^{-1} reported by Berra & Neira (2003). Another otolith was unreadable and discarded from analysis. Combining the remaining 78 specimens, there was no difference (*F*-test, d.f. = 1 and 77, $P = 0.13$) in mean L_S between males (mean ± S.E., 155·0 ± 4·5 mm) and females (170·0 ± 10·9 mm) collected. Likewise, there was no difference (*F*-test, d.f. = 1 and 42, $P = 0.12$) in mean length at age 1 year. At age 2 years, however, females were significantly larger (*F*-test, d.f. = 1 and 18, $P = 0.0006$; Table I). An attempt was made to identify spawning checks on otoliths, however, this could not be done with any degree of accuracy. These marks tend to be unreliable in very rapidly growing fish (unpubl. obs.). In addition, because of the temporally protracted spawning period, it was not possible to determine cohorts based on the size of individuals; large overlap in body size of individuals within and between age cohorts (Table I) is indicative of the long spawning season this species exhibits. Fortunately, the suitability of the otoliths as an ageing structure, and the ease of determining annular rings in these individuals indicated that the size ranges within each age were reliable.

DISCUSSION

The anatomy of the sagitta of *K. gulliveri* is similar to perciform or beryciform fishes depicted by Smale *et al.* (1995). Nurseryfish otolith length is consistently *c.* 4·6% L_S. This is a moderately sized otolith according to the categories given by Paxton (2000) who reported that most Perciformes have small to moderate

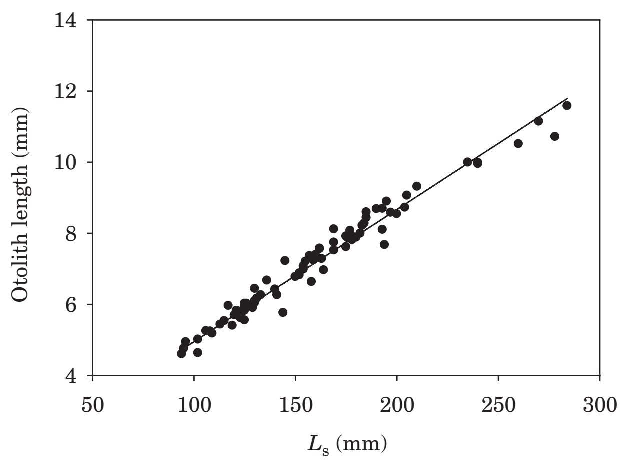

FIG. 6. Plot of otolith and standard lengths. The curve was fited by eye.

TABLE I. Length-at-age for male and female nurseryfish. Data are number, size range and mean ± S.E. standard length for male and female fish at each age

Age (years)	Sex	n	L_S (mm)		
			Minimum	Maximum	Mean
1	Male	22	94·0	193·0	132·0 ± 6·1
	Female	22	95·0	240·0	148·8 ± 8·6
2	Male	16	131·0	235·0	174·8 ± 6·2
	Female	4	204·0	278·0	238·0 ± 18·3
3	Male	10	140·0	195·0	169·1 ± 5·6
	Female	2	270·0	284·0	277·0 ± 7·0
4	Male	2	160·0	183·0	171·5 ± 11·5
	Female	0	–	–	–

otoliths 2–5% L_S. Although the relationship between hearing acuity and otolith size is unclear, some taxa with modified swimbladders, such as the Myripristinae and Sciaenidae, have larger otoliths (Paxton, 2000). *Kurtus gulliveri* clearly has an autapomorphic swimbladder, ribs and nerve apparatus (Carpenter *et al*., 2004), and moderately sized otoliths may play a role as an accessory acoustic system. Several features of *K. gulliveri* otoliths are similar to two species of Berycidae illustrated in Smale *et al*. (1995). These features are the bulbous ostium with a relatively straight cauda, distinct rostrum and small antirostrum, the well developed to ridge-like crista superior, the distinct dorsal depression and the somewhat bulbous shape to the ventral area (M. Smale, pers. comm.). Tominaga (1968) remarked that Kurtidae have some anatomical characteristics intermediate between the Beryciformes and the Perciformes. Johnson (1993) denied the phyletic affinities with Beryciformes and stated that 'there is nothing in the osteology of *Kurtus* to exclude it from the suborder Percoidei'. A pelvic fin ray count of one spine and five rays, and a caudal fin ray count of 17 principal rays reported by Berra (2003) are typical perciform values (Nelson, 1994).

The largest fish aged in this study was a 284 mm L_S female that proved to be 3 years-old, but two smaller males reached 4 years of age (Table I). Whether nurseryfish reach a greater age is not known from the data. A 330 mm L_S female museum specimen was examined during the fieldwork for this study (otoliths were not examined in this study; Berra, 2003), and Weber (1913) and de Beaufort & Chapman (1951) reported a maximum size of 590 mm L_S. It was not possible to verify this, as the specimen could not be located. Based on the data in Table I, a 224 mm L_S male captured on 20 June 2001 carrying the partial egg mass illustrated in Berra & Neira (2003) and a 269 mm L_S running-ripe female captured on 12 July 2001 were presumably at least 2 years old. These otoliths were also not available for ageing. Further analysis of larger and older specimens would be important to ascertain the range in size of otoliths in these larger or older fish. There does not appear to be any sexual dimorphism between otolith size of males and females.

In the 1–3 year age classes, females tended to be larger than males, but the difference was only significant at age 2 years. Larger sample sizes at ages 3 and 4 years would be necessary to delineate differences, but field observations support the notion that females are generally larger than males. Spawning coincides with the lengthy dry season (May to November) and the newly hatched fry (5·5 mm L_S) enter the plankton where they remain until *c.* 25 mm L_S (Berra, 2003; Berra & Neira, 2003). Growth is presumably rapid in the monsoon season (December to April). Because of the elevated temperatures in tropical rivers, growth rates of fishes are faster, maturity occurs at an earlier age, and the life span is shorter than in temperate waters (Lowe-McConnell, 1975). The tropical climate and extended breeding season in which young continue to enter the population over half of the year, result in wide variation of L_S in each age class. From a study of egg development, specimens with ripe ovaries appeared to be >200 mm L_S; thus, most females were probably at least 2 years old before spawning although some may have spawned in their first year (T.M. Berra, unpubl. data). Fieldwork on nurseryfish is difficult due to twice daily tidal variations as great as 7 m and the presence of a large population of saltwater crocodiles. This may explain the dearth of published papers on this unusual fish in the past century.

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