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SEASONAL AND DIEL CHANGES OF THE FISH ASSEMBLAGE EMPLOYING THE FYKE NETS IN A SUBTROPICAL MANGROVE ESTUARY OF PUZIH RIVER, TAIWAN

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Key words: fish assemblages, mangrove, Taiwan.

ABSTRACT

Fish utilization of an *Avicennia marina* mangrove forest in the estuary of Puzih River, in Chiayi County, Taiwan, was investigated based on quarterly sampling surveys in 2008. Fishes were sampled during four ebbing tides on two consecutive days using fyke nets. A total of 1375 individuals weighting 19.2 kg were caught, belonging to 23 families and 37 species. The fish community was dominated by juvenile individuals of estuarine transient species and exhibited significant seasonal variations. The most numerous species were the spotted catfish (*Arius maculatus*, representing 40% of the total biomass) and the shortnose ponyfish (*Leiognathus brevirostris*, representing 33% of the total numbers). Habitat utilization by fish in the mangroves was significantly affected by time of year, but no significant effects of diel periodicity were found. The results confirmed the role of mangroves in the Puzih River estuary as a nursery habitat for nearshore fish.

I. INTRODUCTION

Estuaries are located on the interface between freshwater and sea, and supply various types of intertidal and subtidal environments such as mangroves, salt marshes, tidal creeks and tidal flats for different fish communities. These habitats are recognized worldwide as highly productive areas and play an important role as nurseries or feeding sites for fishes, thus providing a key argument for estuary conservation in general (Boesch and Turner, 1984; Paterson and Whitfield, 2000; Veiga et al., 2006; Maci and Basset, 2009). Mangroves are one such important habitat in estuaries for fish in which larval and juvenile fish take advantages of available food resources and low predation pressure (Boesch and Turner, 1984; Robertson and Duke, 1987; Tzeng and Wang, 1992; Lugendo et al., 2006; Crona and Rönnbäck, 2007).

Seasonal changes in fish community structure in mangroves were generally considered to be affected by factors such as salinity, temperature, turbidity, water depth, and vegetation in the environments (Bell et al., 1984; Kuo et al., 1999; Rozas and Zimmerman, 2000; Tzeng et al., 2002; Huxham et al., 2004; Crona and Rönnbäck, 2007). Several studies on fish communities in estuaries in Taiwan were also concerned of seasonal dynamics of fish assemblages (Kuo et al., 1999; Lin and Shao, 1999; Kuo et al., 2001). Additionally, fish assemblage structures might also be affected by the diel periods (Livingston, 1976; Allen et al., 1983), but reports on fish communites from mangrove habitats are scarce and variable. For instance, Allen et al. (1983) found that fish abundance was greater during day-time catches, whereas Lin and Shao (1999) found the opposite was true. On the other hand, Rooker and Dennis (1991) found no significant evidence for diel changes in fish community structure. How and if the fish assemblages in mangroves are affected by the diel changes remain unclear, but a multitude of factors such as predation pressure, prey density, and abiotic conditions were thought to influence the diel patterns (Nash and Santos, 1998; Kuo and Shao, 1999; Lin and Shao, 1999; Ikejima et al., 2003; Crona and Rönnbäck, 2007). A full recognition of the diel periodicity in fish recruitment is crucial in understanding the niche requirements of fish species in the estuarine area, which, in turn, is necessary to understand the fish assemblage dynamics as well as providing perceptions into mangrove conservation.

The general objective of the present study is to describe the fish community structure in a mangrove forest of Puzih River estuary in subtropical Taiwan with emphasis on seasonal and diel variations. As this river has never been studied before, the results can contribute to our understanding of the distribution

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Table 1. Mean and standard deviations (in parentheses) of environmental conditions in the Puzih River estuary in 4 sampling months in 2008.

Environmental variables	January	April	August	October
Water temperature (°C)	17.6 (0.7)	23.9 (0.3)	28.6 (0.6)	26.5 (0.7)
Salinity (PSU)	29.0 (3.2)	22.5 (2.1)	16.0 (2.6)	17.7 (1.3)
Dissolved oxygen (mg/L)	8.5 (0.4)	5.4 (0.5)	5.8 (0.2)	6.1 (0.6)
Precipitation (mm)	17.5	19.5	132.5	93.5

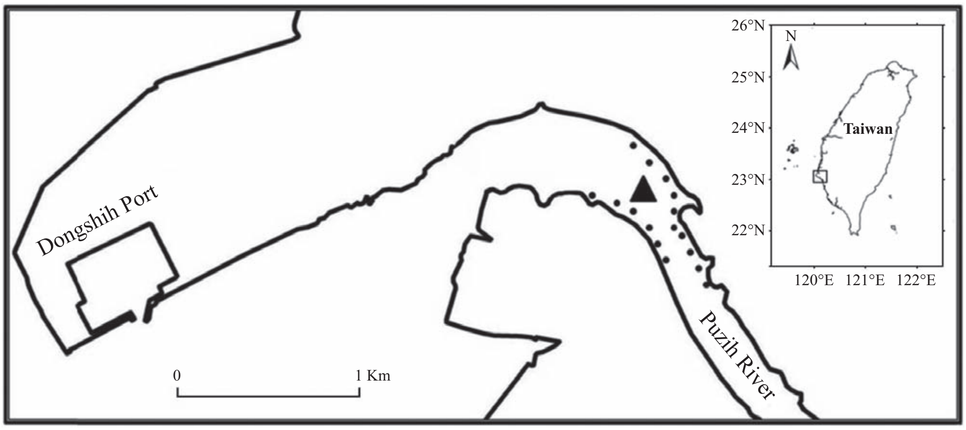

Fig. 1. Map showing the location of the study site (filled triangle) in the Puzih River estuary, Taiwan. Dotted areas indicate the distribution of mangrove forests.

pattern of fish fauna in the coastal region of Taiwan.

II. MATERIALS AND METHODS

1. Study Site and Environmental Conditions

The estuarine mangrove swamp of Puzih River is in Chiayi county in southwestern Taiwan (N 23° 26' 39'', E 120° 08' 27'') (Fig. 1). Puzih River is 76-km long, running southwest from Mt. Ali, with an average slope of less than 2%. It receives household sewage and industrial wastewater from Chiayi County, and is considered one of the most polluted rivers in Taiwan (Suen and Hung, 2013). The substrate of the estuary is mainly mudflat sediment and about 10 ha of the riverbank area on both sides of the river, stretching about 2 km long, is covered by the endangered mangrove species *Avicennia marina*.

The estuary is well-influenced by tidal currents, with a tidal elevation ranged from 0.5 m to 2 m. The study site has a long dry period (October to May) and a short rainy season (June to September) with monthly precipitation ranged from 10 mm in February and December to 581 mm in June (Dongshih Weather Station, Central Weather Bureau).

Water temperature, dissolved oxygen and salinity were measured during the sampling months, with the average daily water temperature ranged from 17.6°C in January to 28.6°C in August, the dissolved oxygen ranged from 5.4 mg l^{-1} in April to 8.5 mg l^{-1} in January, and the mean salinity ranged from 16 (January) to 29 (August) practical salinity units (PSU). The readings were similar between day and night measurements, so only the average values in each day were presented (Table 1).

2. Sampling Method

We collected fish during spring tides in January, April, August and October in 2008 using four fyke nets (10 mm mesh size, 0.75 m deep, 15 m long, and 1 m wide) set across the mangrove creeks during low tides according to the method described by Rozas and Minello (1997). Mangrove forests were mainly distributed along the edge of the river, and the water level was very low during the ebb. The nets were set so that fish were caught as they swam to mangroves during the flood tide. Nets were emptied twice (12 h interval) on each sampling day. All samples were kept in the freezer until processed in the laboratory: each fish was identified to the species and weighed, and number of each species counted. Specimens were fixed in 10% formalin and stored in 70% ethanol in the Department of Life Sciences, National Chung-Hsing University.

3. Data Analyses

Day and night samples were treated separately for each sampling date, while all fish in replicate nets were pooled due to the large variation within sampling periods. Two-way analysis of variance (ANOVA) was used to determine whether fish abundance, biomass, species richness and Shannon-Weiner diversity index differed among diel and seasonal periods.

Table 2. Numerical composition of fish species caught in the 4 sampling periods in Puzih River estuary; total abundance (N); relative abundance (%N); total biomass (W); codes for ecological guilds (EG): F (freshwater species), R (estuarine resident species), T (estuarine transient species); code for economic importance (EI): C (commercial); occurrence months (Month): Jan (January), Apr (April), Aug (August), Oct (October); stage: A (adults), J (juveniles). Rankings are based on individual species abundance.

Family	Species	Rank	N	%N	W (g)	EG	EI	Occur.	Stage
Ambassidae	*Ambassis* sp.	11	13	<0.01	13	R		Aug	J
Ariidae	*Arius maculatus*	4	164	0.12	7794	R	C	Jan, Apr, Aug, Oct	J
Carangidae	*Caranx* sp.	12	9	<0.01	20	T	C	Oct	J
Chanidae	*Chanos chanos*	16	4	<0.01	94	T	C	Aug	J
Clariidae	*Clarias fuscus*	19	1	<0.01	861	F	C	Aug	A
Clupeidae	*Nematalosa come*	5	73	0.05	610	T		Jan, Apr, Aug, Oct	J
	Sardinella lemuru	17	3	<0.01	147	T	C	Oct	J
Drepaneidae	*Drepane longimana*	15	5	<0.01	10	T	C	Oct	J
Elopidae	*Elops machnata*	19	1	<0.01	133	T	C	Aug	J
Engraulidae	*Thryssa chefuensis*	6	53	0.04	168	T	C	Aug, Oct	J
	Thryssa hamiltonii	8	37	0.03	109	T	C	Jan, Apr, Aug, Oct	J
Gerreidae	*Gerres erythrourus*	7	38	0.03	219	T	C	Jan, Aug, Oct	J
Gobiidae	*Glossogobius olivaceus*	18	2	<0.01	36	R		Apr, Oct	J
	Scartelaos histophorus	19	1	<0.01	4	R		Aug	J
	Trypauchen vagina	14	7	<0.01	55	R		Aug	J
Haemulidae	*Pomadasys kaakan*	18	2	<0.01	7	T	C	Oct	J
Leiognathidae	*Eubleekeria splendens*	2	251	0.18	635	T	C	Aug, Oct	J
	Leiognathus brevirostris	1	448	0.33	1307	T	C	Jan, Apr, Aug, Oct	J
	Leiognathus equulus	14	7	<0.01	121	T	C	Aug, Oct	J
	Secutor ruconius	15	5	<0.01	6	T	C	Jan	J
Loricariidae	*Pterygoplichthys* sp.	19	1	<0.01	68	F	C	Aug	J
Mugilidae	*Liza affinis*	19	1	<0.01	11	T	C	Apr	J
	Liza macrolepis	9	25	0.02	1901	T	C	Jan, Apr, Aug, Oct	J
	Moolgarda cunnesius	3	172	0.13	931	T	C	Jan, Apr, Aug, Oct	J
	Mugil cephalus	15	5	<0.01	1715	T	C	Aug	J
Ophichthidae	*Pisodonophis boro*	19	1	<0.01	273	R	C	Aug	A
	Pisodonophis cancrivorus	18	2	<0.01	139	R	C	Aug	J
Plotosidae	*Plotosus lineatus*	19	1	<0.01	21	T	C	Oct	J
Pristigasteridae	*Ilisha melastoma*	19	1	<0.01	4	T		Oct	J
Scatophagidae	*Scatophagus argus*	19	1	<0.01	273	T	C	Aug	J
Sciaenidae	*Johnius* sp.	19	1	<0.01	2	T	C	Oct	J
Sillaginidae	*Sillago japonica*	10	14	0.01	225	T	C	Jan, Apr, Aug	J, A
Sparidae	*Acanthopagrus berda*	10	14	0.01	601	T	C	Aug	J
	Acanthopagrus latus	13	8	<0.01	686	T	C	Aug	J, A
	Acanthopagrus schlegelii	18	2	<0.01	38	T	C	Aug	J
Terapontidae	*Terapon jarbua*	19	1	<0.01	5	T	C	Oct	J
	Terapon theraps	19	1	<0.01	6	T	C	Oct	J
Total	37		1375		19251				

Numeric data were log-transformed to conform to normality and homogeneity before analysis. Multiple comparisons were performed using Tukey-Kramer tests. The Abundance Biomass Comparison (ABC) curves and the W-statistic were used to examine abundance and biomass in each season. Analysis of the differences in fish assemblage structure was performed using a similarity matrix based on Bray-Curtis coefficient of log(x+1)-transformed fish abundance data, and ordination plots were produced by non-metric multidimensional scaling (MDS). Analysis of similarities (ANOSIM) was performed to ascertain the differences derived from MDS. Similarity in percentage (SIMPER) was applied to determine the contribution of fish species to the average Bray-Curtis similarity in each group and the dissimilarity between groups. Multivariate analyses were carried out with the PRIMER computer package (Clarke and Gorley, 2001).

Table 3. Summary of two-way ANOVA in total abundance, total biomass, species richness and Shannon-Weiner diversity index, and in the abundance of the five most common species. Shown are F-values and significance levels (*: $P < 0.05$; **: $P < 0.01$; NS: not significant).

	Month (3 df)		Diel periodicity (1 df)		Month × Diel periodicity (3 df)		Separation
	F	*P*	F	*P*	F	*P*	
Abundance	19.51	**	0.01	NS	1.20	NS	Oct > Jan = Aug > Apr
Biomass	26.07	**	0.49	NS	7.44	**	Aug = Oct > Jan = Apr
Species richness	48.42	**	3.31	NS	1.98	NS	Aug > Oct > Apr = Jan
Shannon-Weiner diversity	51.04	**	1.75	NS	0.33	NS	Oct = Aug > Apr = Jan
Leiognathus brevirostris	17.91	**	0.15	NS	8.34	**	Jan = Oct > Aug = Apr
Eubleekeria splendens	69.49	**	0.32	NS	1.22	NS	Oct > Aug
Moolgarda cunnesius	77.61	**	1.95	NS	51.09	**	Oct > Apr = Jan =Aug
Arius maculatus	42.28	**	0.13	NS	4.71	*	Oct = Aug > Apr > Jan
Nematalosa come	12.96	*	1.69	NS	28.06	**	Oct > Apr

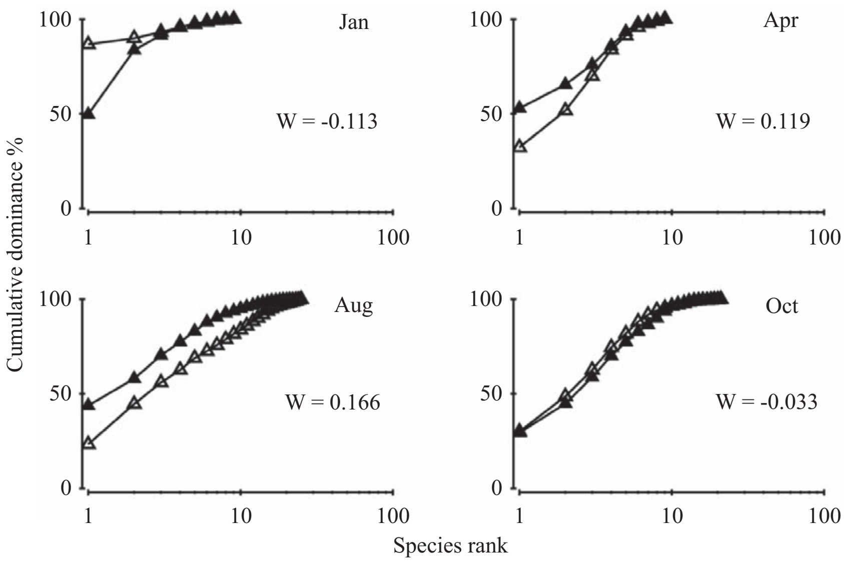

Fig. 2. The ABC curves and W-statistic values in abundance (open triangle) and biomass (filled triangle) of fish community in Puzih River in 4 sampling months.

III. RESULTS

1. Composition of Fish Community

A total of 1375 fish weighing 19.2 kg were collected in 32 fyke net samples, belonging to 37 species in 23 families (Table 2). The three most abundant fish species comprised 64% of the total catch: shortnose ponyfish *Leiognathus brevirostris* (33% of total abundance), splendid ponyfish *Eubleekeria splendens* (18%), and longarm mullet *Moolgarda cunnesius* (13%). The dominant families were Leiognathidae and Mugilidae, accounting for 52% and 15% of the total abundance, respectively, and both were represented by the highest number of species (4) within a family in the samples. Twenty five species had total abundance < 10 from four sampling dates. Most fish was either of juveniles or estuarine transient species (Table 2).

2. Seasonal Variations on Fish Community

There were 9, 9, 25 and 21 species, respectively, sampled in January, April, August and October 2008, and six species occurred in all sampling months (Table 2). Abundance, biomass, species richness, and Shannon-Weiner diversity index differed significantly among seasons (Table 3). The highest mean abundance and diversity occurred in October, and the highest mean biomass and species richness occurred in August (Table 3). In January and October, the abundance curve was above the biomass curve and the W-statistics was negative (Fig. 2), indicating one or a few small species dominated the catches in these months. Non-metric MDS analysis separated the fish assemblage for different sampling month (stress = 0.13) (Fig. 3), and ANOSIM also confirmed a highly significant effect of seasons (Global test: R = 0.86, $p = 0.001$) on fish community structure. Two leiognathids were the most abun-

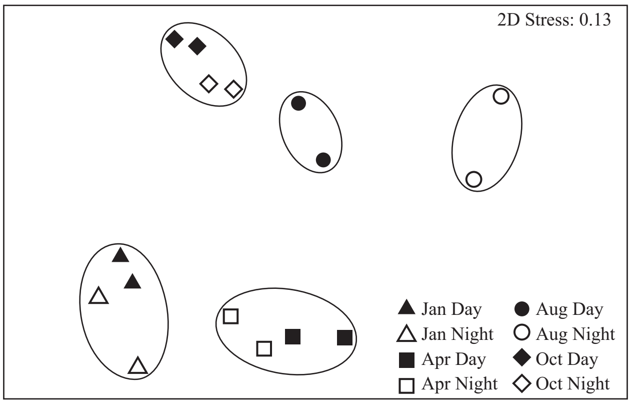

Fig. 3. Non-metric Multi-Dimensional Scaling (MDS) ordination of fish assemblages for day and night catches in 4 sampling occasions based on log-transformed ($\log_{10}(n+1)$) abundance data (where n is the number of individuals).

Table 4. Percentage contributions (%) of the most abundant species (>10% of each sampling) using SIMPER analysis in 4 sampling months.

	January	April	August	October
Average similarity	74	80	65	79
Species				
Leiognathus brevirostris	51	29	20	14
Thryssa hamiltonii	16			
Moolgarda cunnesius	16	22		14
Arius maculatus		25	19	14
Nematalosa come		18		10
Eubleekeria splendens			15	18
Liza macrolepis			10	
Acanthopagrus berda			10	
Thryssa chefuensis				11

Table 5. Percentage contributions (%) of dissimilarities (>10% of each sampling) from SIMPER analysis between sampling months.

	Jan. *vs*. Apr.	Jan. *vs*. Aug.	Jan. *vs*. Oct.	Apr. *vs*. Aug.	Apr. *vs*. Oct.	Aug. *vs*. Oct.
Average dissimilarity	49	63	59	62	61	56
Species						
Leiognathus brevirostris	23	10				
Nematalosa come	14		10			
Arius maculatus	12	11	12			
Gerres erythrourus	11					
Thryssa hamiltonii	10					
Eubleekeria splendens		11	18	12	19	
Thryssa chefuensis			12		12	
Moolgarda cunnesius						11

dant species in all seasons (*L. brevirostris* in January, April and August, and *E. splendens* in October). Similarity in species composition among samples within month was highest in April and lowest in August (Table 4). *Leiognathus brevirostris*, *Arius maculatus*, *M. cunnesius* and *Nematalosa come* contributed the most to the similarity in April. *Leiognathus brevirostris*, *A. maculatus*, *E. splendens*, *Liza macrolepis*, and *Acanthopagrus berda* contributed substantially to the similarity in August. Several species were responsible for the differences in fish assemblages between different months. The dissimilarity of fish assemblages in January and August was due to *L. brevirostris*, *A. maculatus*, and *E. splendens*; and in January and April it was *L. brevirostris*, *N. come*, *A. maculatus*, *Gerres erythrourus* and *Thryssa hamiltonii* that accounted for the observed difference (Table 5). Only one species each contributed to the between-month dissimilarity (over 10%) between April and August, and between August and October.

3. Diel Changes on Fish Community

A total of 728 fish in 23 species were recorded in the day samplings and 647 fish in 32 species were caught in the nights. Five species only occurred in the day catches, and 14 were only captured at nights. No significant differences were found between day and night for abundance, species richness, or Shannon-Weiner diversity index (Table 3). Biomass among seasons and its interaction with season-diel periodicity were the two comparisons that differed significantly in the analysis. The abundance of the five most common species did not differ between day and night catches, but four of which were observed to be significantly different in the interactions terms. Day and night catches were distinct in August, but not in other months (Fig. 3). Overall, no significant effects of diel periodicity on fish assemblages was observed (Global test: $R = -0.05$, $p = 0.64$). In August, ANOSIM analysis revealed a large R value ($R = 1$) but the p value were also large ($p = 0.33$) between the day-night sampling. These statistics suggested a significant difference between the species composition in day and night catches was detected but the sample size was not large enough to support such claim. Several fish species were responsible for the differences between day and night assemblages (Table 6). In August when the dissimilarity was large, no species contributed more than 10%, and three species (*L.*

Table 6. Percentage contributions (%) of dissimilarities (>10% of each sampling) between day and night using SIMPER analysis in 4 sampling months (* represents the three species with the highest value in that comparison but the value were less than 10%).

	January	April	August	October
	Day *vs*. Night	Day *vs*. Night	Day *vs*. Night	Day *vs*. Night
Average dissimilarity	25	37	55	25
Species				
Leiognathus brevirostris	20	10	7*	
Gerres erythrourus	18			
Arius maculatus	13			
Secutor ruconius	12			
Nematalosa come	11			
Eubleekeria splendens		16		
Ambassis sp.		10		
Acanthopagrus latus			7*	
Thryssa hamiltonii			7*	
Moolgarda cunnesius				15

brevirostris, *Acanthopagrus latus* and *T. hamiltonii*) contributed equally at 7% each to the statistic. In January and October when the dissimiarity was low, *Moolgarda cunnesius* was the only species contributing to dissimilarities (over 10%) in October, whereas five species contributed significantly to the dissimilarity between day and night catches in January.

IV. DISCUSSION AND CONCLUSION

Of the 37 fish species constantly or temporarily using the mangrove habitat in the Puzih River estuary, all but a small number of fish were in the juvenile stage. The dominance of juveniles in mangroves supports the idea that estuaries are important in providing habitats for fish in early life stages, either for feeding or predator avoidance (Lin and Shao, 1999; Gray and Miskiewicz, 2000; Paterson and Whitfield, 2000; Laegdsgaard and Johnson, 2001; Ikejima et al., 2003; Spach et al., 2004; Veiga et al., 2006), and further reinforces the importance of estuaries for sustaining biodiversity and the recruitment of populations.

Fish found on the western coast of Taiwan are generally clustered into a northern and a southern group (Kuo et al., 1999; Kuo and Shao, 1999; Tzeng et al., 2002). In Puzih River estuary, the dominant taxa (Leiognathidae and Mugilidae) are similar to those found in rivers further south (e.g., Tsengwen River (Kuo and Shao, 1999) and Chiku lagoon (Kuo et al., 2001) and the community belongs to the southern group. The fish assemblages found in estuaries in northern rivers are dominated by completely different species that are not found or only occur in small numbers in Puzih River (Lee, 1992; Tzeng et al., 2002).

Among the dominant species found in the Puzih River estuary, leiognathids are important prey species for the commercially-important fish in mangroves (Robertson and Duke, 1990), as was evident from stomach contents in carnivorous species (e.g. *A. maculatus*) (pers. obs.). This group is numerically dominant in coastal waters in Thailand (Hajisamae et al., 1999) and Singapore (Hajisamae and Chou, 2003) as well as in Taiwan (Kuo et al., 1999; Kuo and Shao, 1999), suggesting its important role in supporting the ecosystems in these areas. Mugilids (mullets and allies) are common constituents in estuaries and are important for fisheries and aquaculture worldwide (Lin and Shao, 1999; Laegdsgaard and Johnson, 2001; Jin et al., 2007). The family is widely distributed in Taiwan (Kuo et al., 1999; Kuo and Shao, 1999) with some economically important species that are threatened by overfishing during their spawning season (Hung and Shaw, 2006). Mugilids usually spawn offshore in Taiwan Strait and the larvae were carried by ocean currents to estuarine nurseries where they spend their early stages (Lin and Shao, 1999; Chang and Tzeng, 2000; Chang et al., 2000; Chang et al., 2004). A local population of the grey mullet (*Mugil cephalus*) was discovered exclusively in coastal waters of Taiwan that might have been overlooked by all researchers (Ke et al., 2009). In order to better manage the resources of mugilids and the protection of the unique breeding population, more efforts should be undertaken to protect their feeding and spawning habitats in coastal waters in Taiwan.

A significant seasonal pattern of the fish assemblages (Fig. 2) was found in the mangroves of Puzih River estuary, based on the use of the ABC method that has only recently been used in ichthylogical studies (Blanchard et al., 2004; Yemane et al., 2005). This seasonality is common to those found in many regions of the world (Lin and Shao, 1999; Laegdsgaard and Johnson, 2001; Crona and Rönnbäck, 2007; Jin et al., 2007). The increased disparity in abundance and biomass in January and October was due to the presence of small-size individuals utilizing the mangrove habitats. Juveniles of two estuarine transient species (*E. splendens* and *M. cunnesius*) were found in October and in January, large numbers of juvenile *L. bre-*

virostris predominated the catch. The breeding season of these species in Taiwan is not known. However, *E. splendens* spawns in September, October and February in the Philippines (Pinto, 1987), and *L. brevirostris* probably spawn twice a year from May to June and from October to November in the Gulf of Mannar (James and Badrudeen, 1986). Should the breeding dates of these species be indicative of the populations in Taiwan, it would support the general conclusion that seasonal pattern in fish assemblages usually resulted from the reproductive characteristics of dominant species in the estuary (Lin and Shao, 1999; Spach et al., 2004; Jin et al., 2007).

The presence of relatively large benthic carnivores such as *A. maculatus* and sparid species (Melville and Connolly, 2005; Froese and Pauly, 2011) resulted in the peaked biomass and the positive W-statistic in August. Abundant food resource may be one of the reasons that these benthic carnivores entered mangroves during the rainy season. The stomach contents of sparids consisted almost exclusively of the invasive freshwater snail species (*Pomacea canaliculata*), indicating these fish were attracted by the food when organic matter was brought into estuary in summer. Species richness was highest in August and lowest in January in the Puzih mangroves, suggesting temperature as an important regulating factor for the temporal distribution of fish fauna in the estuary (Wang et al., 1991; Lin and Shao, 1999; Laegdsgaard and Johnson, 2001; Veiga et al., 2006). The high species richness may also be related to spawning in some species (Wang et al., 1991), or the increased run-off of organic matter during the raining season (Robertson and Duke, 1987; Kuo et al., 1999). On the other hand, the low species richness in January may result from the migration of some species to deep waters (Laegdsgaard and Johnson, 2001). The seasonal shifts of abundance and biomass in Puzih River estuary were similar to other reports in adjacent estuaries of Taiwan (Kuo et al., 1999; Lin and Shao, 1999).

Differences in fish assemblages between day and night catches were found in several studies (Ross, 1986; Rountree and Able, 1993; Hoeksema and Potter, 2006; Miller and Skilleter, 2006). In a mangrove swamp in southern Taiwan, the biomass and diversity of fish assemblage peaked during the day (Lin and Shao, 1999), but no difference was evident between the day and night sampling in our study in terms of fish abundance, biomass, species richness and diversity. However, a significant difference in the interaction terms in biomass was found between diel and seasonal periodicity in August, and can be attributed to the abundance of the dominant species, e.g., *Leiognathus brevirostris* and *T. hamiltonii*, which were caught almost exclusively in the day catches in August, and to sparid species that appeared almost exclusively at nights. The reasons for most of these diel patterns are unknown. Avoiding competition (Ross, 1986) or predation (Wright, 1989) was proposed to explain the diel variations. Some species in Puzih River showed different activity patterns in terms of diel period in different sampling months. Miller and Skilleter (2006) found a similar pattern in estuarine sandy inshore habitats. Jin et al. (2007) also observed that the day-night assemblages were only separated during July in the Yangtze River estuary. This suggested that diel patterns may only occur in some species or communities in specific seasons.

The dynamic nature of intertidal areas of estuarine environments has great influence on the fish assemblages. Many rare species were found only in the August sample and the species richness in that month was the highest. The monsoon season lowered the salinity and the rainfall and river discharge increased the organic sediments during this period. There were 14 fish species found only in the August sample (Table 1), most of which were estuarine resident and transient euryhaline species and possessed osmoregulatory capabilities dealing with drastic salinity changes (Hwang and Lee, 2007; Wang et al., 2009), and some were probably attracted by the discharged organic matter to feed in the estuary (Kuo et al., 2001).

In conclusion, the seasonal cycle is more important in determining the temporal patterns in this subtropical mangrove estuary fish community than the diel period. Mangroves in the Puzih River estuary are an important nursery habitat for fish, including 31 species with commercial values. We suggested that mangroves in the estuaries, in addition to supporting high fish diversity and fisheries, also act as nurseries for many fish. Mangrove habitats should be included in marine biodiversity conservation and sustainable management strategies should be implemented to ensure their ecological service.

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