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Original Article

# Spatio-temporal distribution of sergestid shrimp *Acetes intermedius* in the coastal waters of southwestern Taiwan

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***SUMMARY:*** Spatio-temporal variation of the sergestid shrimp *Acetes intermedius* in the coastal waters of southwestern Taiwan was investigated based on 1546 samples collected by 13 commercial fishing vessels from July to October 1996. Adult sergestid shrimp started a down-estuary migration with the increased river discharge associated with heavy summer rainfall. Fishing season for this species was to commence after that. In July, the shrimp stock was found on the shallow continental shelf off Tungkang and Fangshan. They mainly aggregated in Kaoping Canyon off Tungkang during August and September occurring at very high densities. In October, the shrimp returned to the coastal waters off Tungkang and Fangshan at lower densities. The heavy rainfall is a factor that triggers the shrimps to make a down-estuary migration that could reduce competition for food between adults and their offspring during the period of high river discharge. When the northeast monsoon prevailed, the sergestid shrimp moved back to the estuaries and the fishing season was terminated.

***KEY WORDS:*** ***Acetes intermedius*, migration, shrimp, southwestern Taiwan, spatio-temporal distribution.**

## INTRODUCTION

Shrimps of the genus *Acetes* are small planktonic shrimps which are widely distributed in the tropical, subtropical and temperate estuaries and coastal waters.[1] There are extensive data on the spatio-temporal distribution of *Acetes*, but migration between different habitats is poorly studied. Wintering and/or spawning migrations have been identified for only two of 14 species.[2] On the other hand, the *Acetes* fisheries are the largest zooplankton-based fisheries in the world. However, their fishery biology was little known except for a few systematic studies on *A. chinensis*.[2]

Sergestid shrimp *Acetes intermedius* can be found along the estuaries and coast of Taiwan Strait,[3] and is one of the most important commercial shrimp resources in southwestern Taiwan. Local fishermen in Taiwan have exploited this species, using boat seine in estuary for more than 40 years. The species can be caught in the estuary all year round, the annual catch being about 1000 tonnes in the Tungkang area, Taiwan before the mid-70s.[1] However, after 1990, Tungkang fishermen trawled this species when the shrimp migrated down-estuary to deeper waters during June and October. The annual catch has increased to 2000–2500 tonnes since then. However, the catches dramatically decreased from 1996 to 1998.

*Acetes intermedius* exhibits a nocturnal vertical migration pattern,[4,5] gathering near the water surface (0–10 m depth) during the night when fishermen in Linyuan, Taiwan use large skimming nets to catch them. *Acetes intermedius* migrates to deeper than 25 m, where fishermen in Tungkang use mid-water trawls to catch them. Many *Acetes* species move vertically in the water column in association with diurnal cycles for various purposes including ontogenetic migration in *A. seerulatus*,[3] and population maintenance in estuary habitats of *A. sibogae*.[6] The latter species further demonstrates a response to light intensity cycles, undertaking nocturnal vertical migration in order to avoid predators.[3] Such vertical migration might be affected by multiple environmental factors, which may vary among species. Even in the same species, the factors regulating migration pattern may differ in different geographical environments.[7]

This species is the prey of many fishes and big shrimp e.g. *Penaeus monodon*,[8] hence this species plays a key role

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in the food web of coastal waters in southwestern Taiwan waters. Annual catch of this species increased 2–2.5-fold in recent years. If the catch and efforts are not regulated in the near future, this stock might dramatically drop to low level. Although some information on *A. intermedius* has been documented, including the variations in catch in relation to lunar phase and weather[4] and the biology of this species,[5,9] many facets of the stock characteristics and the relevant environment in the coastal waters of southwestern Taiwan have not been studied. Hence, the present study aims to provide data on fisheries biology including catch statistic, fluctuation of fishing period and spatio-temporal variation of population density of *A. intermedius*, for management purposes.

## MATERIALS AND METHODS

Daily catch of *A. intermedius* and fishing effort data (number of fishing boats in operation) were collected from the Sergestid Shrimp Production and Marketing Union in Tungkang, Taiwan from 1995 to 1998. Fishing position (Fig. 1), catching depth, time and catch were collected from 13 local fishermen during the fishing season of 1996. In order to determine the center of the fishing grounds, the fishing area was subdivided into 61 equal quadrats of 4 square nautical miles (Fig. 1). Water depth and the catching depth were read from a color echo sounder. Fishing position was determined according to the navigation fix. The amount of catch was recorded based on the number of 16.5 kg shrimp cases obtained. A total of 1546 hauls were analyzed during the fishing season of 1996.

In total, 988 of 1546 hauls by 13 vessels were collected during the main fishing season in September when 28 days of fishing operations were conducted (Table 1). Vertical migration of shrimp was determined by hourly measurement of catching depths for shrimp each day, using an echo sounder. A weighted mean depth of shrimp catching (*WMD* in m) was estimated for each hour in each day from the following equation:

$$WMD = \Sigma(D \times F)/\Sigma F,$$

where $D$ is a depth (m) of the upper edge of shrimp patch and $F$ is density (CPUE, case/haul per h) at such a patch. The height of shrimp patch varied with CPUE ranged between 2 m and 12 m.

The fishing ground was partitioned into two zones according to the geographical location and water depth: zone I is in the area of the Kaoping Canyon, with depth ranges of 80–300 m, while zone II is in the vicinity of Kaoping Canyon and Fangshan Canyon, with a depth range of 40–80 m.

Because *A. intermedius* is prey for fish and other large

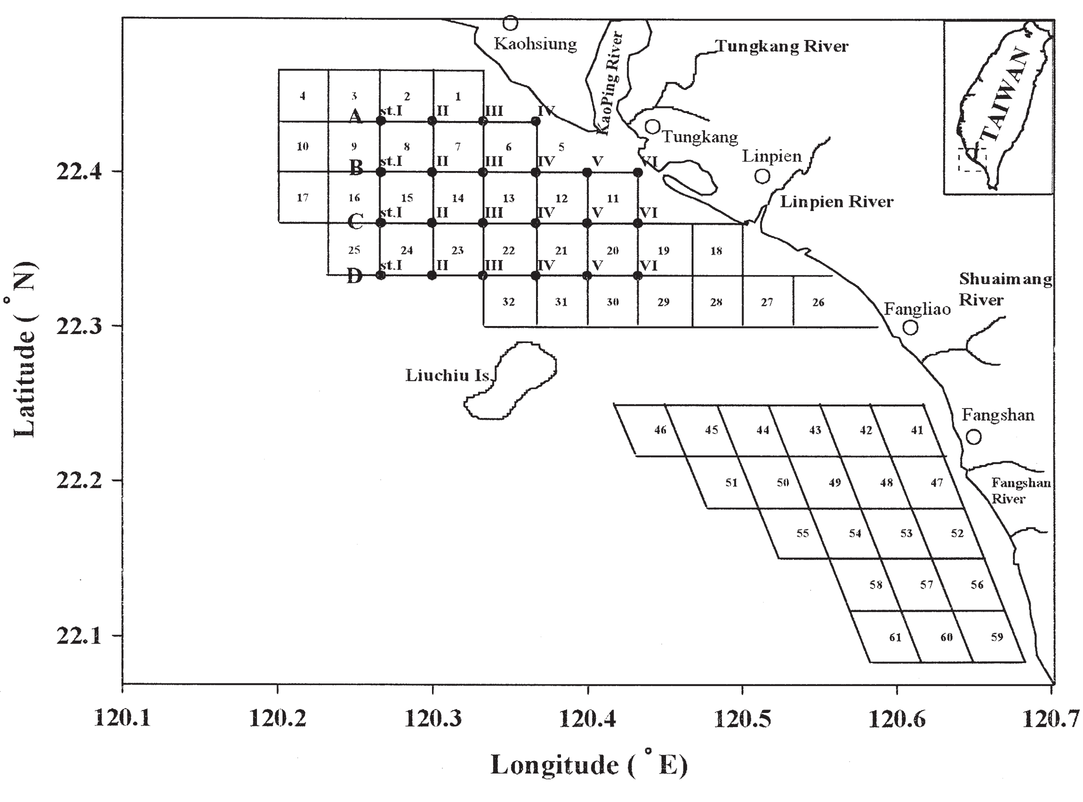


**Fig. 1** Survey regions, fishing quadrat and stations of the oceanographic condition in the coastal waters of southwestern Taiwan. Letters represent the observation lines. (●) Observation station, Numerals: fishing quadrat number.

**Table 1** Vertical migration patterns of *Acetes intermedius* investigated in the surroundings of the Kaoping Canyon by the fishing data of fishermen off Tungkang in September 1996

| Date | Pattern | RWMD (m) | RCD (m) | GSR ($MJ/m^2$) | DS (h) | Weather |
|---|---|---|---|---|---|---|
| 1 | a | 38–60 | 25–60 | 15.30 | 10.00 | S |
| 2 | a | 35–51 | 30–80 | 8.10 | 5.10 | S-C |
| 3 | b | 35–64 | 30–80 | 7.25 | 2.75 | S-R |
| 4 | b | 50–55 | 35–70 | 12.30 | 6.30 | S |
| 5 | b | 57–65 | 40–100 | 11.30 | 5.75 | S-R |
| 6 | b | 62–66 | 45–70 | 6.25 | 1.80 | C |
| 7 | a | 35–65 | 45–65 | 15.40 | 10.45 | S |
| 8 | d* | 42–53 | 40–60 | 8.40 | 2.20 | C-R |
| 9 | a | 30–38 | 25–40 | 10.15 | 6.85 | S |
| 10 | a | 45–70 | 35–70 | 13.85 | 9.25 | S |
| 11 | a | 50–60 | 42–70 | 12.70 | 7.70 | S |
| 12 | a | 47–64 | 40–80 | 13.10 | 6.65 | S |
| 13 | a | 46–65 | 35–100 | 12.85 | 7.85 | S |
| 14 | b | 54–58 | 40–70 | 13.00 | 9.35 | S |
| 15 | a | 39–53 | 25–80 | 13.30 | 8.45 | S |
| 16 | a | 41–65 | 35–100 | 14.20 | 9.00 | S |
| 17 | a | 39–72 | 30–80 | 10.05 | 4.70 | C-S |
| 18 | a | 42–70 | 30–75 | 14.20 | 9.85 | S |
| 19 | a | 42–65 | 30–80 | 14.25 | 9.80 | S |
| 20 | b | 43–60 | 35–80 | 14.70 | 10.65 | S |
| 21 | a | 35–53 | 25–70 | 12.65 | 7.00 | S |
| 22 | a | 37–51 | 25–90 | 10.75 | 5.80 | S |
| 23 | a | 40–63 | 30–70 | 10.10 | 4.50 | C |
| 24 | a | 37–53 | 25–70 | 7.65 | 2.95 | R-C |
| 25 | b | 38–63 | 25–70 | 10.90 | 5.30 | S |
| 26 | b | 49–64 | 40–80 | 12.10 | 7.40 | S |
| 29 | a | 40–67 | 35–70 | 7.80 | 4.55 | C |
| 30 | a | 41–63 | 30–80 | 12.60 | 7.70 | S |

RWMD: range of the weighted mean depth of shrimp patching; RCD: the greatest range of catching depth; GSR: global solar radiation ($MJ/m^2$); DS: duration of sunshine (h); S: sunny, C: cloudy, R: rainy. Pattern d is an irregular vertical movement.

Pattern refers to Fig. 4a and 4b.

shrimps,[2,8,10] the abundance of predators should be estimated in order to determine prey–predator relationships by appropriate sampling of both parameters.

Surveys of oceanographic conditions in the vicinity of Tungkang (Fig. 1) were conducted in May, July, September and October of 1997. Water temperature and salinity were measured at each station at depths of 0, 10, 20, 30 and 50 m.

Daily precipitation and mean river discharge were recorded from the database of Water Resources Bureau, Ministry of Economic Affairs, Taiwan (1994–1998). The offshore meteorological informations were collected from the Fishery Broadcasting Station, Taiwan Area (1998).

## RESULTS

### Catch composition

The overall catch composition of sergestid shrimp off Tungkang was estimated from two sources: samples from eight *in situ* samplings and 114 records of fishing vessels. The catch of cod nets were overwhelmingly composed of *A. intermedius* (99.6%) with fish larvae and other small-sized organisms comprising the remainder of the catch (0.4%). Main catches of other cod nets included *Trichiurus lepturus*, *Leiognathus bindus*, myctophids, and a few large shrimp such as *Parapenaeopsis*, with the sergestid categorized as a by-catch. From 98 hauls of trawlings from zones II during July and September 1997, average catches of sergestid in each haul weighed 11.7 kg, which was equivalent to 6.7% of the total catch. In zone I, no by-catch was recorded in 16 hauls.

The *A. intermedius* specimens caught by mid-water trawlers ranged from 2.68 mm to 9.47 mm in carapace length, but were mostly larger than 3.90 mm.

The by-catch of the sergestid fishery included mainly *Trichiurus lepturus*, *Leiognathus bindus*, and myctophids. The stomach contents from 41 specimens overwhelming contained *A. intermedius*, which was recognized as a main food source for the fishes living in the continental shelf waters of Tungkang.

**The fishing ground**

The catch distribution of *A. intermedius* made by 13 sampling vessels indicated that the fishing grounds were located in the upper half of the Kaoping Canyon (fishing quadrats 21, 12, 13 and 22) and its adjoining areas, as well as the continental shelf areas adjacent to Fangshan Canyon (fishing quadrats 50, 43, 42, 48 and 53) (Fig. 2). The main fishing ground was on the slope of Kaoping Canyon where depth varied from 80 to 300 m. Other fishing grounds were on the continental shelf where the depth was between 40 and 80 m.

In the continental shelf areas, *A. intermedius* were caught near the seabed (mainly 40–65 m), while in the Kaoping Canyon they were caught between 25 and 100 m (mainly 30–70 m).

**Spatio-temporal variation of catch**

The monthly variations of catch in the 61 surveyed quadrats of sergestid shrimp fishing ground is shown in Fig. 3. It was also made by 13 sampling vessels. In July 1996, the beginning of fishing season, shrimp stock was found in the shallow continental shelf off Tungkang and Fangshan, the catch being less than 2.00 tonnes. Subsequently, the shrimp stock moved to the upper half of the Kaoping Canyon and adjacent areas with higher catches occurring in August. The shrimp stock spread out continuously from coast off Tungkang to inshore, but mainly aggregated in Kaoping Canyon with the highest catch (58.38 tonnes) in September. The stock then gradually retreated back to shallower coastal waters in October and distributed off Tungkang and Fangshan again. Catches dramatically decreased less than 4.91 tonnes in October.

**Vertical migration patterns of *A. intermedius* in zone I and zone II**

In the Kaoping Canyon, the species usually performs a diurnal vertical migration from the surface area down to the middle water layer (60–70 m) during the day. The selected example (Fig. 4a) shows the species descending gradually from 06:00 to 09:00 h, reaching a peak depth at 11:00–13:00 h, when the shrimp ascend. In the present study, the swarming depth of this species during the day (06:00 to 15:00 h) ranged from 25 to 100 m, and mainly between 35 and 70 m.

This pattern may change from time to time; the

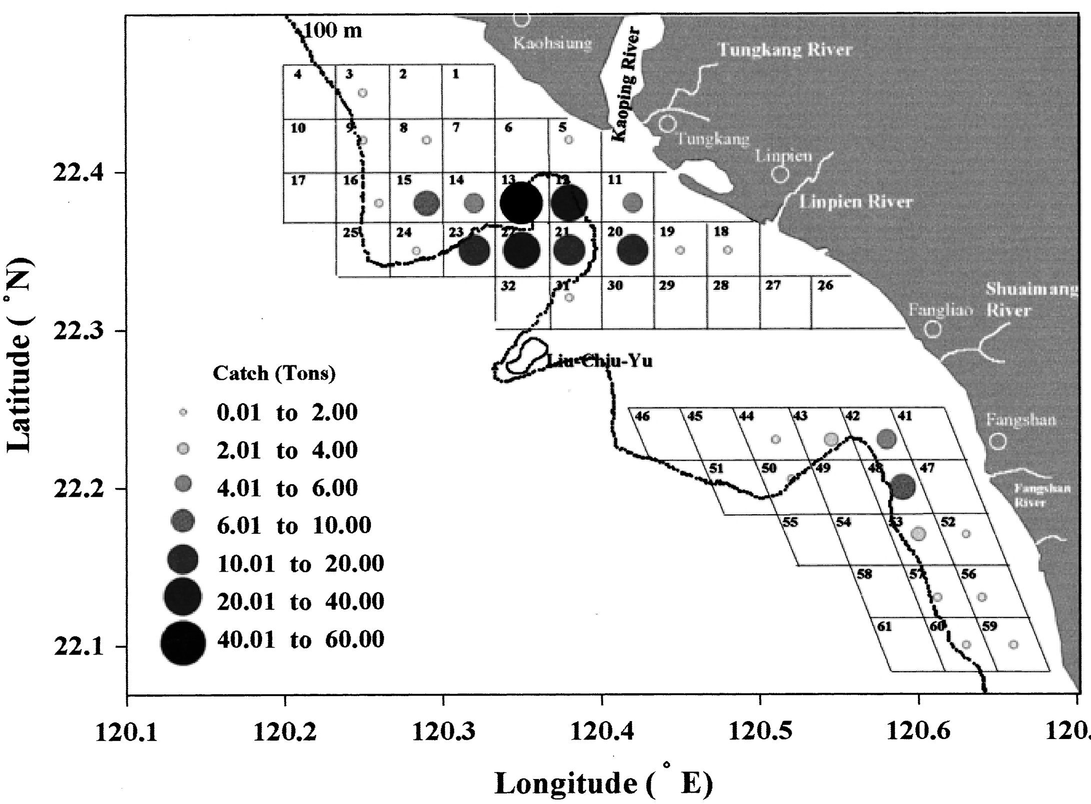


**Fig. 2** Distribution of density index at each fishing quadrat for the Tungkang sergestid shrimp trawl fishery in 1996.

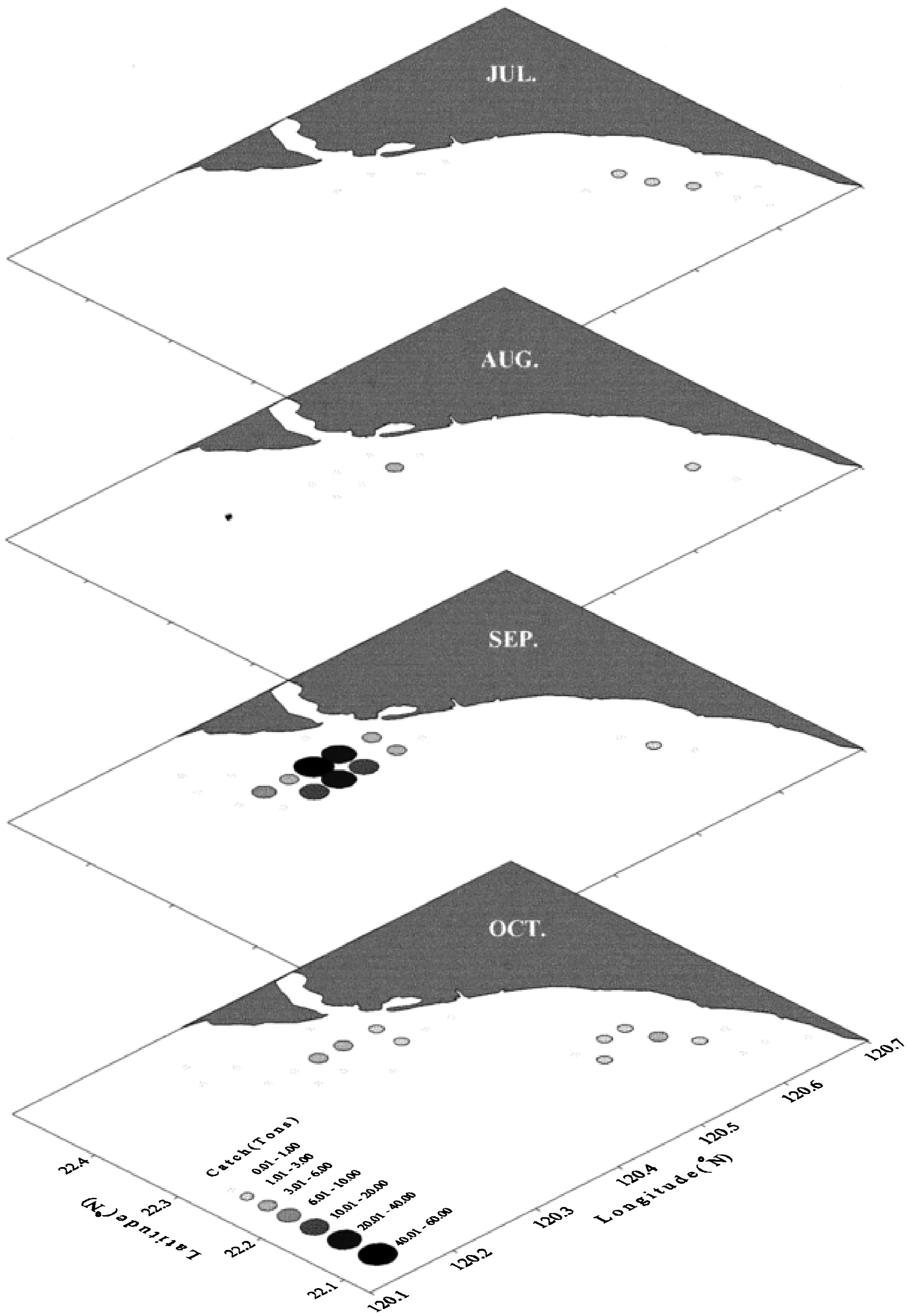


**Fig. 3** Catch distribution of sergestid shrimp in the coastal waters off southwestern Taiwan during July and October in 1996.

shrimp school may rest at 45–68 m in the early morning until dusk when the shrimp resume their ascending movement toward the surface (Fig. 4b).

A slight alteration of diurnal patterns of shrimps would be expected in shallower waters of zones II (40–80 m) than zone I (80–300 m). The results of numerous schooling from the zones II indicated that the shrimp mainly concentrate on the bottom during the day (06:00–16:00 h) (Fig. 4c), followed by a gradual ascent toward the surface until dawn.

### The variation of fishing season

The fluctuation of monthly catch from 1995 to 1998 showed that the fishing period largely ranged from June to October (Fig. 5b). It coincided with the time when the river discharge was greater in southwest Taiwan (Fig. 5a). The monthly change in CPUE (kg/boat per day) (Fig. 5c) and catch further indicated that the fishing season peaked in September when the fishing condition was most favorable, coinciding with the largest mass and the largest mean CPUE (kg/boat per day) as shown in Fig. 5. The fishing condition became worse by October, resulting in a decline of the CPUE value. Hence, September was shown to be the main fishing season.

The beginning or termination of fishing season largely varied year by year, the fishing period not being as consistent as shown in Table 2. The earliest and the latest start to the fishing period were 21 May 1995 and 14 July 1997, respectively. The fishing season usually terminated on the last day of October, but in 1998 it occurred on 6 September.

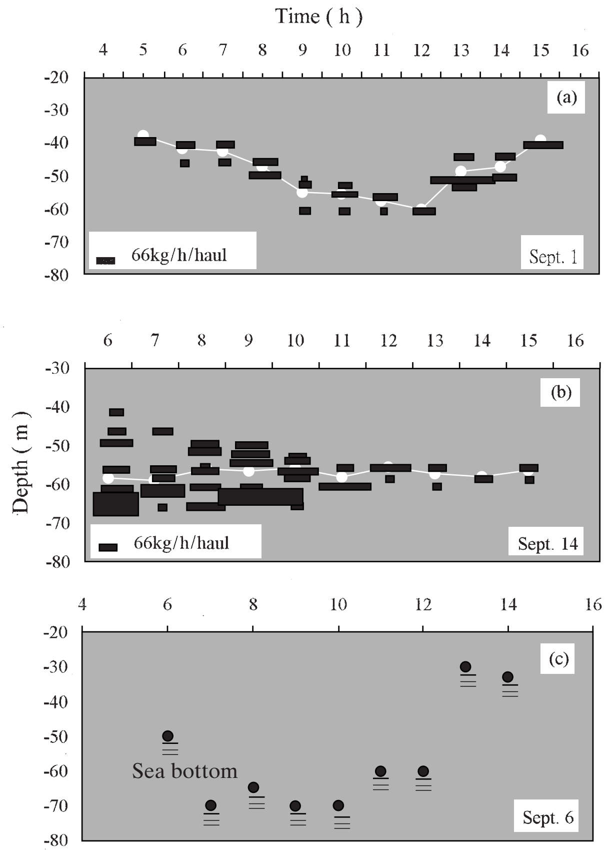


**Fig. 4** Selected examples showing the vertical distribution for *Acetes intermedius* in the waters of Kaoping Canyon (a, b) and in the shallower continental shelf waters (c), detected with fish finder of fishing boats in September 1996. (○) The weighted mean patching depths (a,b) and (●) patching depth (c).

### Relationship between daily heavy precipitation and the *A. intermedius* catch

The beginning of the fishing season was defined as when mean CPUE is greater than 250 kg/boat per day and continued over three successive days with more than 15 boats involved. It was found that fishing season always began within 2 weeks of the first heavy rainy day (precipitation larger than 130 mm/day), based on the data of 1994–1998 (Fig. 6; Table 2). Furthermore, the majority of *A. intermedius* catches in the studied area were made during the rainy season (Fig. 5a).

### Horizontal dispersion of river plume off Tungkang

The monthly distribution of temperature and salinity near Tungkang are shown in Fig. 7 and Fig. 8, respectively. Figure 7 indicated that the river plume mainly flowed in a southwest direction (along the Kaoping Canyon) offshore and its regime (less than 33‰) expanded gradually from July to September. The dispersion area of the river plume mainly covered continental

**Table 2** Some quantity and quality data of the Tungkang sergestid shrimp trawl fishery

| Year | Annual catch (tonnes) | Fishing period (days) /operational days[a] | Date: First fishing | Date: Terminal fishing | Date: Heavy rainfall[b] | Days from the heavy rainfall to the first fishing date |
|---|---|---|---|---|---|---|
| 1994 | 215.0 | 144/unknown | 10 June | 31 October | 1 June | 9 |
| 1995 | 2416.3 | 165/120 | 21 May | 31 October | 18 May | 3 |
| 1996 | 941.4 | 62/89 | 3 July | 28 October | 22 June | 11 |
| 1997 | 518.5 | 91/41 | 14 July | 16 October | 1 July | 13 |
| 1998 | 1221.7 | 64/40 | 17 June | 6 September | 4 June | 13 |

[a] Operational days: fishermen of the Tungkang sergestid shrimp trawl fishery generally stop their operation when the CPUE was very low or the weather was bad.
[b] >130 mm/day.

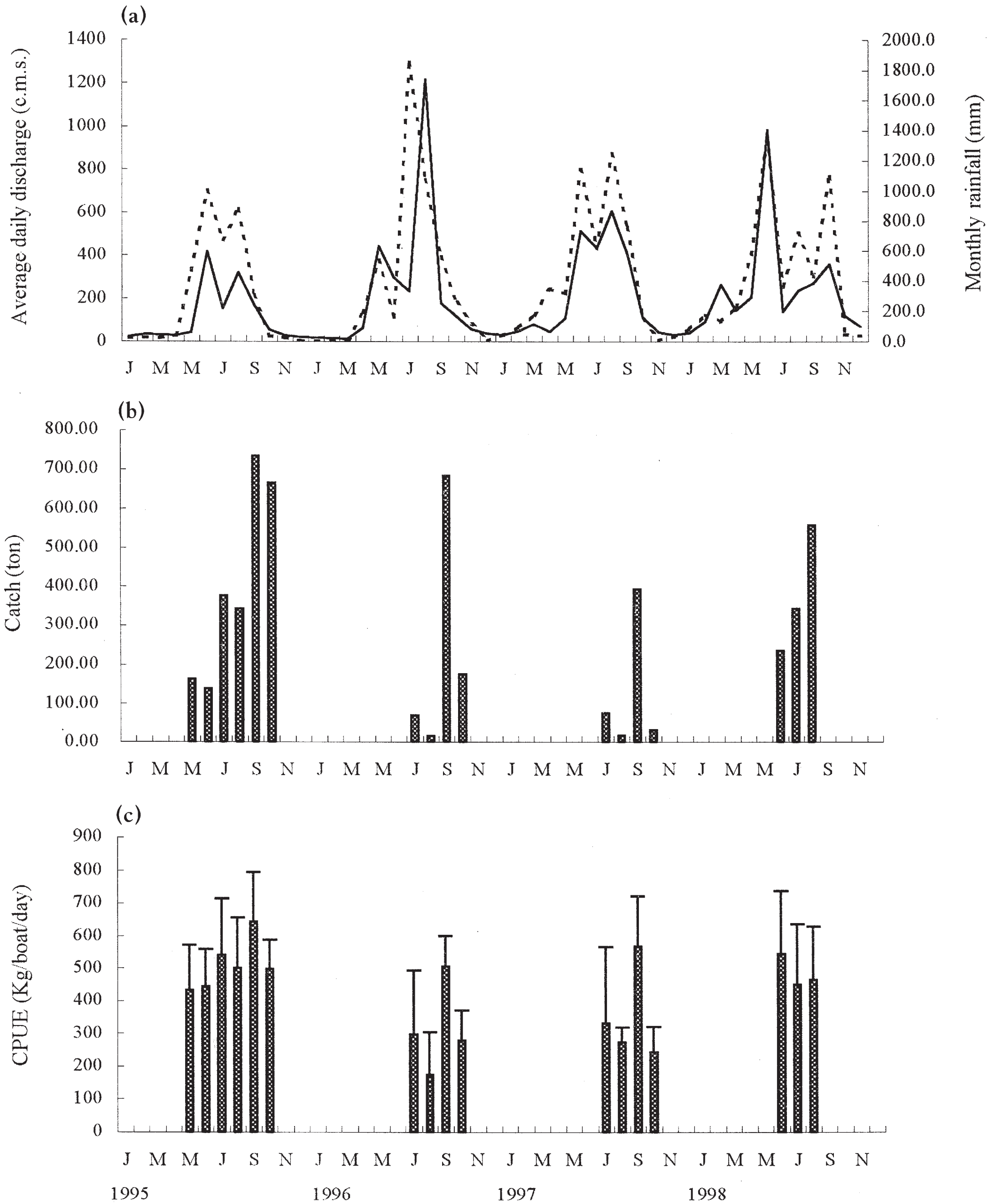


**Fig. 5** Monthly distribution of (a) average discharge and rainfall (—, Kaoping River; ----, rainfall), (b) total catch and (c) CPUE (mean ± SD) of sergestid shrimp trawl fishery in southwestern Taiwan. The fishing operation was stopped in August of 1996 by the spillage of crude oil.

shelf waters within 4 nautical miles off the coast in July but the range was greater than 8 nautical miles in September. By October, the river discharge was greatly decreased and the dispersion area was reduced gradually during the following months. The vertical distribution of temperature and salinity showed a conspicuous stratified phenomenon in the continental shelf waters, but also that a colder water mass was uplifted from deeper waters at D4 and C4 stations (Fig. 8).

## DISCUSSION

In summer when the southwest monsoon prevails and river discharge is greatest, the stock of *A. intermedius* migrate from estuaries to deeper offshore waters and perform a diurnal vertical migration in coastal waters, fishing commences in southwestern Taiwanese waters. The beginning of this fishery changed obviously year by year, although it always began within 2 weeks of the first

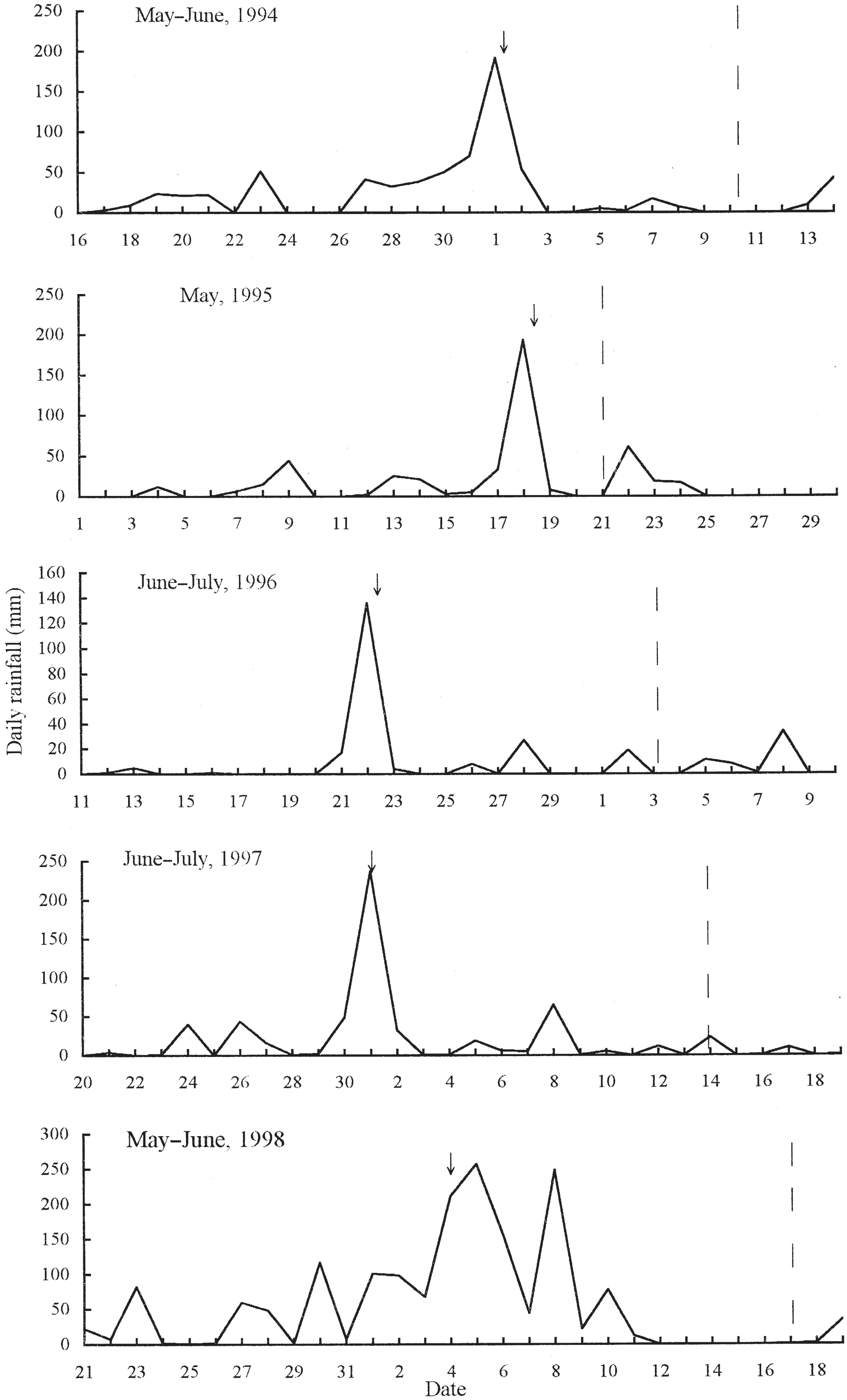


**Fig. 6** The relationship between heavy rainfall date and the first fishing date, 1994–1998. The arrow represents the heavy rainfall date; the vertical broken bar is the first fishing date. Location of rainfall station is 22°36′29″N 120°41′13″E.

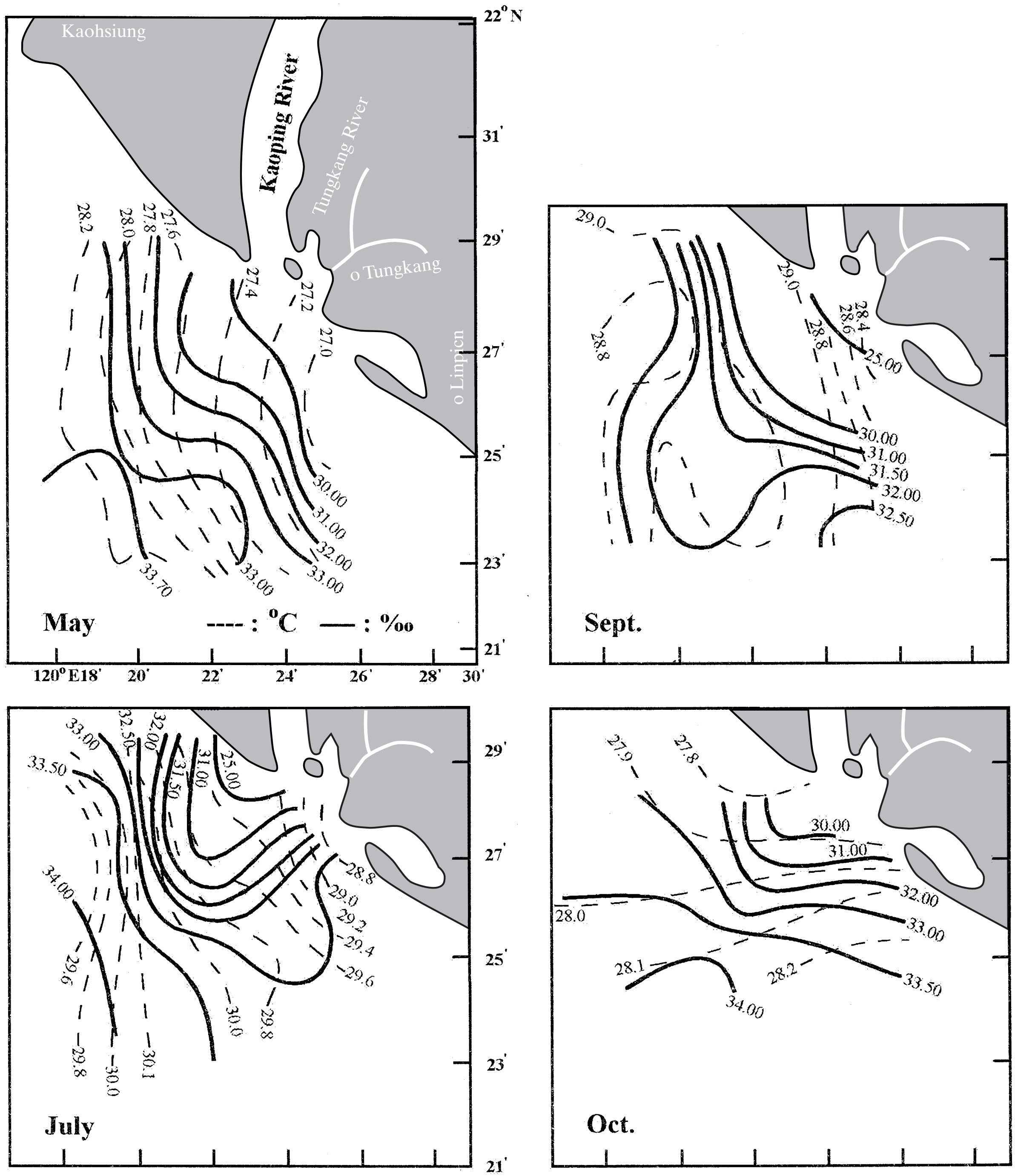


**Fig. 7** Surface dispersions of river discharge near Tungkang from May to October in 1997.

heavy rainy day. This phenomenon caused *A. intermedius* to start moving from the estuaries to the adjacent sea when the rain monsoon came in southwestern Taiwan. Hence, the heavy rainfall is a sign stimulus for *A. intermedius*, which triggers migration offshore. Our results suggest the theory that the migration of *Acetes* is mainly induced by rainfall and/or direction and intensity of wind in subtropical and/or tropical species, but by changes in water temperature and food availability for temperate species such as *A. japonicus* or *A. chinensis*.[2]

During the southwest monsoon season (May to October), the net movement of tidal current flows is toward the northeast,[11] a shoreward current in the coastal waters of southwestern Taiwan. Because *A. intermedius* is a weak swimming organism, their migration from estuaries to the adjacent sea during this period

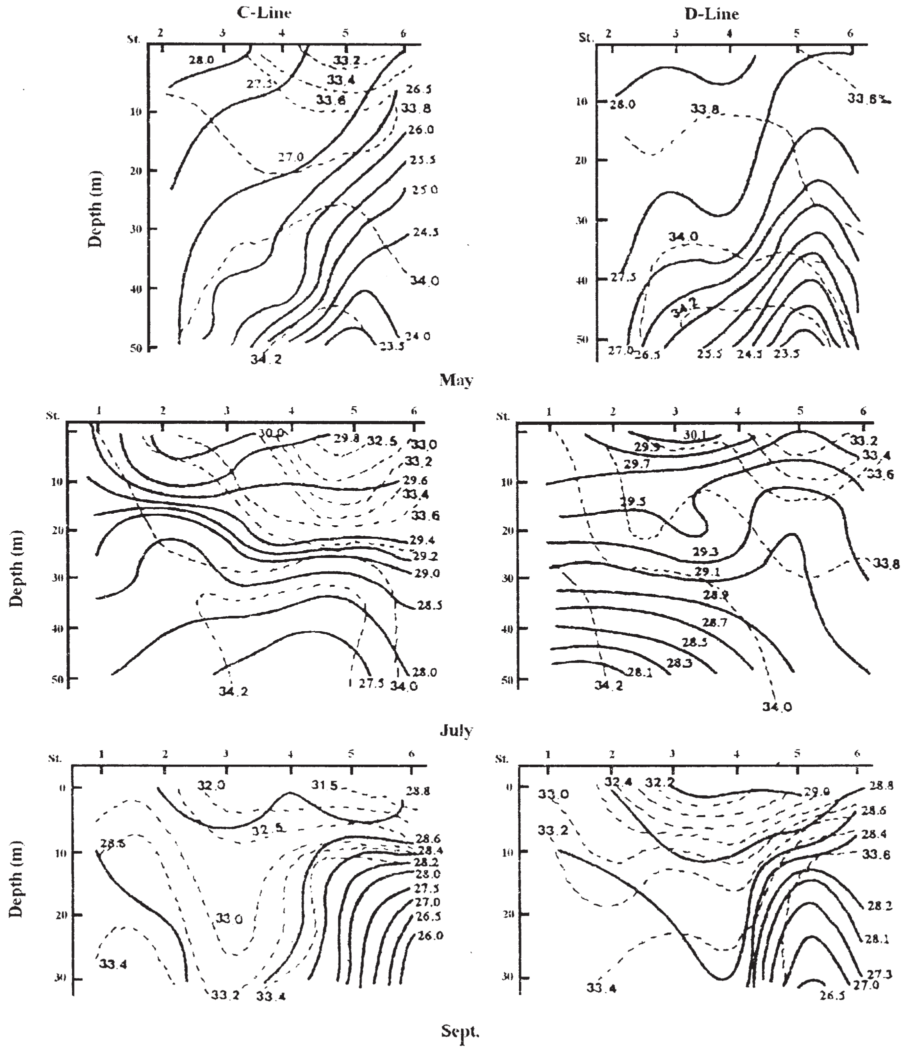


**Fig. 8** Vertical distribution of water temperature and salinity at the oceanic survey lines of C and D off Tungkang in 1997.

could protect them from drift out by current. Following this in November, the northeast monsoon prevailed, and the wind produced an offshoreward current. A colder coastal water mass developed in southwestern Taiwan near Kaohsiung.[12] These conditions were determinants for *A. intermedius* danger causing individuals to return to the estuaries. Consequently, the fishing season generally terminated in October. During the 1998 fishing season, according to the offshore fishery meteorological information (off Tungkang), the northeast monsoon was unusual, commencing in September and resulting in the fishing season of *A. intermedius* terminating on 6 September. The fishing period of *Acetes* coinciding with monsoon shoreward wind currents is also found in various coastal areas of the Indo-West Pacific.[1]

Of Kaoping, Tungkang, Linpien, Shuaimang, Fangshan and Fengkang , the Kaoping River is the largest of six rivers situated along the southwestern Taiwan. There are two main fishing grounds, one located in the upper half of the Kaoping Canyon and adjacent areas, the second being the adjoining continental shelf areas of Fangshan Canyon. The former is off the composite estuaries of Kaoping and Tungkang Rivers and the latter off the estuary of Fangshan River. *Acetes intermedius* prefer the steeper submarine Kaoping Canyon and adjoining areas over the Fangshan Canyon.

The monthly distribution of catches (Fig. 3) and river plume (Fig. 7) indicated that the migration of *A. intermedius* does not exceed the dispersion range of the river plume. With an increase of river discharge during August and September, the range of river water covering the Kaoping Canyon increased gradually. Consequently, the fishing of this shrimp moved to the waters of Kaoping Canyon and adjoining areas, where the population density was very high. Evidently, *A. intermedius* mainly swarms on the slope of Kaoping Canyon for a number of reasons. First, the nutrient-laden waters from Kaoping and Tungkang Rivers flow to the waters of Kaoping

Canyon where nutrient-enriched deeper waters will also be drawn up to the surface.[13] The low transparency waters provide adequate conditions for zooplankton, which in turn serve as the main prey for *A. intermedius*. However, this species can also migrate downward to deep water layers to avoid predation during the day. In short, the canyon provides *A. intermedius* with abundant food and a safe environment. Second, the inshore movement of cold water masses from offshore and the subsequent mixing process in coastal waters were favorable for swarming of euphausiids.[14] Although the coastal waters in southwestern Taiwan are covered with warm water mass during May and October when the oceanic front was not developed, the effect of the colder water mass being uplifted to the surface layer in Kaoping Canyon[13] is similar to the above oceanic conditions. This may provide favorable conditions for swarming of *A. intermedius*. Third, there is an increased migration for the population into deeper waters offshore with the start of fishing season. These factors result in the waters of Kaoping Canyon supporting high densities during August and September.

Organisms which undertake extensive migration must do so for some purpose. Some species of *Acetes* migrate between different habitats in order to complete their life cycles, for example, *A. japonicus* for spawning and *A. chinensis* for feeding and spawning.[2] However, *A. intermedius* moved from the estuaries to the adjacent sea during periods of high river discharge. We suggest that the purpose of this movement is to reduce competition for food between adults and their offspring, as has been found with some fish species,[15] for the following reasons. The abundance of zooplankton is far richer in estuaries than offshore and predators are relatively scarce here. It is not therefore necessary for *A. intermedius* to migrate offshore to feed. *Acetes intermedius* can also spawn in the innermost part of the estuary where the salinities ranged between 25 and 30‰ all year.[5,9] The salinities of 30.40–34.20‰ in the vicinity of Kaoping Canyon are not suitable for spawning. This is substantiated by the fact that no sexually mature shrimps were collected by the sampling ships,[5] although the catches of *A. intermedius* during May and October are mainly comprised of the adult shrimps. Lastly, according to the monthly frequency distributions, approaching maturity in carapace length of *A. intermedius*[5] indicates that recruited young shrimps start to appear in the estuaries in May and July.

Migration patterns and migration ranges vary with the developmental stage of vertical migrators such as euphausiids.[16,17] It is known that the sizes of shrimp trawled depend on the mesh size used. For instance, commercial nets (mesh size 9.6 mm) can retain shrimp mostly (92%) larger than 3.90 mm in carapace length (CL), while larval fish nets (0.33 mm mesh net) can trap 80% of 3.7 mm- and 20% of 2.0–3.6 mm-sized shrimps.[5] Female shrimps spawning in the innermost part of the estuary[9] have a CL at first maturity estimated at 3.90 mm.[5] After spawning, individuals of *A. intermedius*, consisting almost entirely of adult shrimps leave the estuary, moving offshore during the fishing period. Hence, the migratory patterns observed by fishermen might not include all stages of the life history.

Predator avoidance, light, and foraging strategy have been widely used to explain the occurrence of diurnal vertical migration of zooplankton.[18–23] Their order of magnitude importance varies among species and the interactions between these factors and zooplankton behavior have not been completely characterized. The stomach contents of the sampled by-catch indicated that *A. intermedius* served as a food resource for fishes of the shallow continental shelf (zone II), while the predators of these fishes were not found in the waters of Kaoping Canyon (zone I). Shrimp schools of *A. intermedius* in zone I performed a typical diurnal vertical migration pattern (Fig. 4a) with slow up-and-down movements as they retreated to the middle water layer during the day. This pattern is quite similar to that in adult euphausiids under the influence of light intensity.[21] Similar results were noted in the closely related *A. sibogae*.[24] During vertical migration, shrimps aim to find a water layer with optimal light intensity. However, *A. intermedius* in the shallower zone II made a sudden descent to the bottom before sunrise; this can be associated with the predator avoidance hypothesis reducing predation risk during the daytime. A similar case occurred in zone I, where the scattered fish predators might stimulate *A. intermedius* to undergo a sudden escape response. In spite of their efforts to find optimal light intensities, the shrimp tend to make a quick retreat to darkness to avoid predators.

The El-Niño Southern Oscillation (ENSO) episodes could affect the coastal fish stocks and fisheries such as larval anchovy and oceanic bonito,[25,12] because the oceanographic, meteorological and hydrological conditions in the coastal waters of southwestern Taiwan are affected by ENSO episodes.[26] During the El-Niño event that occurred in 1997, the sea surface temperature increased 4°C on the southwestern coast of Taiwan from April,[27] and the annual yield of *A. intermedius* was simultaneously dramatically decreased to a quarter of that of a normal year. Evidently, the stock was also affected by the El-Niño event resulting in a much reduced catch. For the management of *A. intermedius*, an understanding of the relationship between the fluctuation of the stock abundance and El-Niño events is necessary.

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