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Spatio-temporal Changes in Larval and Juvenile Goby Assemblages of the Kalong Estuary, Northern Vietnam

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ABSTRACT. – In Indo-Pacific estuaries, species of Gobiiformes are dominant, and many species have high economic value. However, little is known about the importance of estuarine habitats for the early life stages of gobies, especially in Vietnam. To clarify the distributions of goby larvae and juveniles, fish sampling surveys were carried out monthly from September 2014 to August 2015 using a small seine net within the Kalong estuary located at the northernmost coast of Vietnam. From analyzing a total of 25 taxa of goby fish collected from the Kalong estuary, the present study revealed a diverse assemblage of tropical, subtropical, and temperate species. Temporally, more individuals were collected in the rainy season, however the total number of species between the two seasons was not significantly different. The temporal structure of the goby community was driven more by water temperature. Spatially, the goby community was mainly driven by salinity, and gobies were distributed at stations that had salinities from ca. 4 to 28 psu. Furthermore, the goby community depended on biotopes (presence or absence of mangroves and surf zones) in the Kalong estuary. The present findings indicate that temporal and spatial variations in the goby larval and juvenile community at the Kalong estuary would have been influenced by the occurrences of dominant taxa, i.e., *Gobiopterus chuno*, *Rhinogobius similis*, *Pseudogobius* sp., *Favonigobius gymnauchen*, *Favonigobius* sp., and *Silhouettea* sp. This data may be valuable for the conservation and management of these fishes and the Kalong estuary ecosystem.

KEYWORDS: distribution, early stages of goby, fish community, mangroves, Northern Vietnam

INTRODUCTION

Among fish species occurring in Indo-Pacific estuaries, the gobies (Gobiiformes sensu, Nelson et al., 2016) are dominant taxa in terms of both species diversity and abundance (Blaber and Milton, 1990; Tachihara et al., 2003; Wang et al., 2009; Tran and Ta, 2014a). However, only a few studies are available that have investigated the occurrence of larvae and juveniles of gobies in estuarine areas (e.g., Maeda and Tachihara, 2005; Yokoo et al., 2006; Phung et al., 2016; Tran et al., 2015a, 2018c, 2019). There are more than 90 species of this order in Vietnam, and many of them are of high economic value (Nguyen, 2005).

Recently, the occurrence of larvae and juveniles of several fish species have been recorded from estuaries in northern Vietnam (Phung et al., 2016; Ha et al., 2019; Nguyen et al., 2019b; Tran and Ta, 2014b, 2016; Tran et al., 2015b, 2016a–b, 2017a–b, 2018a–b; Ta et al., 2021). These works indicate the role of estuarine habitats for several species at larval and juvenile stages. Particularly, the Kalong estuary is characterised by having a large area of tidal flats, which could be an important habitat for the early life stage of many fish species, as pointed out in previous studies for *Plecoglossus altivelis* (Tran et al., 2012, 2014, 2018a), and *Lateolabrax maculatus* (Tran and Ta, 2014b; Tran et al., 2017b; Nguyen et al., 2019b).

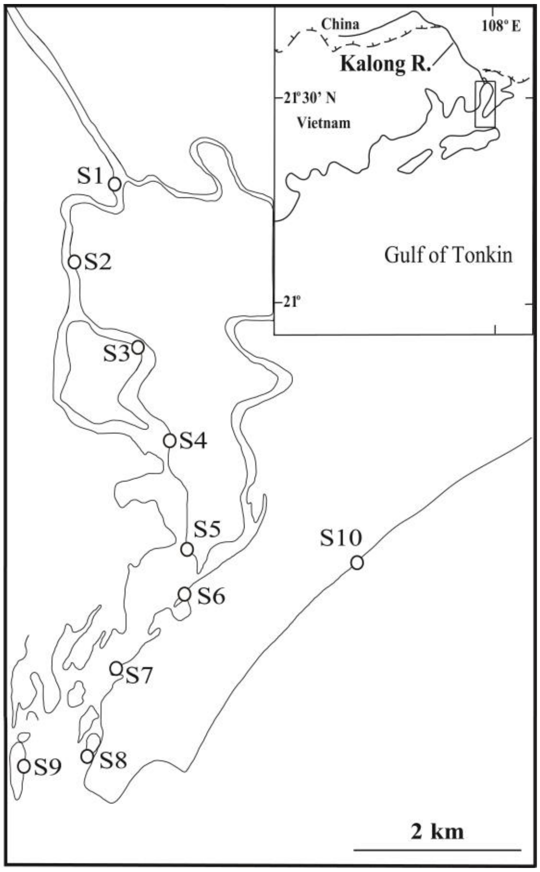

FIGURE 1. Chart showing stations where surveys were carried out in the Kalong estuary area, northern Vietnam, from September 2014 to August 2015. Open circles denote stations where larvae and juveniles of gobies were sampled (stations S1–S10).

In the Kalong estuary, a total of 25 taxa of goby fish have been identified (Ta et al., 2021), and some of these gobies are economically valuable (Nguyen, 2005). Based on detailed information on the distributional pattern of larval and juvenile gobies in the Kalong estuary, a better management plan for this area may be established. This study aimed to describe spatio-temporal distributions and environmental drivers of larval and juvenile gobies, from the Kalong estuary located at the northernmost coast of Vietnam.

MATERIALS AND METHODS

Study area

We conducted surveys in the Kalong estuary, which is located at the northernmost coast of Vietnam facing the Gulf of Tonkin (Fig. 1). The estuary has large tidal flats with an average 3–4 m fluctuation of the tide level (Vietnam Administration of Seas and Islands, Marine Hydrological Centre, 2013). The rainy and dry seasons last from May to October and from November to April, respectively (Dao et al., 2008; Ngo et al., 2013). Ten sampling stations located along the shoreline of the Kalong estuary were selected (Figs 1, 2). Features of sampling stations are detailed in Table 1 and Fig. 2.

FIGURE 2. Photos showing habitats at sampling sites from the Kalong estuary area, northern Vietnam.

Sampling and identification

Fish sampling was conducted every month from August 2014 to September 2015 at every sampling site. At each sampling site, a small

TABLE 1. Biotopes at sampling sites from the Kalong estuary area, northern Vietnam.

Site	Bottom substrate	Biotope	Salinity	Bottom topography
S1	gra-sand	none_mangroves	fresh	high
S2	mud-sand	none_mangrove	fresh	high
S3	mud-sand	none_mangrove	fresh	low
S4	mud-sand	none_mangrove	brackish	low
S5	mud-sand	dense_mangrove	brackish	high
S6	sand-mud	sparse_mangrove	brackish	low
S7	muddy	sparse_mangrove	brackish	low
S8	mud-sand	dense_mangrove	brackish	low
S9	sand-mud	surf_zone	brackish	low
S10	sandy	surf_zone	salty	flat

seine net (1 × 4 m, 1 mm mesh-aperture) (Kinoshita et al., 1988) was towed at a depth of 0.2–1.0 m along the shoreline over a distance of 50 m (2 minutes), one to three times in the day of collection. Due to bad weather and equipment problems, no collections were conducted at station S1 in June, November and December, S2 in September, and October, S4 in September, S6 in October, S7 in September, and S10 in December of the corresponding years. All samples were fixed in 5% formalin in the field and later preserved in 70% ethanol in the laboratory. Water temperature (°C), salinity (psu), and turbidity (NTU) were measured at each station during the sampling period using a water quality checker (WQC-22A, TOA DDK). Based on morphology, 25 taxa of goby fish from three families (Butidae, Oxudercidae, and Gobiidae) were identified (Ta et al., 2021), and used for the spatio-temporal distribution analysis in the present study.

Data analysis

Catch per unit of effort (CPUE) was calculated as the number of individuals in each haul (ca. 2 minutes or 50 m). Fish diversity (Spellerberg and Fedor, 2003), and the evenness (E) index (Buzas and Gibson, 1969) were calculated using the PAST statistical package version 3.25 (Hammer et al., 2001). The E index was calculated using Buzas and Gibson's E: e^H/S in which the H is Shannon-Wiener diversity indices and S is the number of species.

The fish composition and abundance data were standardised as CPUE and then normalised using the equation

$$y'_{ij} = \sqrt{\frac{y_{ij}}{y_{i+}}}$$

where y_{ij} is the original species value for site i and species j, y_{i+} represents the sum of all species values for site i (Legendre and Gallagher, 2001).

The similarity/dissimilarity of the fish community among months and stations were visualised using the non-multidimensional scaling method (NMDS) based on the Brey-Curtis dissimilarity index using the *vegan* package and plotted using the *ggplot2* package in R (Oksanen et al., 2019; Wickham, 2016). The effects of seasons, habitat, biotope, bottom substrate, and bottom topography on the differentiation of the fish community were examined using PERMANOVA tests with 9999 permutations. The contributions of fish species on the differences (if any) among groups of months or groups of sites were tested by SIMPER test. The *envfit* function in the *vegan* was used to visualize the effect of environmental variables on the variation of fish communities by overlaying these variable's vectors on the NMDS plot. These statistical analyses were performed using R version 4.0.2 (R Core Team, 2020). Values of environmental factors were compared between months and sampling stations by t-test. The level of significant difference for all tests was set at $P < 0.05$.

RESULTS

Environmental parameters

Temporally, the mean water temperatures during the rainy season (28.9 ± 0.6 °C) were higher than in the dry season (20.2 °C ± 0.2) ($t(77) = 1.9912$, $P < 0.001$, Fig. 3). The salinity in the rainy months (13.2 ± 1.5 psu) was not significantly lower than that from the dry season (16.8 ± 1.9 psu) ($t(101) = 1.9837$, $P > 0.05$, Fig. 3). The mean turbidity in the dry season (22.2 ± 3.5 NTU) was significantly lower than that in the rainy season (39.1 ± 6.1 NTU) ($t(83) = 1.9889$, $P < 0.05$, Fig. 3).

Spatially, mean salinities were greater at the outer stations (S8–S10), which was more influenced by tides, and lower at the inner stations due to freshwater from the upper reaches (Fig. 4). From stations S1 to S4, the mean salinity was lower than 10 psu, especially at stations S1 and S2 being ca. 0.9 psu. Unlike the above temporal profile, the range of salinities across stations was smaller than temperature and turbidity (Figs 3, 4). There was no significant difference in water temperature and turbidity along the estuary (Fig. 4).

Temporal occurrences of goby fish

Detailed occurrences of larval and juvenile goby fish are presented in Table 2. In one year of the survey, amongst 25 taxa of goby fish as larval and juvenile stages, *Gobiopterus chuno* were collected in 10 months, followed by *Rhinogobius similis* (Table 2). Four taxa collected in six months were *Pseudogobius* sp., *Favonigobius gymnauchen*, *Favonigobius* sp., and *Silhouettea* sp. (Table 2). The number of taxa that occurred in the rainy and dry seasons was equal, being half of those from both seasons. The species *Gobiopterus chuno* and *Pseudogobius* sp. were more abundant in the rainy season than in the dry season; these were the species that mainly contributed to the differentiation among the months (Table 2). Conversely, the species *Rhinogobius similis*, *Silhouettea* sp., and *Acanthogobius flavimanus* were more abundant in the dry season. Moreover, some species, namely *Favonigobius reichei*, *Acanthogobius hasta*, *Periophthalmus modestus*, *Acentrogobius* sp., *Acanthogobius caninus*, *Butis koilomatodon*, only occurred in the dry season, while *Pandaka* sp., *Luciogobius* sp., *Butis butis*, *Rhinogobius* sp., and *Acentrogobius viridipunctatus* only occurred in the rainy season (Table 2).

From the study site, the larval and juvenile goby community structure varied monthly (Table 2). The number of species and the H index ranged from 3 to 10, and 0.22 to 1.62, respectively. The CPUE and E values showed an opposite trend in January, May, July, August, and November. The low E values in these months were related to the abundant occurrence of *G. chuno*, *R. similis*, *Silhouettea* sp., and *A. flavimanus* (Table 2).

The similarity/dissimilarity in fish composition and abundance of species among the months of the years are depicted in the NMDS plot with the stress value of 0.12 (Fig. 5). During the rainy season (from May to October), the fish community of the months seemed to be more similar with each other except for October that separated far from other months. On the other hand, the fish community of dry season months showed a heterogeneous pattern in which the months separated from each other. The two months of January and November of the dry season had communities similar to each other and with that of September and August of the rainy season (Fig. 5).

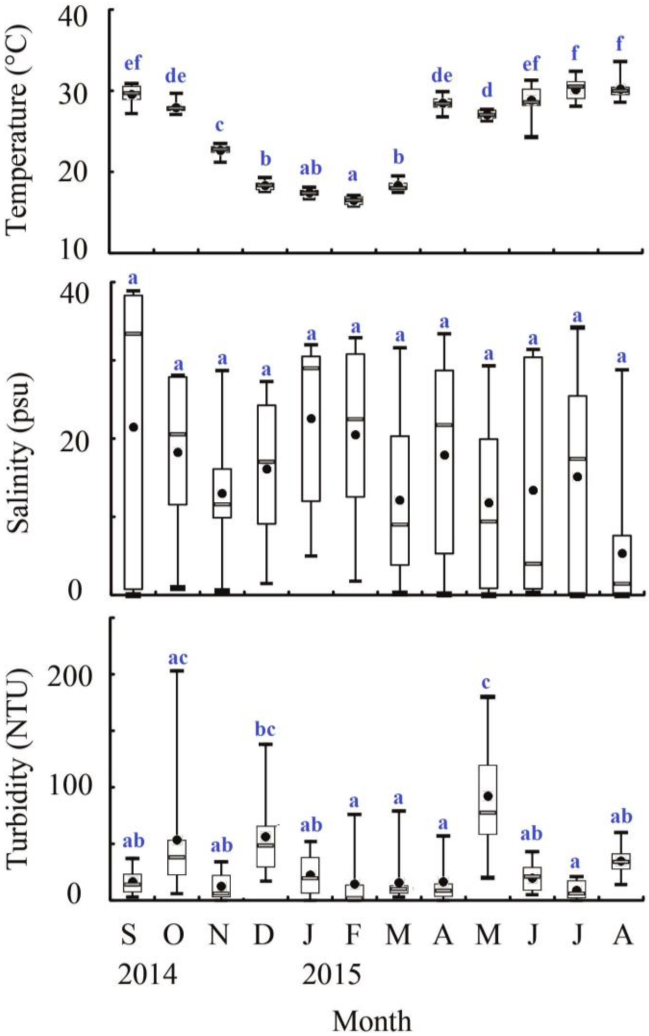

FIGURE 3. Monthly changes in water temperature, salinity, and turbidity from bank waters around the Kalong estuary area, from September 2014 to August 2015. Solid circles and horizontal bars indicate mean and median values, respectively. Different letters are different significantly at a confidence level of $P < 0.05$.

The PERMANOVA test revealed that the difference between the two seasons was not statistically significant ($F = 1.92$, $P = 0.08$), likely due to the similarity of January and November to the months of the rainy season. Even though, the SIMPER analysis still showed slight differences in the abundance and occurrence of fishes between the two seasons (Fig. 5).

The environmental variables of temperature, salinity, and turbidity, were overlaid on the NMDS, scaled by their correlation to the axes of the plot. The change of temperature had the largest effect on the fish community separation ($r^2 = 0.58$) of months and followed by salinity with a smaller effect ($r^2 = 0.37$), and the change of turbidity had the smallest effect (Fig. 5).

Spatial occurrences of goby fish

Somewhat similar to monthly collections, *G. chuno*, *Favonigobius* sp., *Pseudogobius* sp., *F. gymnauchen*, and *Silhouettea* sp. were the top five most frequently occurring goby fish in the Kalong estuary (Table 3). Along the estuary, fishes were mainly collected from stations S3 to S8 in terms of the number of species (Table 3). Few goby larvae and juveniles appeared at stations S1, S2 and S10. The CPUE above ten individuals/haul could be found at stations S1, S3–S5, and S9 (Table 3). The number of species, H and E indices at station S7 were the highest. The E index was low due to the dominance of *G. chuno* at stations S3–S6, *Pseudogobius* sp. at S8, and *Silhouettea* sp. at S9 (Table 3).

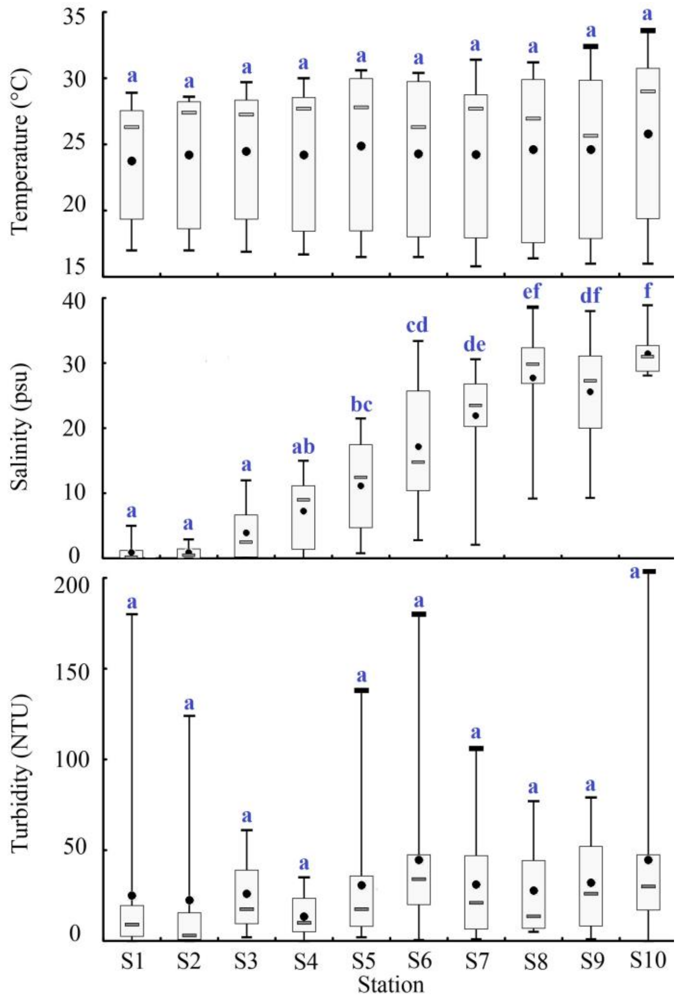

FIGURE 4. Spatial changes, according to stations (S1–S10), of water temperature, salinity, and turbidity in bank waters around the Kalong estuary area, from September 2014 to August 2015. Solid circles and horizontal bars indicate mean and median values, respectively. Different letters are different significantly at a confidence level of $P < 0.05$.

TABLE 2. Monthly changes in number of species, CPUE and diversity indices for larval and juvenile goby fishes from Kalong estuary.

Family and species	Month											
	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Butidae												
Butis butis		2 (0.22)										
Butis koilomatodon			1 (0.06)									
Oxudercidae												
Acanthogobius flavimanus						77 (3.62)	3 (0.16)	4 (0.33)			1 (0.08)	
Acanthogobius hasta						3 (0.14)						
Gobiopterus chuno	8 (1.23)		55 (3.49)	4 (0.30)	90 (7.15)		1 (0.05)		166 (14.76)	116 (11.50)	24 (1.85)	364 (24.00)
Luciogobius sp.						1 (0.15)						
Pandaka sp.		18 (1.95)							13 (1.16)	2 (0.20)	6 (0.46)	
Periophthalmus modestus			2 (0.13)									
Periophthalmus sp.										5 (0.50)	3 (0.23)	
Pseudogobius javanicus			4 (0.25)			1 (0.05)		1 (0.08)	3 (0.27)			7 (0.46)
Pseudogobius masago						1 (0.05)	2 (0.11)			3 (0.30)	1 (0.08)	
Pseudogobius taijiangensis							1 (0.05)	1 (0.08)	3 (0.27)			
Pseudogobius sp.		5 (0.54)						42 (3.43)	25 (2.22)	31 (3.07)	2 (0.15)	1 (0.07)
Rhinogobius similis	2 (0.31)	11 (1.19)	1 (0.06)	28 (2.11)	2 (0.16)	6 (0.28)	4 (0.21)					9 (0.59)
Rhinogobius sp.									2 (0.18)			2 (0.13)
Gobiidae												
Acentrogobius brevirostris					1 (0.08)			1 (0.08)	2 (0.18)			6 (0.40)
Acentrogobius caninus							1 (0.05)					
Acentrogobius viridipunctatus									2 (0.18)			1 (0.07)
Acentrogobius sp.								1 (0.08)				
Favonigobius gymnauchen		1 (0.11)	4 (0.25)					1 (0.08)		4 (0.40)	9 (0.69)	1 (0.07)
Favonigobius reichei				3 (0.23)		1 (0.05)						
Favonigobius sp.			1 (0.06)	18 (1.36)	1 (0.08)	5 (0.24)	4 (0.21)				8 (0.62)	
Parioglossus sp.			1 (0.06)							3 (0.30)		
Psammogobius biocellatus		2 (0.22)	1 (0.06)							1 (0.10)		
Silhouettea sp.			9 (0.57)	5 (0.38)			56 (2.96)		7 (0.62)	1 (0.10)		2 (0.13)
No. of species	3	6	10	5	4	7	8	7	9	9	8	9
No. of individuals	11	39	79	58	94	94	72	51	223	166	54	393
CPUE	1.69	4.22	5.02	4.38	7.47	4.42	3.81	4.17	19.8	16.5	4.15	25.90
H (average)	0.76	1.38	1.17	1.26	0.22	0.75	0.93	0.75	0.98	1.02	1.62	0.39
Evenness (average)	0.71	0.66	0.32	0.71	0.31	0.30	0.32	0.30	0.30	0.31	0.63	0.16

The fish species at the Kalong estuary were distributed heterogeneously among stations and depended on several factors (Fig. 6). The stations located at the river's mouth (S5–S8), and the surf zone area (S9, S10) seemed more similar in species composition and abundance. In contrast, the stations located inside of the estuary differed largely as they separated far from each other on the NMDS plot (Fig. 6).

The PERMANOVA test detected the significant effect of "biotope" (F = 2.818, P = 0.02) and "habitat" (F = 3.078, P = 0.006), but not significant of “bottom substrate” (F = 0.941, P = 0.526), and “bottom topography” (F = 1.598, P = 0.15) on the differentiation of fish community among sites. The SIMPER analyses showed that the differences between biotopes (surf zone area, with dense, sparse and without mangrove) and habitats (fresh, brackish and salty water) were contributed mostly by the fluctuation in abundance of *G. chuno*, *Silhouettea* sp., *Pseudogobius* sp., and *A. flavimanus* (Tables 1, 2). In addition, the species *Luciogobius* sp. and *B. koilomatodon* occurred only in freshwater, while *A. flavimanus, R. similis, P. javanicus, A. brevirostris, P. taijiangensis* occurred only in brackish water. Although they occurred at low abundances, the species *A. flavimanus, P. biocellatus, Rhinogobius* sp., *P. modestus, B. butis, A. caninus* seemed to associate more with the site where the mangrove exists. *G. chuno* was the only species that occurred in every habitat and biotope (Tables 1, 2).

The environmental variables overlaid on the NMDS plot showed that salinity had a significant effect on the differentiation of fish communities among sites (r^2 = 0.89) (Fig. 6). Turbidity and water temperature had a smaller effect with an r^2 = 0.35 and 0.22, respectively.

DISCUSSION

The present study provides a first data of distribution patterns of goby larvae and juveniles at estuarine habitats in Vietnam, where several works have indicated the diversity of these fishes as the adult stage

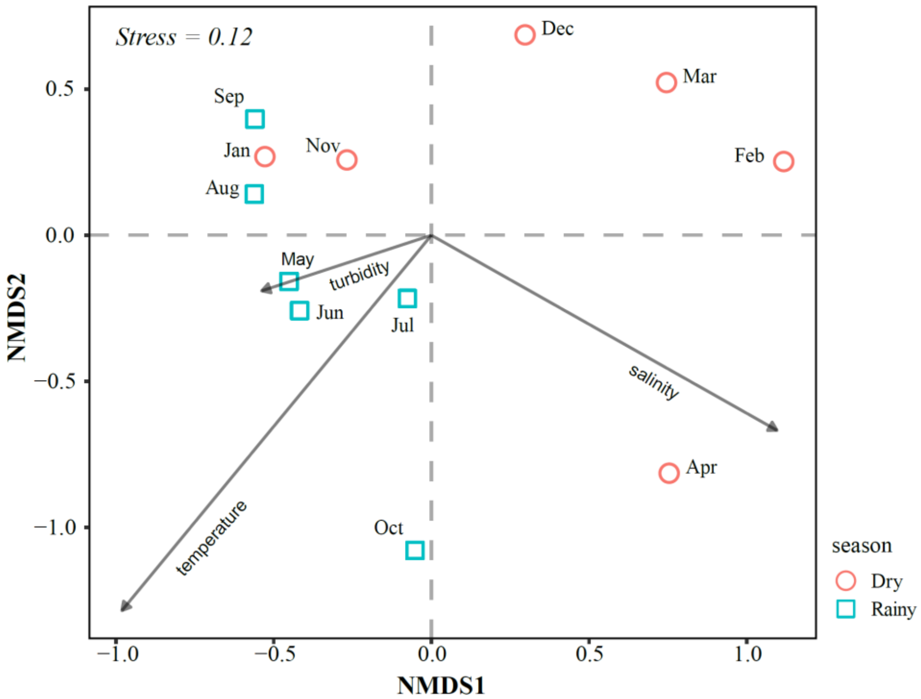

FIGURE 5. The seasonal difference in community structure of larval and juvenile goby species from the Kalong estuary.

(e.g., Nguyen et al., 2012; Diep et al., 2014; Tran and Ta, 2014a; Nguyen et al., 2019a; Tran et al., 2020). The high occurrence of gobies in estuaries of northern Vietnam is probably due to high variations in tidal schedules, and having a diverse range of biotopes (Vu, 2009)). The estuarine habitats in northern Vietnam have been considered to provide nursery grounds for several goby species (Tran et al., 2015a, 2018c, 2019; Phung et al., 2016). The information on temporal and spatial distributions examined in the present study further demonstrates the significance of estuarine habitats for the early stages of fish. It can be seen that goby larvae and juveniles were not abundant in surf zone stations S9 and S10 in the Kalong estuary (Tables 1, 3). The same sampling methods from a surf zone in northern Vietnam (ca. 330 km southward), Japan, and the Philippines also collected very few numbers of gobies (Senta and Kinoshita, 1985; Kohno et al., 1999; Tran et al., 2017a).

It is common to note that dominant species occurrences could characterize the feature of a faunal structure (Smee, 2010), and this case could also be found in ichthyoplankton communities (Senta and Kinoshita, 1985; Kohno et al., 1999; Sichum et al., 2013; Tran et al., 2017a, 2019). In the surf waters of Japan, the presence and absence of 14 dominant species could be utilised to distinguish different ichthyoplankton communities (Senta and Kinoshita, 1985). *Ambassis* spp. and *Sillago sihama* are the most abundant species in the Philippine surf zone, accounting for ca. 50% of the total (Kohno et al., 1999), which probably contribute to the whole community feature. In the Kalong estuary, five top dominant species, *G. chuno*, *R. similis*, *Silhouettea* sp., *A. flavimanus*, and *Pseudogobius* sp., accounted for ca. 88% of the total number of individuals. The occurrence of these species is probably driven the temporal and spatial changes of CPUE, H and E indices of the goby community in the Kalong estuary (Tables 2, 3, Figs 5, 6).

Temporal occurrences of goby larvae and juveniles in the Kalong estuary seemed to be driven by water temperature (Fig. 5). This is consistent with previous studies on *Pseudogobius* spp., and the ichthyoplankton fauna in northern Vietnam (Tran et al., 2017a, 2019) Seasonal variations in fish larvae and juveniles are also found in other areas, such as surf zones in Japan and in the Philippines (Senta and Kinoshita, 1985; Kohno et al., 1999). In the Kalong estuary, the higher water temperature in the rainy season (Fig. 3) would have related to the abundant occurrence of tropical fishes, such as the most frequently occurring species, *G. chuno* (Table 2; Ta et al., 2021). Furthermore, the lower water temperature during the dry season, especially in December to March (between ca. 16 and 19 °C) (Fig. 3), could be a suitable condition for the occurrence of subtropical and temperate fishes, such as *P. modestus*, *A. flavimanus*, and *R. similis* (Table 2; Ta et al., 2021; Tran et al., 2021). Hence, the goby community in December, February and March formed a group (Fig. 6). Other temperate or subtropical fish larval and juvenile occurrences are also reported in this estuary, namely *Plecoglossus altivelis* and *Lateolabrax maculatus* (Tran et al., 2012, 2014, 2018a; Nguyen et al., 2019b).

TABLE 3. The number of species, CPUE and diversity indices per sampling site for larval and juvenile goby fishes from the Kalong estuary.

	Station									
Family and species	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Butidae										
Butis butis			2 (0.12)							
Butis koilomatodon									1 (0.03)	
Oxudercidae										
Acanthogobius flavimanus			30 (1.85)	41 (2.67)	13 (0.81)	1 (0.07)				
Acanthogobius hasta				1 (0.07)		1 (0.07)		1 (0.06)		
Gobiopterus chuno	195 (22.5)	7 (1.33)	172 (10.6)	128 (8.35)	167 (10.4)	134 (9.24)	24 (1.73)			1 (0.05)
Luciogobius sp.									1 (0.03)	
Pandaka sp.				14 (0.91)	8 (0.50)		16 (1.15)	1 (0.06)		
Periophthalmus modestus						2 (0.14)				
Periophthalmus sp.					3 (0.19)	2 (0.14)	2 (0.14)	1 (0.06)		
Pseudogobius javanicus				6 (0.39)	1 (0.06)		9 (0.65)			
Pseudogobius masago				1 (0.07)		2 (0.14)	3 (0.22)	1 (0.06)		
Pseudogobius taijiangensis			1 (0.06)	1 (0.07)			3 (0.22)			
Pseudogobius sp.					20 (1.25)	3 (0.21)	16 (1.15)	53 (3.16)	14 (0.42)	
Rhinogobius similis			43 (2.65)	17 (1.11)			3 (0.22)			
Rhinogobius sp.			2 (0.12)		2 (0.13)					
Gobiidae										
Acentrogobius brevirostris						3 (0.21)	7 (0.50)			
Acentrogobius caninus						1 (0.07)				
Acentrogobius viridipunctatus							3 (0.22)			
Acentrogobius sp.					1 (0.06)					
Favonigobius gymnauchen					11 (0.69)		6 (0.43)	2 (0.12)		1 (0.05)
Favonigobius reichei					3 (0.19)			1 (0.06)		
Favonigobius sp.			7 (0.43)	3 (0.20)	20 (1.25)	1 (0.07)	1 (0.07)	5 (0.30)		
Parioglossus sp.							3 (0.22)	1 (0.06)		
Psammogobius biocellatus			2 (0.12)	1 (0.07)	1 (0.06)					
Silhouettea sp.						1 (0.07)	11 (0.79)		52 (1.56)	16 (0.83)
No. of species	1	1	8	10	12	11	14	9	4	3
No. of individuals	195	7	259	213	250	151	107	66	68	18
CPUE	10.13	0.21	15.46	15.32	17.24	9.44	6.98	4.06	13.00	2.08
H (average)	0	0	1.05	1.27	1.29	0.60	2.3	0.86	0.65	0.43
Evenness (average)	1	1	0.36	0.35	0.30	0.17	0.72	0.26	0.48	0.51

The goby community in two months (November and April) at the transition seasons revealed a different trait. The number of species was greatest in November (Table 2) when the water temperature was significantly different from other months (Fig. 3). Thus, the water temperature in this month (ca. 22.6 °C) may be a favorable condition for the combined occurrence of gobies from tropical (5 species), subtropical (2 species) to temperate zones (1 species) (Table 2; Ta et al., 2021). Moreover, the mean water temperature was 28.5 °C, being significantly different from March and May (Fig. 3), contributing to the separation of the goby community in April to the other months (Fig. 6). The goby community in January was similar to that in August probably because of the occurrence of the dominant species, *G. chuno* (Table 2). In fact, the dominant species influenced the goby community in each season. *G. chuno* constituted 27% of the total number of individuals, contributing to the highest CPUE but the lowest E and H indices in August, and *A. flavimanus* occurred abundantly, leading to the low E index in February (Table 2). A change in the ichthyoplankton community at the transition seasons is also obtained in the Philippines (Kohno et al., 1999). Hence, this point supports that there is a relationship between water temperature and goby larvae and juveniles in the Kalong estuary.

The spatial occurrence of goby larvae and juveniles in the Kalong estuary was driven more by variation in salinity (Fig. 6). The dependence on salinity was clearly observed in other fish larvae and juveniles, such as *Oryzias curvinotus*, *Terapon jarbua*, *Gerres japonicus*, *G. limbatus*, and *Nuchequula nuchalis* occurring in estuaries of northern Vietnam (Tran and Ta, 2016; Tran et al., 2015b, 2016a, 2018b). Similarly, this was also observed in the Kalong estuary since goby larvae and juveniles prefer living in different habitats (Tables 1, 3; Fig. 4).

More species were recorded at stations S3 to S8 (Table 3), where the mean salinity ranged from 3.9 to 27.7 psu (Fig. 4). Hence, it is likely that the brackish waters of the Kalong estuary could be an important habitat for species of goby. Several studies also reported this importance for other fish species in this estuary, such as *Plecoglossus altivelis*, *Hypoatherina valenciennei* and *Lateolabrax*

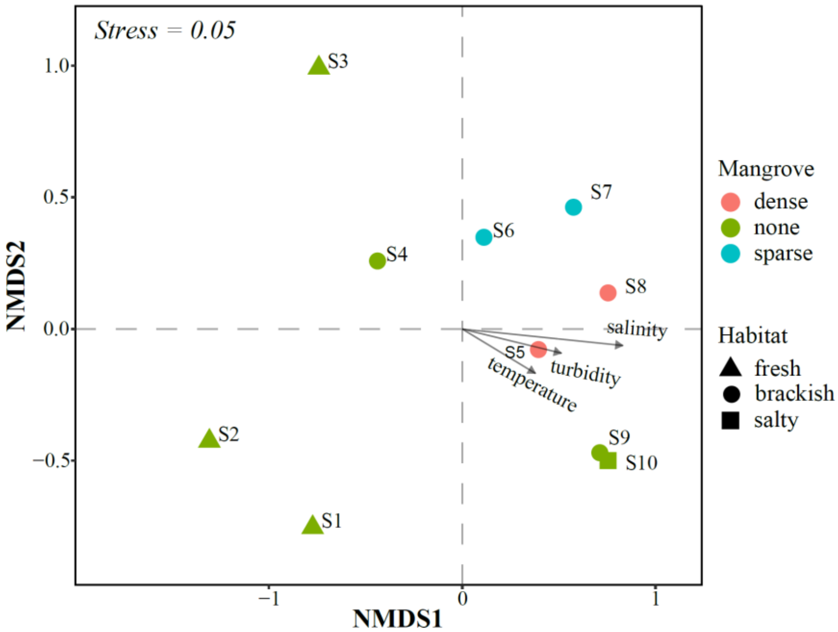

FIGURE 6. The spatial difference in community structure of larval and juvenile goby species from Kalong estuary.

maculatus (Tran et al., 2012, 2016b, 2017b, 2018a; Nguyen et al., 2019b). Similarly, the Tien Yen estuary (ca. 60 km southwestward) plays an important role for some gobies at their larval and juvenile stages (Tran, 2018; Tran et al., 2018c).

Following salinity, the biotope was found to relate to the goby community structure in the Kalong estuary (Table 1; Fig. 6). As mentioned previously, two surf stations, S9 and S10 seemed isolated from the others. There were no mangrove forests at stations S1–S4, whereas the goby community at stations S5–S8 had mangroves and were also closely related (Table 1, Figs 2, 6). Mangroves are recognized as important habitats for juvenile fish (Wang et al., 2009), which were also obtained from the present study as many of the fishes collected from only the mangrove forest were settled fish (Ta et al., 2021; Table 2).

Mangrove habitats are not equal in their species richness and abundance (Wang et al., 2009), and this is partly consistent with the highest H and E indices at station S7 (Table 3) where the mangroves are sparse (Table 1; Fig. 2). Obviously, there are no dominant species at station S7 if compared with nearby stations, S6, S8 (Table 3). *G. chuno*, a dominant species, occurred mostly across the entire estuary, mainly at stations S1 to S6, but the number of individuals collected was not much higher than other species at station S7 (Table 3). In addition to the mangrove forest, water temperature, salinity and turbidity at station S7 were 16.7 to 30.0 °C, 0.05 to 15.0 psu and 0 to 35 NTU, respectively (Fig. 4), which might be in a favourable condition for several fish species that share their food and shelters, and they could co-exist during early stages. The station S7 can be an ideal site for further studies to understand the ichthyoplankton community in the Kalong estuary.

CONCLUSION

This study is the first complete data of goby larvae and juveniles in an estuarine habitat from Vietnam. Temporally, the number of goby species occurred equally between two seasons, and the water temperature is the most important factor contributing to the goby larval and juvenile community. More tropical species were collected in the rainy season, while more subtropical and temperate species were caught in the dry season. Spatially, salinity and biotope are considered to drive the goby community along the Kalong estuary. The middle part of the estuary, primarily at stations with mangroves, is the main habitat of goby species in their early stages. Above all, the dominant taxa occurrences, *G. chuno*, *R. similis*, *Pseudogobius* sp., *F. gymnauchen*, *Favonigobius* sp., and *Silhouettea* sp. would have contributed to the temporal and spatial differentiation of the whole goby larval and juvenile community in the study site.

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