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Stomach content analysis of young Russell's oarfish (*Regalecus russelii*) from Taiwan, and a report on an unusual case of predation

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Abstract

In this study, we analyzed the stomach content of two individuals of rare, young Russell's oarfish, *Regalecus russelii*, from Taiwan. One of them was captured alive along with larval fish and crustaceans by a stow net from the shallow waters (15-18m deep) of the Tamsui River mouth. A total of 38 individuals of larval fish belonging to three species (86.4% of all prey) and 6 individuals of crustaceans belonging to three species were found in the Russell's oarfish specimen's stomach. Among the prey, the Japanese anchovy (*Engraulis japonicus*) was the most dominant fish species, accounting for 44.7% of all fishes; and luciferids were the most dominant crustaceans, accounting for 66.7% of all crustaceans. All the prey fish were sandy or a mixture of sandy and muddy sediment dwellers. The luciferids and Japanese anchovies are characterized by having diel vertical migration behavior. Based on the sampling information and biological characteristics of the fish larvae and crustaceans, we conjectured that the abundance of these prey when they moved up to the upper layer of the Tamsui River mouth at nighttime had attracted the young Russell's oarfish to hunt there. In addition, we speculated that it might be easier for the vertical-swimming Russell's oarfish to hunt a large number of luciferids assembled in the upper layer of the water by its particular posture or angle of view.

Key words: Juvenile oarfish, river mouth, fish larvae, crustaceans

Introduction

The oarfish comprises three species from two genera, *Regalecus* and *Agrostichthys*, under the family Regalecidae (Nelson *et al.* 2016). The fish have been described as sea serpents or messengers from the Sea God's palace, and are believed by some people to portend earthquakes when they are washed ashore. Among the three oarfish species, the Russell's oarfish, *Regalecus russelii* (Cuvier 1816), is found in the Indian Ocean and Pacific Ocean, including Japan and Taiwan in the western Pacific as well as California in USA, Baja in Mexico, and Costa Rica in the eastern Pacific (Nakabo 2002; Forsgren *et al.* 2017).

The Russell's oarfish is a rare mesopelagic fish (Nakabo 2002) and the scientific information about the species is very limited (Forsgren *et al.* 2017). Most knowledge is derived from the stale, dead or dying oarfish occasionally drifted to the coastal areas (Benfield *et al.* 2013) and is rarely from healthy individuals. In addition, most studies about the fish's ecological study were based on mature individuals (Forsgren *et al.* 2017; Feeney & Lea 2018) while little is known about their youths.

Palmer (1986) reported that the species preyed on euphausiid crustaceans, small fishes and squids. Feeney and Lea (2018) reported that krill was found in the stomach of a freshly dead oarfish estimated to be 4.3 m long and discovered near Santa Catalina Island, California, USA. They also reported that another dead oarfish (body length: 5.27 m), discovered along Santa Catalina Island, had empty stomach. According to previously published information, the dead or dying Russell's oarfish found in coastal areas tend to have empty stomachs (Feeney & Lea 2018).

The information on the diet of Russell's oarfish were mostly obtained from adult individuals. So far, there was

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only one report on the diet of an immature Russell's oarfish. A young female Russell's oarfish, 3.225 m long (part of its tail is missing), was caught from the Sado Strait of the Japan Sea by a small motor trawler and subsequently sent to a fish market in the following morning (Nishimura 1960). This Russell's oarfish's stomach was completely empty. There was dark-red mucus in its intestine, but no organism could be identified. One individual of small-sized shrimp-like crustacean was found on its gill rakers, revealing this Russell's oarfish had hunted crustaceans.

Currently the Russell's oarfish specimens used in the studies of their diet were all found in the sea. Most reports were derived from the stale, dead or dying oarfish occasionally drifted to coastal areas, and only a few samples were collected by fishermen.

Predation behavior and diet are two of the most important aspect of understanding the ecology of fishes. Fish stomach content analysis provides important insight into the feeding pattern and quantitative assessment of feeding habits of a species. However, only a few studies have analyzed the stomach contents of adult Russell's oarfish, much less the young individuals. Undoubtedly, the ecological information (such as diet) obtained from young Russell's oarfish will be advantageous to understand the biology of this rare fish, especially in the juvenile phase.

In order to understand the diet and feeding of a fish species, analysis of the stomach content is widely used. It is also important to understand the fish ecology due to the difficulties in observing fish feeding habits in their natural habitats (Sivadas & Bhaskaran 2009). Therefore, a freshly caught specimen can provide the opportunity to study the fish's diet and feeding by analyzing its stomach contents. In addition, most of the reported samples used for studying Russell's oarfish's stomach contents were adult individuals. The information on the juveniles are very limited so far.

In our study, an apparently healthy young Russell's oarfish was captured alive in fairly good condition from a river mouth in northwestern Taiwan. It was promptly fixed and preserved. Some fish larvae and crustaceans were found in its stomach. The stomach content of this well-preserved young oarfish specimen not only can provide an opportunity to examine its prey assemblage, it can also be utilized for understanding the correlation between its prey and its predation behavior.

Wang (1997) studied the larval fish component at four sampling sites around the Tamsui River (shown as Tanshui River in Wang's study) mouth and its adjacent area. The larval fish species were different in different areas near the Tamsui River mouth due to various bottom sediments, and the dominant species were also different at different sampling locations (Wang 1997). In this study, we will attempt to infer which area our captured young Russell's oarfish hunted through the quantitative analysis of the dominant prey species in its stomach content and the comparison with the dominant fish species at each sampling site in Wang's study (1997). The answer to this question perhaps can help us explore why this young Russell's oarfish appeared in estuarine water.

Materials and Methods

In this study, two young Russell's oarfish specimens were dissected for the examination of their stomach and intestine contents. One specimen, measuring 113 cm in total length, was collected from Daxi fish market, Yilan, Northeastern Taiwan, on August 8, 2006 (Catalog number: ASIZP0067242). The sampling location of this specimen is in the northeastern Taiwanese waters, but the actual location is unknown.

The other specimen (Catalog number: ASIZP0060540) is a young, apparently healthy individual (measuring 157.5 cm in total length) that was captured alive accidentally by a fishing boat using a larval fish stow net at the mouth of the Tamsui River in northwestern Taiwan before dawn on May 21, 2000. The longitude and latitude data of the exact location were recorded using the GPS system on the boat (GPS position: 121.4 E, 25.17 N) (Fig. 1). The sampling location is characterized by sandy sediments, with water depths ranging from 15 m to 18 m (Fig. 2). When the young Russell's oarfish was found to be alive in the stow net, it was brought back to the fish specimen room in Academia Sinica where it was preserved as a specimen using the following protocol: fixed in 10% formalin for several days and then transferred to 70% ethanol for long-term preservation.

The two oarfish specimens were dissected in the laboratory and the contents of the removed stomachs and intestines were examined. Nothing was found in the stomach of the specimen collected from Daxi fish market whereas well-preserved fishes and crustaceans were found in the stomach of the specimen captured from the Tamsui River mouth (Fig. 2). All the prey items were identified to the lowest taxonomic level using a dissecting microscope (Zeiss Stemi 2000). The identification of fish species was based on Okiyama (1988) and the Fish Database of Taiwan

(Shao 2022). The number of individuals belonging to each fish species was counted. The fishes were measured by standard length (SL) and the crustaceans were measured by total length (TL). The two Russell's oarfish specimens examined along with the stomach contents were deposited at the Biodiversity Research Museum, Academia Sinica, Taipei, Taiwan.

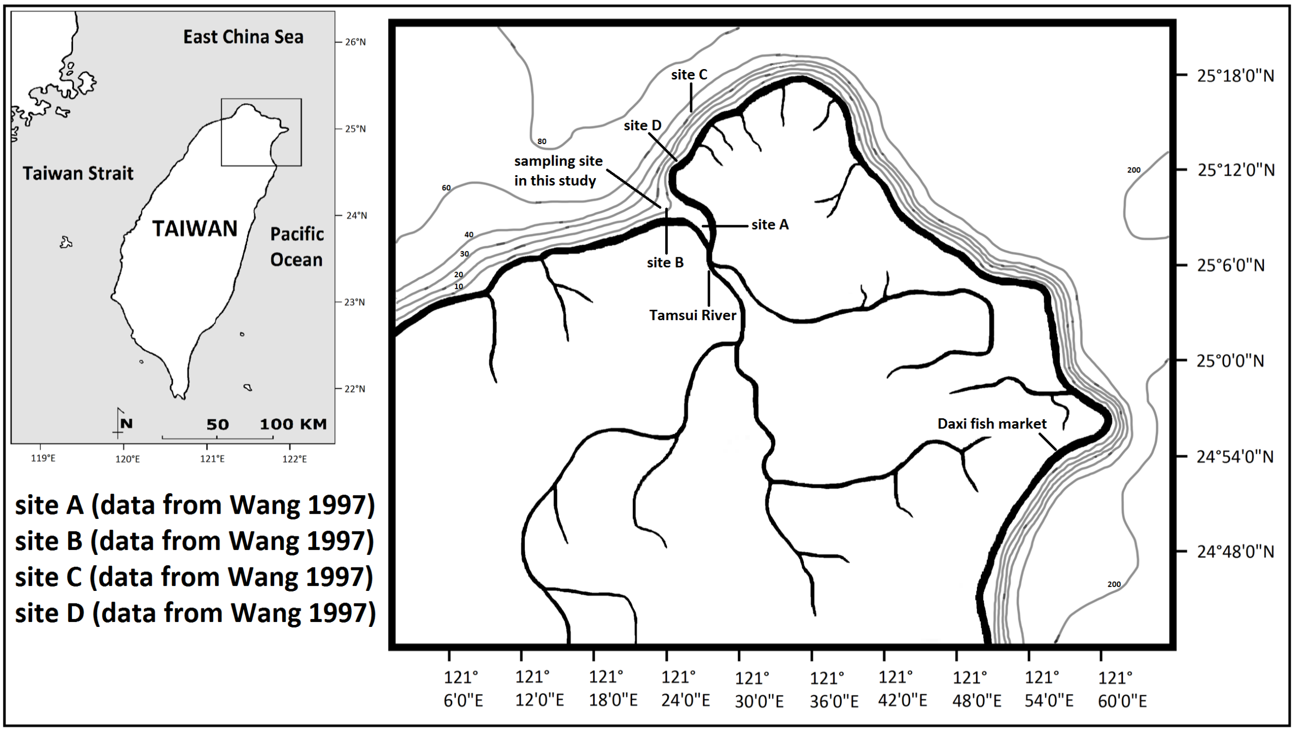

FIGURE 1. Map of sampling site in this study and the four sites (sites A, B, C, D) in Wang's study (1997). Grey lines denote depth contour.

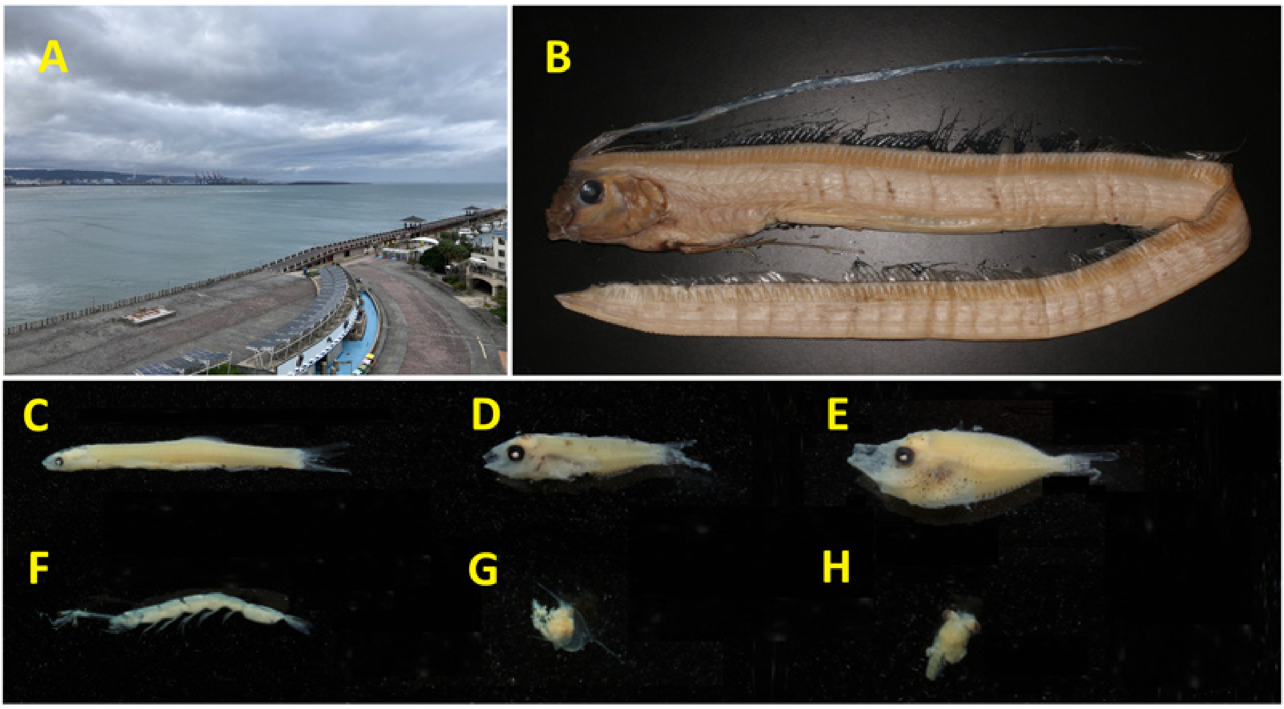

FIGURE 2. Sampling site at the Tamsui River mouth (A), specimen photograph of Russell's oarfish (B) (catalog number: ASIZP0060540), and preys found in its stomach: *Engraulis japonicus*, 18.1 mm SL (C); *Pomadasys kaakan*, 9.8 mm SL (D); *Secutor* sp. 11.1 mm SL (E); Luciferidae gen. sp., 12.5 mm TL (F); Pinnotheridae gen. sp., 3.8 mm TL (G); and crab megalopa, 3.1 mm TL (H).

Wang (1997) studied the larval fish component at four sampling sites around the mouth of the Tamsui River (shown as Tanshui River in Wang's study) and its adjacent area, given that the larval fish component and dominant species might vary in different areas of the Tamsui River mouth region. In order to understand the basic biological information on the captured young Russell's oarfish in our study, the fish components and dominant species from all sampling sites in Wang's study were used as the comparative data against the species component and dominant species from the stomach content of the captured young Russell's oarfish.

An overall comparison of the larval fish component from different sediments and areas around the Tamsui River mouth such as in Wang's study (1997) can promote our understanding of the correlation between the larval fish composition, dominant species and the locations of these fish. The actual location where the young Russell's oarfish fed on its prey can then be explored. The fish larvae composition from Wang's study and that from the stomach content of this study's young Russell's oarfish specimen are provided in Table 2. All sampling sites from our study and Wang's study (sites A, B, C and D) are labeled in Figure 1; their similarity will be discussed herein.

Results

Several studies have revealed a positive correlation between body length and reproductive development. Based on the study of four stranded dead Russell's oarfish, Forsgren *et al.* (2017) reported that the two female individuals (4.32 m and 5.2 m long in total length) were determined to have reached sexual mature stage and be spawning capable. The total length measurements of the two mature male individuals were 4.3 m and 4.1m, respectively. On the other hand, the two immature Russell's oarfish collected in Japan were 2.92 m and 2.65 m long (Honma *et al.* 2004). The much smaller size of the two Russell's oarfish specimens examined in our study clearly indicated that they were immature individuals.

This study focused on the young Russell's oarfish specimen captured from the Tamsui River mouth. Part of its caudal fin tip is missing, but the terminus had completely healed. A total of 38 individuals of fish larvae and 6 individuals of crustaceans were found in its stomach. The fish larvae comprised three species, with 17 individuals identified as Japanese anchovy (*Engraulis japonicus*) (14.3-20.6 mm SL), 16 as ponyfish (*Secutor* sp.) (4.1-12.4 mm SL) and 5 as Javelin grunter (*Pomadasys kaakan*) (6.5-11.3 mm SL). All the fish prey are associated with sandy bottom or a mixture of sandy and muddy sediment habitats. These prey species are rather common around the inshore waters of Taiwan with their sub-adults commonly found in estuaries (Chen & Fang 1999).

The crustaceans comprised three species, with four individuals identified as prawn (Luciferidae gen. sp.) (8.5-12.5 mm TL), one as soft-bodied crab (Pinnotheridae gen. sp.) (3.8 mm TL) and one as crab megalopa (3.1 mm TL). The sample of crab megalopa was incomplete, making it impossible to identify to the family level. Based on the morphological character and size, among all recorded crustaceans, one species (Luciferidae gen. sp.) is at the mature stage and the remaining two species are juveniles. The basic measurements of these prey species are provided in Table 1.

Table 2 shows the comparison of the larval fish component and dominant species found in the stomach content of the present study's oarfish specimen and those recorded in Wang's study (1997). Wang's study (1997) selected a total of four sampling sites (sites A, B, C and D) located at the Tamsui River mouth and its adjacent areas to collect fish larvae (Fig. 1). The sampling site A is located at the tidal river section of the Tamsui River, at the upper position of its river mouth, close to the mangrove. Depth at the site is more than 10 m, with muddy bottom substrate. The sampling site B is located at the shallow water region at the south bank of the Tamsui River mouth, with sandy sediments. The sampling site C is located at the offshore waters on the north bank of the Tamsui River mouth and is far from the coast. The site has a depth ranging from 5 m to 60 m, mainly 30-40 m, and its bottom substrate is a mixture of sand and reef-sand. The sampling site D is located at the inshore shallow waters on the north bank of the Tamsui River mouth and is close to the coast. Depth at the site ranges from 0.3 m to 3 m, and its bottom substrate is a mixture of mud, sand and reef.

In general, the sampling sites A and B are located at the same river system, with muddy sediments and sandy sediments, respectively. The sampling sites C and D are located at the north bank of the Tamsui River mouth and not part of the Tamsui River system. The bottoms of sites C and D are similar with a mixture of mud, sand and reef, but at different depths. It is noteworthy that Wang's sampling site B and our sampling locality are located at the same shallow water region at the south bank of the Tamsui River mouth with sandy sediments.

By analyzing the research results of Wang (1997), we found that there were different dominant species of fish larvae at each sampling site near the Tamsui River mouth. At site A, Clupeidae was the most dominant fish quantitatively, accounting for 70.9%; at site B, it was the Japanese anchovy (*Engraulis japonicus*), accounting for 61.8%; at site C, it was Engraulidae, accounting for 46.6%; and at site D, it was Teraponidae, accounting for 51.3% (Table 2).

TABLE 1. Species, number and length of prey found in the stomach of analyzed Russell's oarfish.

Class	Family	Species	No.	Length (mm)	Ave. (mm)	Condition
Actinopterygii	Engraulidae	*Engraulis japonicus*	17	14.3-20.6 SL	18.1	complete
Actinopterygii	Haemulidae	*Pomadasys kaakan*	5	6.5-11.3 SL	9.6	complete
Actinopterygii	Leiognathidae	*Secutor* sp.	16	4.1-12.4 SL	7.2	complete
Malacostraca	Luciferidae	Luciferidae gen. sp.	4	8.5-12.5 TL	10.4	complete
Malacostraca	Pinnotheridae	Pinnotheridae gen. sp.	1	3.8 TL	3.8	complete
Malacostraca	–	crab megalopa	1	3.1 TL	3.1	legs missing

Fishes were measured by standard length (SL); crustaceans were measured by total length (TL).

Discussion

The Russell’s oarfish has toothless protrusile jaw to suck in krill-laden water, eventually retaining its prey in the gullet (Roberts 2012). Similar to krill, the marine fish larvae’s swimming speed is low, and their size is small (Voesenek *et al.* 2018), thus allowing Russell’s oarfish to capture schools of fish larvae and crustaceans. In other words, the low-speed fish larvae and crustaceans probably are ideal potential prey for the oarfish. However, larval fish are fragile and easily digested when compared to larger prey or crustaceans with hard outer shells. Therefore, in order to better understand the diet of this little-known fish species, more freshly caught or newly dead Russell’s oarfish need to be studied in the future.

The industrial fishing of fish larvae is one of the most important inshore fisheries in northern Taiwan. Between the two major fishing methods in the inshore waters of northern Taiwan, stow nets have become more common in recent years (Lee 2004). Occasionally, fish larvae predators are caught along with their prey by a stow net.

In our investigation, the young Russell's oarfish was captured along with larval fish and crustaceans by a stow net. All the prey found in the stomach of the specimen, including larval fish and crustaceans, were intact and undigested. Based on the finding, we concluded that this young Russell’s oarfish had approached the Tamsui River mouth and was captured while feeding on large schools of fish larvae and crustaceans.

Feeney and Lea (2018) reported that krill was found in the stomach of a 4.3 m long Russell's oarfish. Oarfish were also reported to feed on small fishes (Palmer 1986). This study demonstrated that the main prey item for the young Russell's oarfish was fish larvae, comprising 86.4% of its diet by numbers while crustaceans accounted for the rest.

Oarfish primarily inhabit epipelagic and mesopelagic zones, ranging from 30 to 200 m and possibly as deep as 1600 m (Heemstra 1986; Nakabo 2002). Benfield *et al.* (2013) reported that the observation videos by ROVs showed that the giant oarfish (*Regalecus glesne*) could be found in situ at depths ranging from 38.7 to 492.7 m in the northern Gulf of Mexico. Dead or dying Russell's oarfish were usually found on the coast or beach near the deep-sea region or oceanodromous area in eastern and northeastern Taiwan. This paper is the first to report that a healthy young oarfish had approached the river mouth waters (as shallow as 15-18 meters in depth) in northwestern Taiwan to hunt its prey. Such an unusual case of predation can help with the understanding of the predation behavior of this species.

TABLE 2. Comparison of larval fish component data from this study (stomach content of young Russell's oarfish) and Wang's study (1997). The numbers denote individual numbers of each family/species.

Sampling site / taxa	Engraulidae/ *Engraulis japonicus*	Haemulidae/ *Pomadasys kaakan*	Leiognathidae spp.	Anguillidae	Clupeidae	Engraulidae (other)	Chanidae	Scorpaenidae	Teraponidae	Sillaginidae	Gerreidae	Sparidae	Mugilidae	Gobiidae	Others
Tamsui River mouth (this study)	17	5	16	–	–	–	–	–	–	–	–	–	–	–	–
% of all larval fish	44.7	13.2	42.1	–	–	–	–	–	–	–	–	–	–	–	–
Site A (Wang's study)	6857	–	161	–	31530	3308	–	56	3	240	1193	49	165	72	857
% of all larval fish	15.4	–	0.4	–	70.9	7.4	–	0.1	0.01	0.5	2.7	0.1	0.4	0.2	1.9
Site B (Wang's study)	791	–	3	–	–	2	–	261	5	5	–	–	–	41	171
% of all larval fish	61.8	–	0.2	–	–	0.2	–	20.4	0.4	0.4	–	–	–	3.2	13.4
Site C (Wang's study)	3127	–	1019	–	8394	12281	–	4	2	274	397	46	10	135	654
% of all larval fish	11.9	–	3.9	–	31.9	46.6	–	0.02	0.01	1.0	1.5	0.2	0.04	0.5	2.5
Site D (Wang's study)	–	–	104	1033	–	130	713	2	33835	2006	7164	993	3991	14007	2010
% of all larval fish	–	–	0.2	1.6	–	0.2	1.1	0.003	51.3	3.0	10.9	1.5	6.0	21.2	3.0

Among all sampling sites in Wang’s study (1997), site B is characterized by having the Japanese anchovy, *Engraulis japonicus*, as the most dominant species quantitatively (up to 61.8% of all fish individuals). The fish was not dominant at the other three sites; accounting for only 15.4% at site A, 11.9% at site C and 0% at site D (Table 2). The results showed that the Japanese anchovy are more dominant around the Tamsui River mouth waters (sites A and B) than the north bank of the River mouth (sites C and D). These findings demonstrated that the larval fish assemblages around the Tamsui River mouth and adjacent waters were closely correlated to geographic region, bottom substrate and water depth. Wang and Tzeng (1997) proposed that the differences in spatial use of sympatric clupeoid larvae might lead to the avoidance or reduction of competition for habitat, thereby maximizing resource utilization in the Tamsui River mouth.

Our present study revealed that the dominant species from site B in Wang’s study is similar to that from the stomach of the young Russell's oarfish, with the Japanese anchovy as the most dominant species in the young Russell's oarfish’s stomach content (44.7% of all fish individuals). This result suggests that if the Japanese anchovy is used as an indicator, then the feeding ground of the young oarfish would be closest to the sampling site B in Wang's study (1997).

In addition, Shih’s study (2013) uncovered that the larvae of Japanese anchovy and deep pugnose ponyfish (*Secutor ruconius*) were two of the 12 most dominant species among 78 larval fish species in the Tamsui River mouth. The fish component in our study also revealed that the region where the Japanese anchovy and ponyfish hunted by the young Russell's oarfish was around the Tamsui River mouth, near site B (Wang 1997), where the young Russell's oarfish was captured by a fishing boat. Lin (1999) proposed that the larvae of *Engraulis* appear at night in the inshore waters of northeastern Taiwan. Similarly, Shih’s study (2013) showed that the larvae of Japanese anchovy and deep pugnose ponyfish exhibited diel vertical migration behavior. They moved up to the surface layer at night, and returned to the ocean floor during the daytime.

The most dominant crustaceans in this study are luciferids (66.7% of all crustacean individuals). Five species of Luciferidae have been recorded in Taiwan (Ma 1998; Chung & Shao 2022); all belong to the genus *lucifer*. Ma (1998) reported that several *lucifer* species exhibited diel vertical migration behavior similar to the larvae of Japanese anchovy and deep pugnose ponyfish, moving up to the surface layer at nighttime in southwestern Taiwan.

The young Russell's oarfish specimen in our study was captured before dawn. According to the ecological information of the luciferids as well as those of the larvae of Japanese anchovy and deep pugnose ponyfish, we conjectured that these larval fish and crustaceans were hunted by the young Russell's oarfish around the shallow waters of the Tamsui River mouth when these prey moved up to the upper layer at nighttime. In addition, the Tamsui River mouth and its adjacent area is one of the three most important fishery ground of fish larvae in Taiwan (Wang 1997). As the river mouth is abundant in larval fishes and larval crustaceans, it probably attracted the young Russell's oarfish to approach the area.

Oarfish have been observed swimming vertically (Roberts 2012) and this particular behavior is hypothesized to be advantageous to the predators (Moyle & Cech Jr. 2004). In the present case, we speculated that it might be easier for the vertical-swimming Russell's oarfish to hunt a large number of luciferids as well as the larvae of Japanese anchovy and ponyfish assembled in the upper layer of the ocean by its particular posture or angle of view.

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