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SUMMARY

The Vietnamese Mekong Delta boasts a rich diversity of fish species, including over 300 types in its freshwater, brackish, and saltwater environments. The Mekong River plays a crucial role in supporting these fish populations. The region is particularly prosperous in fish families like Butidae, Gobiidae, and Eleotridae, which have economic significance. Although research has been conducted on these fish species in recent years, it has been fragmented, making it challenging to assess and conserve these resources effectively. This monograph addresses this issue, offering a comprehensive perspective on the fish family in this region. This monograph culminates a decade of research, featuring in-depth investigations, including genetic characteristics, morphology, reproduction, feeding habits, and population dynamics. The goal is to provide a holistic understanding of these species and their ecosystems, aiding their conservation. The research contributes to the broader sense of aquatic ecosystems and the intricacies of fish survival in this region.

PREFACE

In recent years, the authors have studied the biological, ecological, and genetic characteristics of fish species of the families in the Vietnamese Mekong Delta. However, these studies are independent and not systematic. Therefore, assessing the resources and conserving these fish species is difficult. *Gobiidae in the Mekong Delta* was compiled to accomplish this goal and provide a comprehensive view of this fish family in the Vietnamese Mekong Delta. This is also the result of the authors' 10 years or so of research, including four projects supported by MOET, two by NAFOSTED, ten by CTU, and >90 papers. The monograph is divided into six chapters with specific contents as follows:

Chapter 1 introduces the study areas, comprehensively understanding their unique characteristics. The chapter further clarifies the research subjects, providing a detailed look at their meaning and importance in the context of this research. Furthermore, the program covers how analysis is applied, giving the reader an overview of the scientific methods used to collect and analyze data.

Chapter 2 focuses on the genetic characteristics, morphology, and classification of research subjects. The chapter delves further into the details of several mitochondrial genes to pave the way for a discussion of species' identification based on genetic markers. Genetic distances and differences take center stage, followed by a comprehensive analysis of phylogenetic relationships.

Chapter 3 continues to delve into the relationship between the length and weight of research subjects. The discovery extends to evaluating the condition factors, providing valuable insights into aquatic organisms' health and development.

Chapter 4 takes the reader on an exploration of reproductive aspects, revealing the complexities of ovarian and testicular development. In addition, the chapter provides important reproductive biology characteristics of fish, such as spawning season, length at first maturity, and spawning capacity, providing a comprehensive picture of the dynamics of fish reproduction.

Chapter 5 shifts to the study subjects' eating habits. This chapter breaks down the nutritional composition of the diet, integrating the Clark index and

the gastrosomatic index to provide a comprehensive understanding of the healthy behavior of these fishes.

Chapter 6 takes the reader through population dynamics, emphasizing length distributions and important population parameters. This chapter summarizes the results and ends with insights into the broader consequences of the findings. In particular, this chapter also provides the status of the exploitation of this fish species so that appropriate measures can be taken to conserve these endangered species.

We hope this research journey provides readers with an exciting experience, revealing the intricacies of aquatic ecosystems and other diverse aspects that make up the survival of fish species in the Vietnamese Mekong Delta. As contributors, we aspire to contribute to the breadth of knowledge revolving around these enigmatic environments, creating a deeper appreciation of the interplay of life in our underwater world.

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CHAPTER 1

GENERAL INTRODUCTION

QUANG MINH DINH, TRAN THI HUYEN LAM,
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Abstract. This chapter gives an overview of the geographical and climatic characteristics of the places where samples are collected, the morphological features and distribution of several gobies, and research methods on morphology, growth, food composition, reproductive biology, and population structure. The sampling sites are located in the Vietnamese Mekong Delta, where the fish fauna is very diverse, especially the goby fish. Gobies show distinct morphological differences, but there are still many similarities between species in the same genus that can confuse taxonomy. Research methods on morphology, growth, food composition, reproduction, and population help to systematize these species' biological and ecological characteristics.

Keywords: food composition, gobies, growth, population, morphology, reproductive biology, Vietnamese Mekong Delta

1.1. The study sites

The Mekong River is one of the longest rivers in the world, flowing ~4400 km from the Tibetan Plateau in China to Vietnam; after crossing Myanmar, Laos, Thailand, Vietnam, and Cambodia, it forms a vast delta. With a catchment area of 795,000 km^2, inland fish diversity in the Mekong River is the second highest globally, with over 1100 species. It is one of the most productive inland fisheries, with about 2.6 million tons of fish caught annually, or 25% of the freshwater catch worldwide. The Mekong River and the Vietnamese Mekong Delta (MD) are being heavily impacted by climate change and human activities, especially saline intrusion, due to rising sea levels. Several studies have investigated fish biodiversity and fishing in the Mekong Basin (Tran et al. 2020). This diversity makes the Mekong River a significant food source for more than 70 million people in the region. However, overexploitation, pollution, habitat changes, dam construction

upstream, and other factors have severely reduced biodiversity and fish productivity, especially in the river's lower reaches. There is no clear indication that wild fish stocks, in general, are being overexploited. However, the changes in species composition, especially the decline in species richness, suggest the current exploitation rate is relatively high.

The Hau River, also known as the Bassac River, is the largest tributary of the Mekong River, with a length of 226 km. The river flows through four provinces of the MD: An Giang (104 km), Can Tho (48 km), Hau Giang (15 km), and Soc Trang (59 km). This river flows in a direction partly influenced by the tidal regime of the eastern coast, with irregular semi-diurnal tides and two high and low tides per day (Nguyen 2022). The hydrological cycle is the primary physical parameter affecting the river's ecology. The annual flood pulse caused by monsoon rains creates extensive floodplains. These wetlands are highly productive for fish and other aquatic animals. Most fish species depend on different habitats at different stages of their lives and different seasons of the year. Most species use the flooded area during the season to forage, breed, and raise fry.

The MD, located mainly in Vietnam, is one of the largest deltas in the world. The average elevation of the delta is less than 1 m above sea level, so it is prone to subsidence and coastal erosion. Natural mangrove vegetation traps sediment for soil accretion, wave energy absorption, and shoreline erosion reduction. In the MD, local precipitation combined with the seasonal discharge of the Mekong River causes spatial and seasonal variations in water availability in the delta. The upstream region experiences deep and prolonged flooding during the rainy season, while the downstream coastal area faces freshwater scarcity and saline intrusion in the dry season (February–April).

Can Tho is located in the center of the MD with a natural area of 1401.6 km^2, on the west bank of the Hau River, 75 km from the East Sea. It borders An Giang and Dong Thap Provinces to the north, Hau Giang Province to the south, Kien Giang Province to the west, and Vinh Long and Dong Thap Provinces to the east. Can Tho is influenced by a tropical monsoon climate. The year has two distinct seasons: dry and wet. The dry season is from December to April, with the wind coming from the northeast. The highest number of sunshine hours is recorded in January, February, and March, with the average sunshine hours ranging from 190 to 240. The wet season is from May to November, with a southwest monsoon. Rainfall is concentrated in September and October, with an average of 220–420 mm. Can Tho has been located in the alluvial deposition area of the Mekong River for many years, bringing a typical plain topography. It has a system of interlaced rivers and canals. The Hau River is the largest river, with a total length of 65 km

flowing through the city; the Cai Lon River is 20 km long, and the Can Tho River is 16 km long, emptying into the Hau River at Ninh Kieu Quay (Nguyen 2022).

Tra Vinh is located southeast of the MD, with a natural area of nearly 2295 km², between two large rivers, Co Chien and Hau. Tra Vinh's topography is a coastal plain influenced by river and sea interference, forming low, flat areas interspersed with dunes. The terrain in the northern districts is more balanced than the coastal communities. The landscape along the two river banks is usually high, and deep into the field, it is divided by arc-shaped dunes, creating local low-lying areas. Tra Vinh is located in the tropical monsoon coastal zone. The climate is divided into two distinct seasons: wet and dry. The wet season is from May to November, and the dry season is from December to April of the next year. The average annual temperature is 26–27.6°C, the average number of sunny hours is 2556 hours per year, the annual rainfall is about 1520 mm, and the annual average humidity is 84%. Tra Vinh has a coastline of 65 km, a shallow sea in the contiguous area of the two seas of the southeast and the southwest, and further away is the East Sea—Truong Sa. This sea area has rich resources, high economic value, and a system of interlaced rivers and inland aquatic resources, which has great potential for promoting the province's economy to develop (Nguyen 2022).

Soc Trang is a province in the MD with a natural area of nearly 3311 km^2. Soc Trang has a low and relatively flat terrain. In general, the topography of Soc Trang Province is in the form of a basin, high in the Hau River and East Sea, lower inward. The weakest areas are in the west and northwest. The sub-terrain has irregular ripples, alternating with relatively high terrain dunes and the low-lying regions contaminated with salt and alum. The average annual temperature in Soc Trang is about 26.7°C; the highest is 28.2°C in April; the lowest is 25.2°C in January. There are two distinct seasons: wet and dry. The average annual rainfall is approximately 1800 mm; the wet month is up to 549 mm. The total average hours of sunshine in the year is 2372 hours; the yearly radiation amount is 140–150 $kcal/cm^2$; the average humidity is 86%. Soc Trang province has 72 km of coastline with two large estuaries, Hau River (which flows into two large rivers, Tran De and Dinh An), and My Thanh River, with significant seafood sources including bottom fish, pelagic fish, and shrimp. Soc Trang has many advantages for developing a general marine economy, aquatic products, marine agriculture and forestry, marine industry, commercial ports, fishing ports, seaport services, import and export, tourism, and transportation sea (Nguyen 2022).

Bac Lieu is a province on the Ca Mau peninsula, with a natural area of 2585 km^2. Bac Lieu has a tropical monsoon climate with two distinct seasons: the wet season (May to November) and the dry season (December to April of the next year). The average annual rainfall is 2000–2300 mm. The average temperature is 26°C; the highest is 31.5°C, and the lowest is 22.5°C. The number of hours of sunshine in a year is 2500–2600. The average humidity in the dry season is 80%, and in the wet season, it is 85%. The tides of the East Sea and part of the daily tidal regime of the West Sea strongly influence this area. Bac Lieu has relatively flat terrain, mainly about 1.2 m above sea level; the rest is dunes, and some low-lying areas are flooded all year round. The landscape tends to slope from the coast to the interior, from the northeast to the southwest. Bac Lieu has a 56-kilometer coastline connecting with significant seas such as Ganh Hao, Nha Mat, and Cai Cung. Marine animals include many species with high value, such as shrimp, snapper, goby, starfish, mackerel, pompano, sugar fish, etc. Bac Lieu could become a place for directly importing and exporting all kinds of this valuable seafood (Nguyen 2022).

Ca Mau is the country's southernmost province, with a natural area of 5332 km^2, equal to 13.1% of the area of the MD and 1.58% of the whole country's sea. Ca Mau has a coastline of 254 km, and the sea area of Ca Mau is over 71,000 km^2, adjacent to the waters of the following countries: Thailand, Malaysia, and Indonesia. A sub-equatorial monsoon tropical climate characterizes Ca Mau. The average temperature is 26.5°C. The highest average temperature in April is about 27.6°C; the lowest average in January is about 25°C. The Ca Mau climate is divided into two distinct seasons: wet and dry. Ca Mau has a coastline of 254 km, accounting for 7.8% of the length of the country's coastline, 107 km of the east coast, and 147 km of the west coast. The sea area and continental shelf are under the sovereignty and jurisdiction of Vietnam and managed by Ca Mau Province, covering an area of about 71,000 square kilometers. The continental shelf of Ca Mau's sea is shallow and gentle. Near Ca Mau Cape, there is a large shoal area. The Ca Mau Sea area is an excellent resource for seafood; it is one of the four critical fishing grounds of the country, with large reserves and diversity of seafood species, many of which have high economic value, such as shrimp, squid, crab, snapper, scad, mackerel, pompano, grouper, etc. (Nguyen 2022).

1.2. Research objects

1.2.1. Butidae family

Butis genus

With more than 30,000 species existing worldwide, the number of fish species accounts for more than half of all vertebrates. In addition to being an essential component of biodiversity, fish have direct economic value and are an indispensable source of animal protein for humans (Ward et al. 2005). *Butis* is a genus in this family with six recognized species in Vietnam; however, there are three recorded species in estuary areas in MD, Vietnam: *Butis koilomatodon*, *Butis humeralis*, and *Butis butis* (Tran et al. 2020).

Figure 1.1. A photo of *Butis koilomatodon*
(Source: Lam and Dinh (2020))

Butis koilomatodon (Figure 1.1), known as the mud sleeper, is found in the Indo-Pacific region's fresh, brackish, and saltwater, ranging from Madagascar and Mozambique to the Philippines, China, and Australia. It has been introduced to the Atlantic region and is considered invasive and originates from Panama, Venezuela, Brazil, and Nigeria (Froese and Pauly 2022). In MD, Vietnam, *Butis koilomatodon* is found in Tra Vinh, Soc Trang, Bac Lieu, and Ca Mau provinces (Dinh et al. 2020a; Dinh et al. 2021b; Lam and Dinh 2021).

Figure 1.2. A photo of *Butis humeralis*

Similarly, *Butis humeralis* (Figure 1.2), the dark sleeper or olive flathead gudgeon, is a species native to Indonesia and Indochina and has been recorded in almost all salt, brackish, and freshwater environments (Froese and Pauly 2022). In MD, it is recorded in Tra Vinh, Soc Trang Bac Lieu, and Ca Mau provinces (Dinh et al. 2021a).

Figure 1.3. A photo of *Butis butis*

Butis butis (Figure 1.3), also known as the crazy fish, the duckbill sleeper, or upside-down sleeper, is native to brackish and freshwater coastal habitats of the Indian Ocean and the western Pacific Ocean, from the African coast to the islands of Fiji (Froese and Pauly 2022). They prefer well-planted waters and are demersal fish frequently found in mangrove swamps near the muddy bottoms of lagoons, estuaries, and mangrove forests with abundant vegetation. In MD, it is recorded in Tra Vinh, Soc Trang Bac Lieu, and Ca Mau provinces (Dinh et al. 2021a; Phan et al. 2021a).

The common traits observed in three species of the genus *Butis* are numerous melanophores on the body and a pair of pointed bones at the interorbital. The head and body of *Butis koilomatodon* are shorter than others. Besides, there are four to seven dark bands on the lateral body of *Butis koilomatodon* and its snout is serrated (Lam and Dinh 2020). Classifying *Butis humeralis* and *Butis butis* is more difficult because of their similar morphology. The caudal peduncle of *Butis humeralis* is higher than that of *Butis butis*. In addition, the first and second dorsal and anal fins are covered with numerous melanophores in *Butis humeralis* but scattered in *Butis butis*.

1.2.2. Gobiidae family

1.2.2.1. Glossogibius genus

With more than 1,700 described species in freshwater (tropical and temperate regions), brackish, and marine water, the Gobiidae is considered one of the most prominent fish families worldwide. Gobiidae is the most noticeable family in many fish faunas, including coral reefs, because they

comprise about 35% of the total fish and 20% of the species diversity. *Glossogobius* is one of the genera with the most species (speciose genera) in the Gobiinae subfamily of the Gobiidae family. Almost 29 species of the *Glossogobius* genus are recorded in the Indian Ocean and Western Tropical Pacific (Froese and Pauly 2022); some species are reported, and several are unreported. Nevertheless, in the MD, there are only three species in the *Glossogobius* genus recorded and described: *Glossogobius aureus*, *Glossogobius giuris*, and *Glossogobius sparsipapillus* (Tran et al. 2020).

Glossogobius is native to fresh, brackish, and marine waters from Africa to the western Pacific Ocean. The *Glossogobius* is widespread and found in many regions and territories, from Africa to Oceania (Froese and Pauly 2022). In the MD, *Glossogobius* is found in estuarine or coastal areas, for instance, Can Tho (Dinh 2008); Soc Trang (Diep et al. 2014; Dinh and Ly 2014); Bac Lieu (Dinh et al. 2021d); Hau River basin in Hau Giang (Le et al. 2018); the estuarine areas of Hau river (East Sea), and Bay Hap and Ong Trang rivers (West Sea) (Tran et al. 2020). The *Glossogobius* is characterized by a tubular body with two distinct dorsal fins and fused pelvic fins; some other unique features such as a large mouth (10–15% SL), a depressed head, a long snout long and pointed lower jaw projecting at least six lines of longitudinal papilla running longitudinally on the cheek, 27–30 vertebrae, a bilobed tongue, and a gill opening reaching below a point just before to just behind the posterior preopercular margin are also recorded.

Glossogobius aureus has a narrow distribution in South Africa, Asia, and Oceania: Japan to Australia, the Mekong and Chao Phraya basins, and the Western Pacific. The body color is brownish (Figure 1.4). There are blackish spots on the second dorsal fin and the caudal peduncle. It also has longitudinal black lines on the side of the body, but they are usually blurred. There are five sensory-papillae rows on the cheek but no short vertical sensory papillae at the middle operculum. The caudal fin has vertical bars. The standard length is 26.9 cm (Tran et al. 2020).

Figure 1.4. A photo of *Glossogobius aureus*
(Source: Phan et al. (2021b))

Glossogobius sparsipapillus is also called the line-cheek tank goby and is found in the MD's tidal zone and perhaps in Cambodia and Singapore. Dinh (2008) and Nguyen et al. (2019) also recorded this species in brackish and freshwater in An Giang, from Bac Lieu to Ca Mau, Vietnam. Some rows of vertical sensory papillae on the middle operculum are short (Figure 1.5). The head and body are pretty slender. It is moderate, with 9.3 cm of SL (Tran et al. 2020).

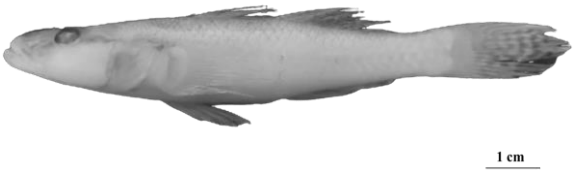

Figure 1.5. A photo of *Glossogobius sparsipapillus*
(Source: Truong et al. (2022))

Glossogobius giuris, known as the tank goby, bar-eyed goby, flat-headed goby, and the Gangetic tank goby, dwells in streams, canals, ditches, and ponds. It is distributed in coastal and estuarine regions and freshwaters alongside the coasts of East Africa, the Red Sea, and most inland freshwater bodies across the Indian Ocean and western Pacific. *Glossogobius giuris* has 22 fin rays, a unique criterion distinguishing tank gobies from the two other congeners (Figure 1.6). There are some rows of sensory papillae on the cheek. The body is elongated, slender, compressed laterally, and has some longitudinal black lines. The caudal peduncle is deep and flat. The head is large, comprehensive, and long. The most extended standard length in a group of three species is up to 35 cm (Tran et al. 2020).

Figure 1.6. A photo of *Glossogobius giuris*
(Source: Truong et al. (2022))

1.2.2.2. Periophthalmus genus

The genus *Periophthalmus* comprises nineteen amphibious fishes, commonly called “mudskippers”. When the tide is low, these fish forage, defend territories, pursue mates, and maintain burrows on exposed mudflats. The popularity of these fish as pets has soared in past decades, facilitated by the burgeoning global trade in aquaria. Traded fish are not reared in captivity; therefore, global supply chains depend on wild-caught specimens. Mudskippers and other gobioid fish supplement the daily protein intake of coastal communities in Asia. The exploitation rates of these fish are unknown, although many nearshore and estuarine fisheries, where mudskippers naturally occur, are collapsing. In the MD, for example, the overexploitation of many fisheries’ stocks continues unabated, and management strategies to recover fish communities are being implemented. One of the primary elements in fisheries management is understanding target taxa's growth and reproductive biology (Dinh et al. 2021b).

These fish are incredibly active during the ebb tide. Individuals are observed to forage throughout the mangrove zones, defend their territories, pursue mates, and maintain burrows, often in pairs (Murdy and Zeehan 2017). *Periophthalmus* species are omnivorous and opportunistic foragers, and these are reflected in their morphology. Their teeth are typically caniniform, thick basally, and recurved at the tips, while their gill rakers are short, knob-like projections that are widely separated. Species of *Periophthalmus* are known to be visual and tactile hunters. More recently, these species have been found to possess well-developed olfactory epithelia, which provides evidence for the importance of olfactory cues during foraging bouts.

Periophthalmus chrysospilos (Figure 1.7) has morphological features such as joint ventral fins; ventral fins situated directly behind pectoral fins; a pelvis connected with the shoulder girdle; pelvic fins united into a rounded disk; the first dorsal fin is tall, its margin straight, no stripes or spots on the fin; the first two spines elongate in males, only the first spine elongates in females; the first spine in males is relatively more extended than the first spine in females; the second dorsal fin has a dusky stripe mesially; the dorsal fins are not connected by a membrane (Murdy and Zeehan 2017).

Figure 1.7. A photo of *Periophthalmus chrysospilos*
(Source: Dinh et al. (2022))

Periophthalmus variabilis (Figure 1.8) is characterized by the following: the first dorsal fin is rounded, of moderate height, has a white margin, and one brown or black stripe inframarginal; the first spine of the first dorsal fin is always longest, rarely elongated; rounded to elliptical red-orange spots present from the ventral to the inframarginal bar, turning black in preservative; the second dorsal fin has a yellow-orange margin and one black band inframarginal; rounded red-orange spots present on the membrane between elements at the base, turning black in preservative; live color with caudal and pectoral red-orange fins.

Figure 1.8. A photo of *Periophthalmus variabilis*

Periophthalmus gracilis (Figure 1.9) is distinguished from two congeners by the following characteristics: no pelvic frenum, or if present, only visible with magnification; separate pelvic fins; the first dorsal fin is short and rounded; a brown inframarginal stripe terminates into a prominent black spot; no elongated spines; the first dorsal fin has a single dusky stripe mesially; dorsal fins are not connected by a membrane.

Figure 1.9. A photo of *Periophthalmus gracilis*
(Source: Dinh et al. (2021c))

Regarding the most prominent morphological traits for classification, *Periophthalmus chrysospilos* have small orange spots, and *Periophthalmus variabilis* have black spots. In contrast, *Periophthalmus gracilis* has horizontal bars on the body, while pelvic fins in both *Periophthalmus variabilis* and *Periophthalmus gracilis* are separate but are conjugate form the disc in *Periophthalmus chrysospilos*.

1.3. Research methods

1.3.1. Sampling sites

Specimens are collected at seven locations along the Hau river estuary in Vietnam (Figure 1.10): Cai Rang-Can Tho (CRCT; 10°00’42.6” N-105°48’42.4” E); Duyen Hai-Tra Vinh (DHTV; 9°41’18.6” N-106°30’35.8” E); Long Phu-Soc Trang (LPST; 9°37’34.4” N-106°08’25.6” E); Tran De-Soc Trang (TDST; 9°29’26.8” N-106°11’58.5” E); Hoa Binh-Bac Lieu (HBBL; 9°12'24,8" N-105°42'54,9" E); Dong Hai-Bac Lieu (DHBL; 9°06’03.2” N 105°29’49.1” E); and Dam Doi-Ca Mau (DDCM; 8°58’17.5” N 105°22’51.8” E). The typical vegetation at these sites includes *Acanthus ebracteatus* Vahl., *Avicennia marna* (Forssk.) Vierh., *Bruguiera gymnorrhiza* (L.), *Nypa fruticans* Wurmb., Savigny *Sonneratia caseolaris* (L.) A. Engl., and *Rhizophora apiculata* Blume.

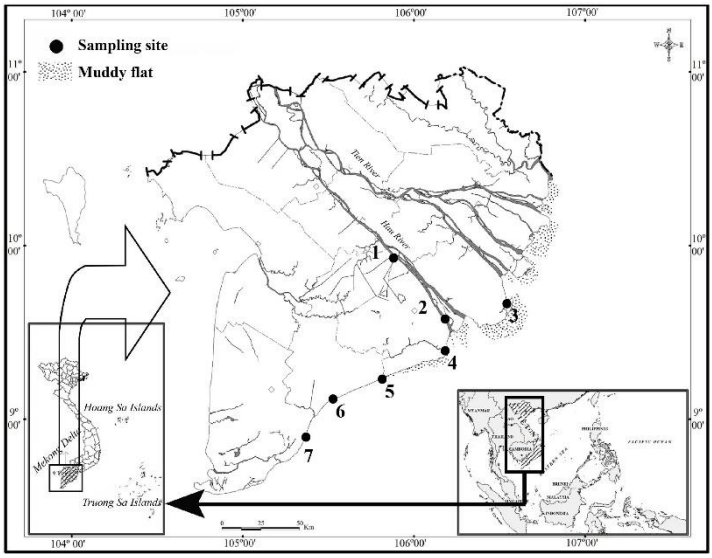

Figure 1.10. Sampling sites (•) in the Vietnamese Mekong Delta, modified from Dinh (2018)
(1: Cai Rang-Can Tho; 2: Long Phu-Soc Trang; 3: Duyen Hai-Tra Vinh; 4: Tran De-Soc Trang; 5: Hoa Binh-Bac Lieu; 6: Dong Hai-Bac Lieu; 7: Dam Doi-Ca Mau)

1.3.2. Fish collection and morphological analyses

Specimens are collected using gill nets (with a 1.5 cm mesh size at the cod end) set up in canals along mudflats and mangrove forests at the highest tide in each study site. Next, the gill nets are retrieved after 2–3 hours to collect fish (Dinh et al. 2015). After fish identification using the external description of Tran et al. (2020), they are anesthetized with benzocaine and stored in 5% formalin to transport them to the laboratory.

The fish sexes are differentiated based on the morphology of the urogenital papilla, e.g., round in females and narrow in males (Dinh et al. 2020b). In the zoological laboratory, fish specimens are measured as total length (nearest 0.1 cm) and weight (nearest 0.01 g). Some of the morphometric and meristic data are taken, such as total length (TL), standard length (SL), head length (HL), body depth (BD), eye diameter (ED), and the distance between the eyes (DE). Some ratios, such as HL/SL, BD/SL, ED/HL, and DE/HL, are also calculated. In parallel, some meristic data are taken, such as the number of scales along the body, circumferential scales, and the number of rays in the first and second dorsal fins. The length