Occurrence patterns and ontogenetic intervals of fishes in the inner Tokyo Bay

SUMMARY

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Background:

Tidal flat is defined as an extensive flat or nearly flat terrain or stretch of land, bordering estuaries, that is alternately covered and uncovered by the rise and fall of the tide (Bates and Jackson, 1980; Coastal Nature Restoration Working Group, 2003; Jackson, 1997; Wada, 2000).

Tidal flats are composed by several biological niches that provide habitats for many organisms including fish species (i.e. Inui *et al*., 2010; Selleslagh and Amara, 2008). The different fish communities in such areas is likely to represent species-specific differences in habitat use (Rakocinski *et al*., 1992). Some individuals may follow certain rules to maximize fitness when they make choices which habitat to use. They may then choose to stay in, or migrate between, habitats on a shorter or longer time scale to maximize their lifetime fitness (Beier, 2016). They are able to move free of costs between habitats, while having full information such as predation risk, availability of food and suitable nursery ground, and of course also with consideration of affecting abiotic factors, e.g., water temperature, salinity and oxygen level (Beier, 2016; Dunson and Travis, 1991). In relation with these, the tidal flats thus are the most productive aquatic systems worldwide and also play a very important role in the population dynamics of many invertebrate and fish species (Selleslagh and Amara, 2008).

In a temperate country like Japan, the estuarine tidal flat serves as a nursery ground and/or primary habitat for many important species of fish in fisheries (Lamberth and Turpie, 2003; Inui *et al*., 2010), such as *Plecoglossus altivelis altivelis* (Uehara, 2016), *Lateolabrax japonicus* (Tamura *et al*., 2013), *Sillago japonica* (Angmalisang *et al*., 2019) and *Konosirus punctatus* (Kimura *et al*., 1999). Fujita *et al*. (1988) also explained that the estuarine tidal flat

is a temporary area for marine fish juveniles' colony, not only because of the high temperature during spring and summer in the area but also of this system providing food that helped the rapid growth and lower predator encounters. Whitefield (1994) elucidated that numerous fish species, which are exploited by recreational and commercial harvesting in the inshore marine environment, are depending on the estuarine systems for the early stages of their growth.

Tidal flats in Tokyo Bay are most likely characterized by strong daily and seasonal fluctuations in salinity and oxygen saturation, and by the tidal movements. Even though, the areas are thought to play an important role to support a number of teleost species (Kanou *et al*., 2004, 2005a, 2007) and to serve as nursery grounds for some local species (Kanou *et al*., 2000, 2005b; Okazaki *et al*., 2011).

In the present study, the term of "tidal flat area" will follow the description of Kanou (2005) who was describing the coverage of the area. Tidal flat in this study is an area is the intertidal zone. Shallow water referss to the area is shallower than 1 m depth during the low tide of spring tide. And what will be called as "tidal flat area" is including both of tidal flat and shallow water.

Tidal flats are known as important areas for fish larvae and juveniles as nursery grounds (Kohno, 2011); therefore, various studies have been conducted in the inner Tokyo Bay regarding fish assemblages on several tidal flats (see. Hermosilla *et al*., 2012; Kanou *et al*., 2000; Kuwabara *et al*., 2003; Nasu *et al*., 1996; Yamane *et al*., 2004).

Ontogenetic habitat shift is a common strategy of many fish species, the larvae of which settle in other habitats that serve as early life stages nurseries. The coastal systems such as a tidal flat represents important nursery habitats (Beck *et al*., 2001) before individuals migrate to adult habitats. The ontogenetic habitat shifts become necessary with the increase of body size (Werner, 1988), which is in fish larvae and juveniles consisting the changes in swimming and feeding abilities. With the change in those features, it will considerably allow the fish larvae and juveniles to exploit more possibilities in choosing which habitats to utilize.

Given the above facts, the rapid reclamation on the coastal area of the inner Tokyo Bay, which happened in parallel with the economic growth of Japan, has led to a massive deterioration in 1960s (e.g. Kohno (ed.), 2006). Under these circumstances, variouss artificial wetlands and tidal flats were constructed in the inner Tokyo Bay from around 1970 (i.e. Nakase *et al*., 2009). The total area of tidal flats has increased to 1,640 ha (c.a. 16.4 km^2) by 1997 (Nature Conservation Bureau of National Agency, 1998). These are the results of an attempt to artificially restore the shoreline of the inner Tokyo Bay.

In this relation, this study was aimed to clarify how tidal flat is being so important as the area serves whether as permanent habitat, transit habitat, or even just an area where the larvae/juvenile strand. With a better understanding of the important roles of tidal flat, it might lead to better population management of the fish species occurring in the Tokyo Bay.

Approach:

First approach was the observation on functional development which consisting swimming- and feeding-related characters of larvae and juveniles of target species. The observation of those characters was undergone on cleared and stained specimens of target species, which were made by following the methods of Potthoff (1984).

The second approach was the occurrence patterns study of the target species in the inner Tokyo Bay. For this, samplings were conducted on selected tidal flats of the bay, as well as compiling the data from published prior studies and reports. These two approaches would be described more detail in the next following chapters of each target fish species. The five target species are *Konosirus punctatus, Nuchequula nuchalis, Sillago japonica, Eutaeniichthys gilli,* and *Chaenogobius gulosus*.

In order to compare with the target species, six other species which have been previously studied with same approaches were also added. The additional species are *Plecoglossus altivelis altivelis* (Uehara, 2016), *Lateolabrax japonicus* (Tamura *et al*., 2013), *Acanthogobius flavimanus* (Kanou, 1999), *Gymnogobius breunigii* (Shinjo, 2020), *Gymnogobius heptacanthus* (Oguma, 2020), and *Gymnogobius macrognathos* (Hirano, 2019).

Furthermore, the occurrences of fish species in several tidal flats in the inner Tokyo Bay will be observed and the data will be compiled. The selected tidal flats are: Tidal flats around the mouth of Tama-gawa River (3 sampling stations: Haneda, Keihin and Ebitori), Artificial tidal flat and sandy beach in Furuhama Park, Kasai artificial tidal flat, Artificial lagoonal tidal flat of Shinhama-ko, and Tidal flats of Obitsu-gawa River (in lower, middle and upper stream).

Results and Discussions:

The occurrence patterns and ontogenetic development of some fish species in the inner Tokyo Bay were observed in this study. Occurrence patterns of the following five species were examined in this study: *Konosirus punctatus* (*n*= 6,105; 3.0 – 34.1 mm BL; collected from April 1996 to March 1999); *Nuchequula nuchalis* (*n*= 256; 3.8 – 28.4 mm BL; collected from August 2009 to September 2013); *Sillago japonica* (*n*= 262; 2.0 – 49.3 mm BL; collected from January 2006 to September 2009); *Eutaeniichthys gilli* (*n*= 1,336; 2.5 – 40.6 mm BL; collected from May to December 2005, March and April 2006, July 2009 to June 2010, and from October 2006 to August 2012; and *Chaenogobius gulosus* (*n*= 1,938; 3.8 – 107.1 mm BL; collected from February 2010 to April 2011, January 2015 to August 2018, and from January to December 2016). Their osteological development was observed on the specimens deposited in the Laboratory of Ichthyology (*K. punctatus*, *n*=129, 3.6 – 25.1 mm BL; *N. nuchalis*, *n*= 49, 3.8 – 20.1 mm BL; and *S. japonica*, *n*=111, 2.0 – 21.1 mm BL; *E. gilli*, *n*= 100, 3.5 – 39.1 mm

BL; and *C. gulosus*, *n*= 94, 3.9 – 25.5 mm BL), and the developmental phases were determined. The information regarding their occurring months or seasons and sizes were also examined. Based on these two approaches, the ontogenetic habitat shifts of each species were recognized in relation to developmental phases. Information of the following six species was gathered and compared with other species in this study: *Plecoglossus altivelis altivelis* (mainly cited from Uehara, 2015), *Lateolabrax japonicus* (Tamura *et al*., 2013), *Acanthogobius flavimanus* (Kanou, 1999), *Gymnogobius breunigii* (Shinjo, 2019), *Gymnogobius heptacanthus* (Oguma, 2020), and *Gymnogobius macrognathos* (Hirano, 2017).

Based on the development of swimming- and feeding-related elements, the eleven species were divided into four and two groups, respectively. Four groups based on swimming-related elements were as follows: fishes beating the caudal fin to produce the propulsion force first then shifting to whole-body propulsion (Group A composed of *K. punctatus*, *P. altivelis altivelis*, *L. japonicus*, *S. japonica* and *E. gilli*); those swimming with caudal propulsion first then shifting to maneuverability-increased phase (Group B of *A. flavimanus*, *G. breunigii* and *G. heptacanthus*); those possessing caudal+whole-body propulsion first then shifting to maneuverability-increased phase (Group C of *C. gulosus* and *G. macrognathos*); and those possessing enough ability to swim with caudal fin and whole-body since after being hatched and then shifting to maneuverability-increased phase (Group D of *N. nuchalis*).

Two groups based on feeding-related elements were species possessing a primordial/initial sucking after being hatched and developing their sucking ability thereafter (Group A of *K. punctatus*, *P. altivelis altivelis*, *L. japonicus*, *S. japonica* and *C. gulosus*) and those possessing the sucking phase equipped with dentary-related elements (Group B of *N. nuchalis*, *A. flavimanus*, *E. gilli*, *G. breunigii*, *G. heptacanthus* and *G. macrognathos*).

Furthermore, based on the swimming and feeding behavior, the eleven species were divided into respective two groups. The first group divided by the swimming behavior was free-swimming species (Group I of *K. punctatus*, *P. altivelis altivelis*, *L. japonicus*, *N. nuchalis* and *S. japonica*), and the second group was bottom-dweller species, which was divided into two subgroups as follows: fishes staying on the bottom after settlement (Group II-1 of *A. flavimanus*, *C. gulosus*, *E. gilli* and *G. macrognathos*); and those swimming occasionally in the lower and middle layers of water column after the settlement (Group II-2 of *G. breunigii* and *G. heptacanthus*). Meanwhile, the following two feeding modes were recognized: fishes swimming through the water with mouth open to feed (Group I of *K. punctatus*, *P. altivelis altivelis*, *L. japonicus* and *S. japonica*); and those sucking in individual food items with the surrounding water (Group II of *N. nuchalis*, *A. flavimanus*, *C. gulosus*, *E. gilli*, *G. breunigii*, *G. heptacanthus* and *G. macrognathos*).

From the occurrences of eleven species in the selected twelve tidal flats, these species are considerably divided into three groups: Group A, for the species that occurred in all tidal flats, which composed of *Acanthogobius flavimanus*, *Gymnogobius breunigii*, and *Gymnogobius macrognathos*. Group B is for those are observed occurring at forehead tidal flats of Haneda, Obitsu-gawa River lower stream and/or Kasai with high in number, which composed of *Konosirus punctatus, Nuchequula nuchalis, Sillago japonica, Eutaeniichthys gilli*, *Plecoglossus altivelis altivelis,* and *Lateolabrax japonicus*. Group C is for the species that occurring significantly only at some particular tidal flats, which composed of *Chaenogobius gulosus* (in Furuhama Park tidal flat and Keihin) and *Gymnogobius heptacanthus* (in Shinhama-ko).

Moreover, the eleven species could also be grouped into four groups based on the area of their spawning ground (Table IX-5). Group I is for the species that assumed to spawn in offshore waters, and composed of *Konosirus punctatus* and *Lateolabrax japonicus*. Group II is composed of the species that spawned in tidal flats: *Eutaeniichthys gilli*, *Gymnogobius macrognathos*, *Gymnogobius breunigii*, and *Gymnogobius heptacanthus*. Group III is for those spawned in shallow waters, and composed of *Sillago japonica*, *Nuchequula nuchalis*, and *Acanthogobius flavimanus*. And Group IV is composed of the species that spawned in other areas (river stream and boulder area).

Eventually, by the similarity of the swimming and feeding developments and behaviour, occurrences and spawning ground, the total eleven species could be then categorized into 5 types. The first type composed of *Konosirus punctatus*, *Plecoglossus altivelis altivelis*, *Lateolabrax japonicus*, *Sillago japonica*, and *Nuchequula nuchalis*. This type is characterized of the free swimmers that firstly swim using tail beat and feed using primordial sucking ability by swim through the water while mouth open, after being hatched; then being able to beat their whole body with the possession of improved sucking, although a small difference was observed on *N. nuchalis*. These species are observed to utilize the forehead tidal flats or river mouth tidal flats as the nearest area they could reach after being hatched in offshores, shallows., or river stream.

The second is for *Eutaeniichthys gilli*, in which the swimming development similar to the first group but categorized as a bottom-dweller that stays on the bottom after being settled. The feeding development was observed progressing from sucking equipped with biting characters to improved feeding abilities, and feeding by suck in individual food items with surrounding water. This species was observed appearing in the Obitsu-gawa River lower stream forehead-tidal-flat after being hatched.

The third group is composed of *Acanthogobius flavimanus*, which swimming development was observed progressing from caudal fin to whole-body equipped with maneuverability to settle down as a bottom-dweller, and stay on the bottom after settled down. Regarding the feeding development and behaviour are similar to the second group. This species was observed appearing in all tidal flats in the inner Tokyo Bay after being hatched in shallows.

The fourth group is composed of *Chaenogobius gulosus* and *Gymnogobius macrognathos*. These species were observed progressing from caudal and whole-body propulsion to improved swimming ability equipped with maneuverability, which allow them to settle down and stay on the bottom thereafter. The feeding development of *C. gulosus* was observed similar to the first group, in other hand for *G. macrognathos* is close to the second and third groups. As for the first species, it is observed appearing at particular tidal flats, and the latter at all tidal flats in the inner Tokyo Bay.

The fifth group is composed of *Gymnogobius breunigii* and *Gymnogobius heptacanthus*. The swimming development of these species are close to the third group, in which equipped with maneuverability, but they will remain to swim in lower and middle layers after settled down. The feeding development and behaviour are observed being close to other gobiids. *G. breunigii* was observed appearing in all selected tidal flats in the inner Tokyo Bay, but in other hand *G. heptacanthus*, was observed only appearing at some particular tidal flats with high in number. Both species are assumed to spawn in tidal flat.

Conclusion:

From this whole study, I could assume that the total target eleven species occurring in the inner Tokyo Bay utilize various areas during their life, such as offshores, shallows, boulder areas, and/or river streams. Five types have also been determined with the basis of functional development, area utilization and spawning ground of the eleven species.

Therefore, this study suggests for a wide-range conservation covering many habitats in order to manage the population of the fish occurring in the Tokyo Bay. In connection with this, since this study was only targeting eleven species, similar study of other species occurring in Tokyo Bay is also needed regarding their habitat.