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Stomach contents of a megamouth shark *Megachasma pelagios* from the Kuroshio Extension: evidence for feeding on a euphausiid swarm

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**Abstract:** More than 50 specimens of the megamouth shark *Megachasma pelagios* have been reported so far, but biological observations on the species are still limited. We examined a female megamouth specimen that was captured by the bonito purse seine fishery in the Kuroshio Extension in July 2007 and donated to the Okinawa Churaumi Aquarium. The specimen was an immature female, 3,667 mm in total length and 361 kg in weight. The stomach contents measured 2,200 mL excluding the portion that was lost from the specimen before measurement. Detailed examination of a small part (14.6 mL) of the stomach contents revealed undamaged worm-like organisms, 10 partially damaged euphausiids and abundant fragmented pieces of euphausiids. The worm-like organisms were probably parasites such as tapeworms. The partially damaged euphausiids were identified as *Euphausia pacifica* except for one individual of *Nematoscelis difficilis*. Based on the number of fragmented right mandibles, which were less damaged than the other fragmented appendages, the total number of euphausiids in the stomach contents is estimated to be at least 18,000 individuals. The high abundance of euphausiids in the stomach contents suggests that the present specimen has fed on a swarm of *E. pacifica* in an oceanic area.

**Key words:** euphausiids, Kuroshio Extension, megamouth shark, morphometric measurements, stomach contents

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The megamouth shark, *Megachasma pelagios* Taylor et al., 1983 was first described as a species belonging to a new genus of a new family, based on a male specimen captured off Hawaii (Taylor et al. 1983) and thereafter more than 50 specimens have been reported from tropical to temperate areas throughout the world oceans (Mollet 2012). Most of them have been stranded on beaches and a few were caught accidentally by various fisheries (Compagno 2001). Biological observations on the shark have been limited; biometric measurements were made on five specimens (Taylor et al. 1983, Berra & Hutchins 1990, Nakaya et al. 1997, Amorim et al. 2000, White et al. 2004) and stomach contents were examined for three specimens (Taylor et al. 1983, Berra & Hutchins 1990, Yano et al. 1997). Data for both biometric measurements and stomach contents only exist for two specimens, i.e. one from Hawaii (Taylor et al. 1983) and one from Hakata Bay, Fukuoka (Nakaya et al. 1997, Yano et al. 1997). We had the opportunity to examine a relatively fresh female megamouth shark specimen deposited at the Okinawa Churaumi Aquarium, Okinawa, Japan, and herein report its biometric measurements and stomach contents.

The present specimen (Fig. 1) was captured by the bonito purse seine fishing boat, *Taishi-maru*, from the western North Pacific 700 km off Ibaraki Prefecture, Japan in the Kuroshio Extension. The stomach contents contained undamaged worm-like organisms, 10 partially damaged euphausiids and abundant fragmented pieces of euphausiids. The worm-like organisms were probably parasites such as tapeworms. The partially damaged euphausiids were identified as *Euphausia pacifica* except for one individual of *Nematoscelis difficilis*. Based on the number of fragmented right mandibles, which were less damaged than the other fragmented appendages, the total number of euphausiids in the stomach contents is estimated to be at least 18,000 individuals. The high abundance of euphausiids in the stomach contents suggests that the present specimen has fed on a swarm of *E. pacifica* in an oceanic area.

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**Fig. 1.** The female *Megachasma pelagios* specimen (3,667 mm TL) captured from 700 km off Ibaraki Prefecture, Japan.
Table 1. Measurements of the megamouth shark caught from off Ibaraki, with the data of previous five specimens from Fukuoka, Hawaii (holotype), Sumatra, Brazil, and Perth for comparison.

| Sampling area | Off Ibaraki1 | Fukuoka2 | Hawaii3 | Sumatra4 | Brazil5 | Perth6 |
|---------------|--------------|----------|---------|----------|---------|--------|
| Total length (mm) | 3667         | 4710     | 4460    | 1767     | 1900    | 5150   |
| Body weight (kg)  | 361          | 790      | 750     | 13.82    | 24.4    | 690    |
| Sex            | Female       | Female   | Male    | Male     | Male    | Male   |

|                | mm | %TL | %TL | %TL | %TL | %TL |
|----------------|----|-----|-----|-----|-----|-----|
| Precaudal length | 2536 | 69.2 | 69.6 | 69.3 | 64.7 | 67.4 | 66.6 |
| Prenarial length  | 103  | 2.8 | —   | 2.2 | 1.8 | 1.7 | 2.0 |
| Preoral length   | 20   | 0.5 | —   | 1.5 | 1.0 | 0.8 | 1.2 |
| Preoral length   | 197  | 5.4 | 5.4 | 5.4 | 5.2 | 4.7 | 6.8 |
| Prebranchial length | 345  | 9.9 | 7.9 | 10.1 | 10.2 | 10.5 | 18.5 |
| Head length      | 678  | 18.5 | 20.8 | 19.1 | 18.6 | 17.9 | 21.2 |
| Prepectoral length | 932  | 25.4 | 27.2 | 26.5 | 24.3 | 23.4 | 25.6 |
| Prepelvic length  | 897  | 24.5 | 27.0 | 24.9 | 24.1 | 23.8 | 27.0 |
| Presecond dorsal length | 1100 | 30.5 | 33.0 | 34.5 | 30.3 | 29.5 | 32.4 |
| Interdorsal space | 2548 | 14.9 | 11.7 | 14.0 | 13.6 | 12.5 | 12.4 |
| Pectoral-pelvic origins | 304  | 8.3 | 8.1 | 8.9 | 8.3 | 8.9 | 8.4 |
| Pelvic-anal space | 499  | 13.6 | 12.1 | —   | 12.7 | 14.4 | 13.9 |
| Pelvic-caudal space | 128  | 3.5 | 4.5 | 5.2 | 5.5 | 5.3 | 4.2 |
| Eye length       | 50   | 1.4 | 1.1 | 1.3 | 1.8 | 1.7 | 1.2 |
| Eye height       | 42   | 1.1 | 1.0 | 1.2 | 1.3 | 1.3 | 0.8 |
| Interorbital space | 364  | 9.9 | 10.8 | 8.3 | 8.7 | 8.2 | 10.7 |
| Spiracle diameter | 12   | 0.3 | 0.4 | —   | 0.3 | 0.4 | —   |
| Nostril width    | 26   | 0.7 | 0.7 | 0.7 | 0.6 | 0.5 | 0.6 |
| Internarial space | 274  | 7.5 | 8.7 | 7.6 | 6.4 | 6.3 | 7.7 |
| Anterior nasal flap length | 10   | 0.3 | —   | 0.1 | 0.2 | 0.1 | —   |
| Mouth length     | 372  | 10.1 | 11.3 | 6.1 | 6.7 | 7.5 | 8.7 |
| Mouth width      | 536  | 14.6 | 9.6 | 18.5 | 13.1 | 11.6 | 11.3 |
| First gill slit height | 172  | 4.7 | 5.1 | 5.9 | 3.7 | 4.7 | 4.3 |
| Second gill slit height | 198  | 5.4 | 5.1 | 5.8 | 3.9 | 4.1 | 4.4 |
| Third gill slit height | 216  | 5.9 | 5.9 | 5.9 | 5.3 | 4.2 | 4.4 |
| Fourth gill slit height | 215  | 5.9 | 4.2 | 5.7 | 4.1 | 4.6 | 4.1 |
| Fifth gill slit height | 208  | 5.7 | 3.3 | 5.2 | 4.4 | 4.8 | 3.9 |
| Caudal peduncle height | 156  | 4.3 | 5.6 | 5.3 | 5.9 | 4.7 | 5.4 |
| Pectoral-anterior margin | 736  | 20.1 | 19.6 | 18.8 | 19.1 | 19.9 | 19.2 |
| Pectoral height | 275  | 7.5 | 5.9 | 5.9 | 5.3 | 5.7 | 6.4 |
| Pelvic anterior margin | 626  | 17.1 | 17.5 | —   | 17.8 | 17.6 | 16.9 |
| Pelvic base      | 250  | 6.8 | 6.8 | 5.9 | 7.7 | 7.2 | 6.4 |
| Pelvic height    | 182  | 5.0 | 5.5 | 4.6 | 4.4 | 4.7 | 6.2 |
| Pelvic inner margin | 220  | 6.0 | 4.9 | 5.7 | 6.1 | 5.6 | 3.6 |
| Pelvic posterior margin | 94   | 2.6 | 2.2 | 0.8 | 2.5 | 1.1 | 0.7 |
| First dorsal anterior margin | 200  | 5.5 | 5.1 | 4.1 | 3.7 | 4.0 | 3.8 |
| First dorsal base | 374  | 10.2 | 9.4 | 9.3 | 6.7 | 10.6 | 5.4 |
| First dorsal height | 396  | 10.8 | 8.7 | 9.1 | 6.4 | 8.9 | 9.7 |
| First dorsal inner margin | 220  | 6.0 | 6.2 | 5.1 | 4.9 | 6.7 | 4.9 |
| First dorsal posterior margin | 80   | 2.2 | 1.9 | 1.8 | 2.1 | 2.2 | 1.6 |
| Second dorsal anterior margin | 280  | 7.6 | 6.1 | 5.9 | 3.8 | 6.6 | 5.7 |
| Second dorsal base | 140  | 3.8 | 5.4 | 4.4 | 4.9 | 3.5 | 4.7 |
| Second dorsal height | 168  | 4.6 | 5.4 | 4.3 | 3.8 | 3.8 | 5.0 |
| Second dorsal inner margin | 102  | 2.8 | 2.5 | 2.3 | 2.8 | 2.6 | 1.9 |
| Second dorsal posterior margin | 85   | 2.3 | 1.7 | 1.8 | 1.6 | 2.2 | 1.5 |
| Anal length      | 196  | 5.3 | 4.5 | 5.1 | 2.3 | 4.4 | 2.8 |
| Anal anterior margin | 132  | 3.6 | 2.9 | 4.4 | 2.0 | 2.8 | 3.0 |
| Anal base        | 134  | 3.7 | 2.7 | 3.6 | 1.1 | 2.5 | 1.6 |
| Anal height      | 72   | 2.0 | 1.8 | 1.7 | 1.2 | 2.1 | 1.6 |
| Anal inner margin | 62   | 1.7 | 1.8 | 1.5 | 1.1 | 1.9 | 1.3 |
| Anal posterior margin | 98   | 2.7 | 1.8 | 1.8 | 0.7 | 2.5 | 1.7 |
| Dorsal caudal margin | 1540 | 36.5 | 34.6 | 32.3 | 32.3 | 33.6 |
| Prepectoral caudal margin | 538  | 14.7 | 16.0 | 14.0 | 15.2 | 16.4 | 14.0 |
| Lower Postventral caudal margin | 346  | 9.4 | 7.0 | 8.5 | 8.2 | 10.5 | 8.4 |
| Upper Postventral caudal margin | 1040 | 28.4 | 22.5 | 27.4 | 23.8 | 21.6 | 23.5 |
| Terminal caudal margin | 90   | 2.5 | —   | 2.2 | 1.9 | 2.6 | 2.0 |
| Subterminal caudal margin | 48   | 1.3 | 1.2 | —   | 1.4 | 1.8 | 1.7 |

"—" shows no measurements.

References: 1 present study, 2 Nakaya et al. 1997, 3 Taylor et al. 1983, 4 White et al. 2004, 5 Amorim et al. 2000, 6 Berra & Hutchins 1990.
Megamouth shark feeding on euphausiid swarm

Extension (36°05′N–148°16′E) on 9 July 2007. It was identified as the 41st published record of a megamouth shark specimen in the world and the 12th record in Japan (K. Nakaya pers. comm.). The shark was alive on deck and was carried to Ishinomaki fishing port, Miyagi Prefecture, where it was preserved at −30°C in a cold storehouse. The specimen was finally donated to the Okinawa Churaumi Aquarium. The specimen was in excellent condition and was examined on 1 to 3 March 2011.

Methods of measurements and terminology follow Compagno (2001). Measurements of the present specimen and, for comparative purposes, those of the previous five specimens are given in Table 1. The present specimen was an immature female with a poorly developed uterus and narrow oviducts, 3,667 mm in total length and 361 kg in weight. Of the previous specimens, the Fukuoka specimen was the only female and was suggested to be close to maturity (Tanaka & Yano 1997). We were unable to find notable differences between the present specimen and the Fukuoka specimen. There were fairly large differences in body proportions among the specimens, but this is probably primarily due to the very soft and flaccid body, where measurements could vary greatly according to the condition of specimens.

The stomach was J-shaped and filled with a reddish turbid fluid. The volume of the stomach contents measured 2,200 mL, excluding the contents spilt from the specimen when the body was hoisted up from the storage tank. The contents were well mixed and a small amount (46.6 mL) was preserved in 10% formalin solution. A part of the preserved sample (14.6 mL) was examined under a stereo microscope.

In the stomach contents that were examined, undamaged white worm-like organisms, ten partially damaged euphausiids and abundant fragments of crustaceans were found. The worm-like organisms are probably parasites (Fig. 2a) such as tapeworms, which have been previously reported from the stomach of a megamouth shark (Caira et al. 1997). The partially damaged euphausiids were identified as *Euphausia pacifica* Hansen, 1911 by the features of the petasma and thoracic endopods with long narrowly spaced bristles, in addition to one female of *Nematocelis difficilis* Hansen, 1911, which had large peculiar shaped eyes, slender antennules and a characteristically narrow rostrum (Sawamoto 1997) (Fig. 2b). The abundant crustacean fragments were composed of the appendages of mouth parts and abdomen, eyes, carapaces, sternites and spermatophore sacs. These fragments were identifiable as euphausiids by having features distinct from those of other crustaceans such as copepods, amphipods, and shrimps. Thus the present specimen fed exclusively on euphausiids as reported for specimens from off Sanriku, northeast part of Japan (c). a: 1–6, fragments of crustaceans identifiable as euphausiids (1, antennal sympod; 2, eye; 3, mandible; 4, abdominal somites with pleopods; 5, uropods; 6, telson); 7, worm-like organisms. b: damaged euphausiids (upper, *Nematocelis difficilis*, middle and lower, *Euphausia pacifica*). c: mandibles of *E. pacifica* (left) and *N. difficilis* (right) (1, mandibular palp; 2, pars incisive; 3, pars molaris). Scale bars indicate 1 mm for a, 2.5 mm for b, and 0.5 mm for c.
with palp were identical to that of intact specimens of *E. pacifica* collected from off Sanriku, northeast part of Japan on 15 March 1985 (Sawamoto unpublished data). The mandible of the *N. difficilis* specimen, which was 18 mm in total length, was as large as that of the *E. pacifica* specimens of the same length. However, the pars incisive of *N. difficilis* was sharper and the palp was shorter (Fig. 2c). Only one *N. difficilis* mandible was found among the fragmented appendages. The other mandibles were considered to belong to *E. pacifica* and were almost the same size as in the Sanriku specimens of 9–20 mm in total length. In the present 14.6 mLs of stomach contents that were examined, 118 right and 101 left mandibles, different in the form of the pars incisive and pars molaris, were observed. On the basis of the number of right mandibles, the total number of euphausiids in the total stomach contents (2,200 mL) was calculated to be at least 18,000 individuals. Given that the average individual wet weight of *E. pacifica* is approximately 31 mg (Terazaki 1980), the wet weight of euphausiids in the stomach contents was 558 g, which is 0.15% of the shark’s body weight.

The present megamouth specimen is considered to have fed almost exclusively on *E. pacifica* of 9 to 20 mm in total length. Extremely high abundances of *E. pacifica* have been observed in surface swarms of this species in the northeastern part of Japan, where the swarms have been reported to consist of individuals from 12.1 to 21.5 mm in total length, with densities ranging from 2,505 to 5,125 ind. m⁻³ (Terazaki 1980). According to *in situ* observations by Hanamura et al. (1984) in Sendai Bay, northeastern Japan, a *E. pacifica* swarm of about 20 m in diameter consists exclusively of adults of 12.3–21.5 mm with densities of about 10,000–72,000 ind. m⁻³ and it excludes other macrozooplankton. Those swarms formed at the surface in daytime. Nakaya et al. (2008) suggested that the megamouth shark performs engulfment feeding like a rorqual whale, and is morphologically distinguished from a basking shark and a whale shark in the buccal structure which is composed of a larger bucco-pharyngeal cavity and stretchable skin on the ventral and lateral sides of the head in the megamouth shark. The present results on stomach contents and previous information suggest that the megamouth specimen was caught soon after feeding on a surface swarm of *E. pacifica*.

Yano et al. (1997) reported that the megamouth specimen from Fukuoka fed on *Euphausia nana* Brinton, 1962 of a body length of 20–30 mm. However, the identification of this euphausiid species is doubtful because *E. nana* is much smaller at maturity (ca. 7–10 mm) (Brinton 1962).

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