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Mudskippers in Tainan: The ecology and lifestyle of mudskipper Periophthalmus modestus in Tainan coastal wetland

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Abstract*—The mudskipper is one of the important wetland species. It plays a key role in the conservation of wetlands and waterfowl. The special and changing environment has given rise to the evolution of many physiological mechanisms adapted to wetlands. With high sensitivity to environmental changes, mudskippers are considered as indicator organisms of wetland environmental changes. This survey is focused on the ecology and lifestyle of the mudskippers in Tainan wetland, including mudskipper species, population size, Body Mass Index change, environmental change, ecological behavior, courtship and reproduction, nest analysis, etc. The results show that there are at least two species; namely, Periophthalmus modestus and Boleophthalmus pectinirostris in the coastal wetlands of Tainan with the population size growing and declining dynamically along with the natural environment and human activity. Moreover, there are growth changes affected by the environment. Based on three observation points; namely, Keliao, Mangrove and Anping, mudskippers grow best in Mangrove while thrive poorly in Anping. Salinity is the main environmental factor while dissolved oxygen is the second. The nest is found to have a dendritic structure. The mudskipper's environmental tolerance is not strong as expected. This may cause mudskippers to disappear due to their vulnerability to environmental changes such as embankments, fish farms, roads and other public buildings that bring cement and affect their habitat. Relevant authorities are expected to include mudskippers in the list of endangered species and begin conservation measures that give importance to mudskipper ecology and related wetland research that will help develop a sustainable society and country.

***Index Terms*— mudskipper; the coastal wetland of Tainan; wetland ecology; indicator organisms**

I. Introduction

The mudskipper has many common names which include mud monkey and jumping fish. Residents near the coast of Tainan prefer to call it "kon-kyan-a". The mudskipper is a common wetland organism and a food source of waterfowl and large fishes. It is also used as an ecological indicator organism because of its environmental sensitivity and its important role in wetland ecology. As far as wetland studies are concerned, the interaction between mudskipper growth and the environment is an indispensable part of wetland ecology.

The coastal wetland of Tainan is ecologically complex. In addition to its lagoons, estuaries, coasts, sandbars, marshes and other natural ecosystems, it consists of a number of human environments such as drains, fish farms, salt pans, reservoirs, etc., making it a unique ecosystem of natural and human communities. The precious endemic black-faced spoonbills of Tsengwen Estuary Wetland have attracted the interest of international scholars. The living environment and environmental factors that support these birds have become the focus, along with mudskippers as one of the important species that influence wetland ecological factors.

In order to understand the ecological characteristics of mudskippers in the coastal wetlands of Tainan, it is necessary to set a few regular observation points before conducting the survey. The survey factors include the mudskipper species, population size, Body Mass Index change, environmental change, ecological behavior, courtship and reproduction, nest analysis, etc.

Periophthalmus modestus with English name shuttles hoppfish and old name Periophthalmus cantonensis, belongs to the Perciformes, Gobiidae, Periophthalmus. Before 2004, the world discovered seventeen kinds of Periophthalmus species [1]. The number increased to eighteen in 2008 [2] after the identification of the Periophthalmus takita species in Northern Australia. The eighteen species of mudskippers are listed in alphabetical order: P. argentilineatus, P. barbarous, P. chrysospilos, P. darwini, P. gracilis, P. kalolo, P. magnuspinnatus, P. malaccensis, P. minutus, P. modestus, P. novaeguineaensis, P. novemradiatus, P. spilotus, P. takita, P. variabilis, P. walailakae, P. waltoni, and P. weberi. The eighteen kinds of mudskippers are found in the brackish environment between the sea and estuary from the tropical

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zone to subtropical zone on three major continents; namely, Europe, Asia and Africa.

The Periophthalmus modestus in the Tainan coast is found in the Northwest Pacific, specifically from Vietnam, the southeast coast of China and Taiwan, to the north of Korea and central Japan [3]. Its main distribution in Taiwan is on the west sandy coast. Peng-hu offshore islands have records of this. These mudskippers belong to the same species (Periophthalmus modestus). Given the geographical isolation caused by separate islands and with no genetic exchange, there will most likely be a formation of new species with Taiwan, playing a critical role since it is located at the center of Northeast Asia.

Periophthalmus modestus mudskippers have a body length of up to 10 cm [4]. They mainly thrive along the border where land meets water, such as estuaries, wetlands, marshes and mud flats. They use their strong caudal fins for jumping and they move rapidly on mud flats to gather small organisms or food residues [5]. Mudskippers live in nests and take refuge in underground nests to avoid enemies. They can regulate temperature inside caves by opening and closing their stomata [6]. They are rarely used by people but records show that they have been used in China as herbal medicine [7]. Incidentally, the author has once purchased Tsukudani, a product from Japan made of mudskippers.

In Taiwan, there are at least five fish species named after mudskippers in several literatures; these are Periophthalmus modestus, Boleophthalmus pectinirostris, Scartelaos histophorus, Scartelaos gigus [8] and Periophthalmus argentilineatus [9]. With the exception of Periophthalmus argentilineatus which belong to the Periophthalmus species, the rest are under different categories, such as Scartelaos and Boleophthalmus.

In the west coastal wetland of Tainan, Periophthalmus modestus and Boleophthalmus pectinirostris are the most common species [5], with the species, distribution, quantity, behavior and ecology unknown. This survey is expected to study mudskipper types and ecology in the coastal area of Tainan, to promote the implementation of wetland conservation and provide reference for municipal construction.

There are quite a few international scholars who have published ecological research results related to mudskippers. The following are the summarized physiological characteristics of mudskippers adapted to the wetland ecosystem.

1. An amphibious fish better than other aquatic life for long-time survival without water

2. Breathing oxygen in wet environments using the gill, mouth, throat, skin, etc.

3. Easily sensing the movements of intertidal water surface with spherical eyeballs protruding from the head, unlike aquatic fish whose eyeballs are on both sides of the head

4. With small gill openings to prevent water loss and plump gill chamber to store water and keep moisture, which has abundant capillaries and mitochondria for good gill respiration and ion exchange. [10]

5. With mucus on the skin for breathing, moisturizing and preventing injuries. [11]

6. With specialized pelvic fin that adheres to rocks, exposed roots and stems of mangrove plants

7. Able to burrow and build its nest to adjust the temperature, evade enemies, breed and lay eggs, etc. [12]

8. The parent fish would carry oxygen to the nest if the oxygen in the nest is insufficient [12].

9. Unlike the ordinary fish, it removes ammonia from the body (i.e. ammonia metabolism) using the gill to maintain life in the wetlands [13].

The mudskipper has evolved its physiological structure and behavior to adapt to special wetland environments. If the environment changes due to human factors, the ecology, behavior and population would change accordingly. The organism sensitive to environmental adaptation is considered as an environmental indicator organism. With mudskippers as indicator organisms, the ecological growth and decline of wetlands can be understood and discussed. This study focuses on mudskipper species identification in coastal wetlands of Tainan, population movements, ecological habits, wetland environmental changes, nest types and other related ecological factors.

The study of mudskipper ecology and behavior would be helpful in learning the changes in wetland ecological environments. It can serve as a reference and basis for managing wetlands, so that habitat destruction, wetland environmental changes and other critical factors can be further understood and necessary measures can be applied in education, management and reconstruction of wetlands, and practical infrastructure construction.

II. Methods

1. Time, Location and Survey Frequency

The survey of coastal wetlands in Tainan was conducted from January 2012 to December 2012. Survey locations included Keliao (N23.076455, E120.042286), Spoonbills area (N23.066426, E120.046406), Mangrove (N23.118930, E120.088382) and Anping (N23.004056, E120.146983). The four locations were long-term observation points (Figure 1); the survey was made once every two weeks.

2. Sampling, Species Identification and Observation

According to previous study, the main species found in Tainan's coastal wetlands are Periophthalmus modestus and Boleophthalmus pectinirostris [5], with the former as the topic of this study. (Figure 2) Using fishing gears and traps, the species in Tainan's coastal wetlands were identified. The book "The fishes of the Japanese" [3] and the Fish Database of Taiwan [9] were taken as taxonomic bases. The features of the species were determined using a telescope while the laboratory classification and analysis were performed after sampling.

3. Study of Population Size

It is estimated that biological population size changes with biological characteristics. The Mudskipper population was estimated using line transect methods [14] that count the quantity and type of mudskippers located in the strip area one meter away from the waterline and ten meters along the shore. The population size was sampled on March, April and May.

$$\text{Unit Number} = \text{Population Size} / \text{Total Area}$$

4. Analysis of Mudskipper Body Mass Index

The body weight and length of 8-10 mudskippers collected randomly were tested every two weeks using an optical ruler and electronic scale. The measurement of Body Mass Index (BMI) and Rohrer Index (RI) followed the Eknoyan method. [15]

$$BMI = \text{Body weight (Kg)} / \text{Body length}^2 (m^2)$$

5. Environmental Factors

The long-term monitoring focused on the dissolved oxygen, pH, salinity, water temperature, and soil particle size in Tainan's wetland environment in order to understand the relationship between environmental changes and ecological habits in Tainan's wetlands. (Figure 3)

6. Observation of Ecological Behavior

Ecological behaviors of mudskippers such as foraging strategy, enemy evasion, threats, courtship, burrowing, nesting, spawning and incubation were observed with the naked eye or with the use of a telescope and camcorder.

III. Results and Discussion

Species Identification of Mudskippers

There are at least two or more types of mudskippers in Tainan's coastal wetlands. One is the common Periophthalmus modestus and the other is the Boleophthalmus pectinirostris. Both are found in Mangrove and Anping, while only the former exists in Keliao. Based on literature, the Periophthalmus argentilineatus thrives mainly in Asia, but it was not found in the survey.

Morphological Observation and Classification of Mudskippers

The classification and identification of the Periophthalmus modestus sample was performed in the lab with its characteristics described as Masuda et al. [3].

It was easy to make different between Periophthalmus modestus and Boleophthalmus pectinirostris in wetland. The physical and behavior characteristics were two important points. The physical characteristics of Periophthalmus modestus were as follows: body size smaller than Boleophthalmus pectinirostris, neck unclear and body shape like wood block (Boleophthalmus pectinirostris like tadpole), the first anterior dorsal fin small (Boleophthalmus pectinirostris the first anterior dorsal fin large and like sail), with black twill or without markings (Boleophthalmus pectinirostris with blue small spots), toothless mouth, etc. Sometimes they were very similar and difficult to make different. The behavior characteristics become the only one method. In wetland, Boleophthalmus pectinirostris always scraped Diatomaceous on surface of mud, so they usually shook their heads (to eat Diatomaceous). Periophthalmus modestus was carnivorous fish without this behavior.

Population Size Survey

As mentioned above, the population size is not easy to measure since mudskippers live in caves and can only be estimated. The number of Periophthalmus modestus was estimated using line transect methods.

Since the population size of mudskippers is affected after the month of June when a large number of fish larvae are generated after hatching and before February when over half of them hide in caves due to cold weather, the data was gathered in March, April and May. According to the data taken on 3/17, 4/25, 5/12 based on three observation points, the mudskipper population was about 720 (within a 200-meter range) in Anping, around 720 (within an 80-meter range) in Keliao and about 140 (within a 60-meter range) in Mangrove.

Mudskipper Body Mass Index Analysis

Body Mass Index (BMI) is often used as indicators between biological growth and nutrient uptake. Normally, individual organisms with better nutrition have higher BMI. In addition, juvenile fish and berried female usually have higher BMI values compared to adult fish. Mudskippers in Mangrove had the highest BMI average from July to November, followed by those in Keliao with an average of middle. Those in Anping had the lowest BMI average. The student t-test of BMI is shown significant between Mangrove and Anping ($p < 0.05$). This shows that Mangrove is rich in food while Anping has less food due to the water drainage system in fishponds. The analytical value of Rohrer Index was close to that of the BMI.

Environmental Factors

The analysis of environmental change factors focused on the long-term monitoring of daily changes of dissolved oxygen, pH, salinity, and water temperature, in the coastal wetland of Tainan. The average air temperature in the main observation area of Periophthalmus modestus remained above 25 degrees between March and October, and it was kept in a lower level between November and February. It can be observed that mudskippers prefer the warm environment. Mudskippers were active in intertidal mud flats with dramatic salinity changes of over 40 degrees in Anping (in February) and Keliao (in March and April); and only 5 degrees in Mangrove in July. It is obvious that salinity change is an important factor in environmental adaptability of mudskippers. According to salinity change and mudskipper reproductive behavior, low salinity is likely to be closely associated with incubation, which means incubation requires lower salinity. The pH of habitat intertidal beach was rather more alkaline, which was low in summer and higher in winter. Dissolved oxygen as an important factor of survival was low during hot weather and affected by local currents and tides. There was less change in other environmental factors with smaller influence.

The sediment was collected to analyze the size of sediment particle in the living environment of mudskippers. Given the samples from Mangrove taken on November 24th 2012, the surface (3 cm), middle (5 cm) and lower (15 cm) layers were observed and analyzed using a microscope. There is not much difference in the particle size between the 3cm sample and 5cm sample, with approximately 0.005 -0.008 cm size. The particle with 15 cm depth was larger with 0.005 - 0.01 cm size.

Ecological Behavior

The Periophthalmus modestus in the coastal wetland of Tainan was found to be one of the perennial species. The adult mudskippers with body length of about 5-7 cm and strong territorial feature are better species adapted to the

terrestrial life and are active within 1-5 meters of the intertidal wetland waterline. Their distribution is related to the steepness of the embankment. Mudskippers live mainly within 15 degrees of the slope and their populations obviously decline over 30 degrees of the slope. They are fiercely territorial and will threaten and drive away intruders that occupy a 5-10 centimeter range from their nests. These intruders include other mudskippers and fiddler crabs. Mudskippers intimidate intruders by raising their dorsal fins as a form of attack. They forage for food using their mouths and quick movements in order to survive. They are carnivorous and feed on small creatures such as polychaetes, small crustaceans, insects, juvenile fish, biological debris, etc. In the face of predators, they can move fast and slap their tails on water, similar to a "dragonfly touch" or "stone skipping". They can travel a distance several times greater than their actual length using their short and powerful tail. Their "dragonfly touch" behavior is not easily found in other fish species, which can be considered as a specific behavior of mudskippers. Their movement can be classified into two types: one entails the use of the tail to quickly bounce using the strength of the tail as it bends and straightens; the second involves crawling using pectoral fins and pelvic fins with "sucking" ability.

The skin of Periophthalmus modestus contains mucus with moisturizing property. Since water on any physical surface easily dries up due to evaporation by the sun or air, mudskippers have the ability to flip their body to wet their backs and keep the whole body moist. This action is performed quickly and normally entails less than 0.5 seconds. Burrowing for nest is also one of the male mudskippers' characteristics, which was discovered first in mudskippers found in Mangrove on April 20th 2012. Male mudskippers burrow for nests by performing a "Mudskipper Dance" which involves twisting their bodies to attract female mudskippers after burrowing. The male mudskippers use their mouths to dig out soil and create a small mound composed of granules with the same size as their mouths. If the soil is rich in water, mud piles would be formed. In winter, mudskippers create high mud piles, or close some cave holes to regulate temperature. In addition, a channel is formed to connect to the hole with the water below the ebb-tide line, which is presumed to be related to the adjustment of humidity in the cave.

The male mudskippers' courtship dance behavior was first observed at the Mangrove observation point on April 20th 2012. The skin of male mudskippers during courtship showed significant color change (nuptial coloration), from the original gray to orange or white-gray, while the female skin showed no obvious color change. Based on observation, the earliest juvenile mudskipper appeared in Anping on May 12th, which was two weeks after a male mudskipper was first found to perform a courtship dance on April 29th. The two weeks was attributed to incubation.

The burrowing behavior of mudskippers may not be simply attributable to spawning because this behavior was clearly present in the month of September and disappeared in November. Therefore, passing the winter may be another reason besides spawning. The variety of nests had been discussed in our previous studies. The nest modes of samples collected were not only in the form of V, Y and J, but also in complex forms, which were quite different from relevant studies here and abroad. With the functions of ventilation, adjustment of air pressure and water pressure, and escape, nesting means a lot for mudskippers. Nests are dug deeper during the reproduction period for spawning. They are also used for protection, water storage, incubating and avoiding enemies.

IV. Conclusion

The survey shows that mudskippers are weak in terms of environmental tolerance; they are vulnerable to human or natural factors which can cause serious harm and damage. Local departments should give importance to this issue. Mudskippers have been quite scarce in the coastal wetlands of Tainan, and they are expected to be included in the list of endangered species for conservation. There is a lack of research on mudskippers. It is hoped that more attention be given to mudskipper ecology and other related studies.

V. Referrance

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VII. Biography

Ming-Chih Huang received the B.S degree from National Cheng-Kung University, Tainan, Taiwan and Ph.D degrees from the University of Tokyo, Tokyo, Japan, in 1997 and 2004, respectively. His postdoctoral training was in Genomic Science Center, Yokohama, RIKEN from July, 2004 to July 2008. He back Taiwan on Aug 2008. Now he is interesting in marine biology like bluefin tuna, shark, sergestid shrimp and mudskipper.

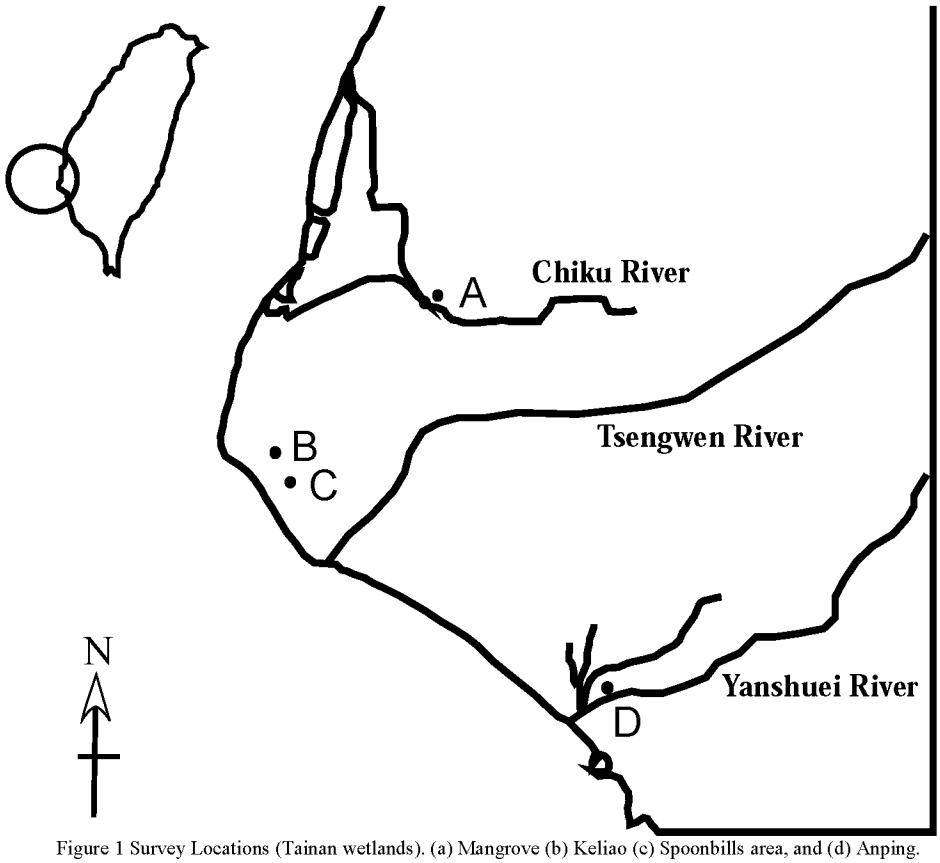
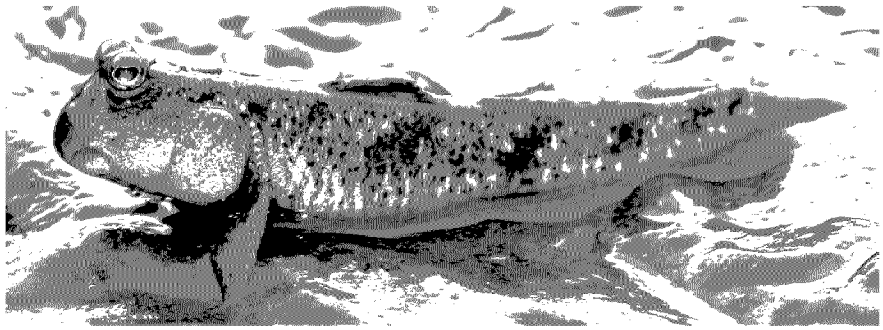


Figure 1 Survey Locations (Tainan wetlands). (a) Mangrove (b) Keliao (c) Spoonbills area, and (d) Anping.

(a) Pattern Type of mudskipper (**Periophthalmus modestus**)



(b) Non-Pattern Type of mudskipper (**Periophthalmus modestus**).

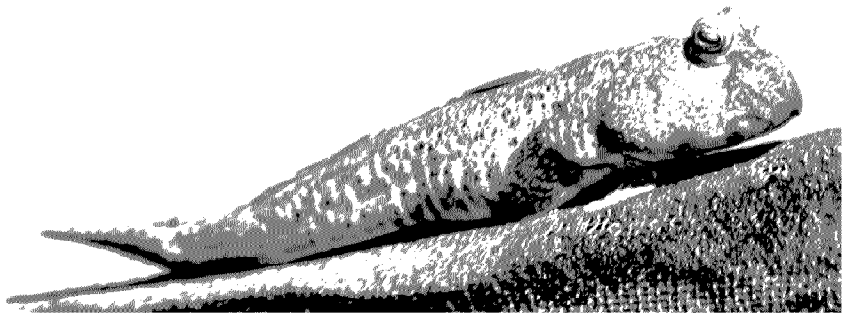


Figure 2 Distribution of **Periophthalmus modestus** in Tainan. (a) Pattern Type, and (b) Non-Pattern Type. (Both of pictures was taken by Huang MC.)

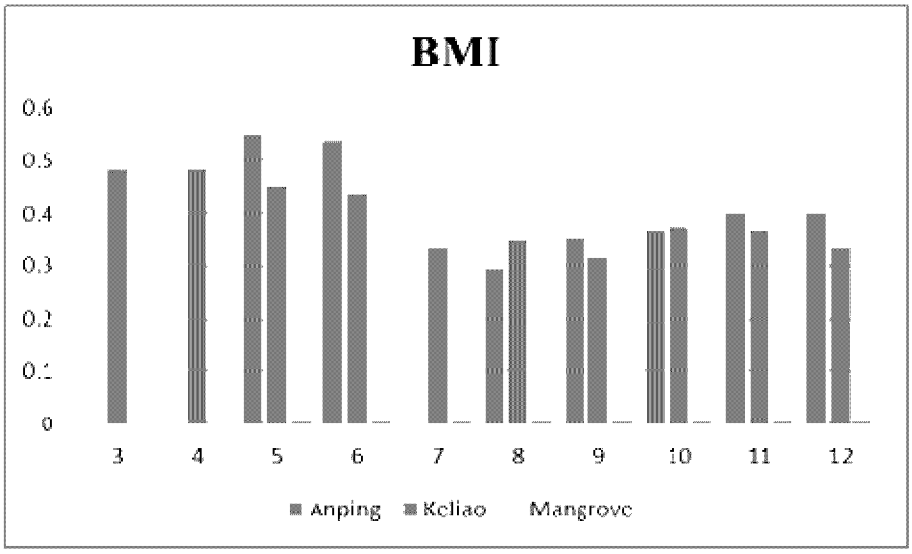


Figure 3 Body Mass Index (BMI) of mudskipper (**Periophthalmus modestus**) in various months. Blue bar is Keliao, brown bar is Anping, and green bar is Mangrove.

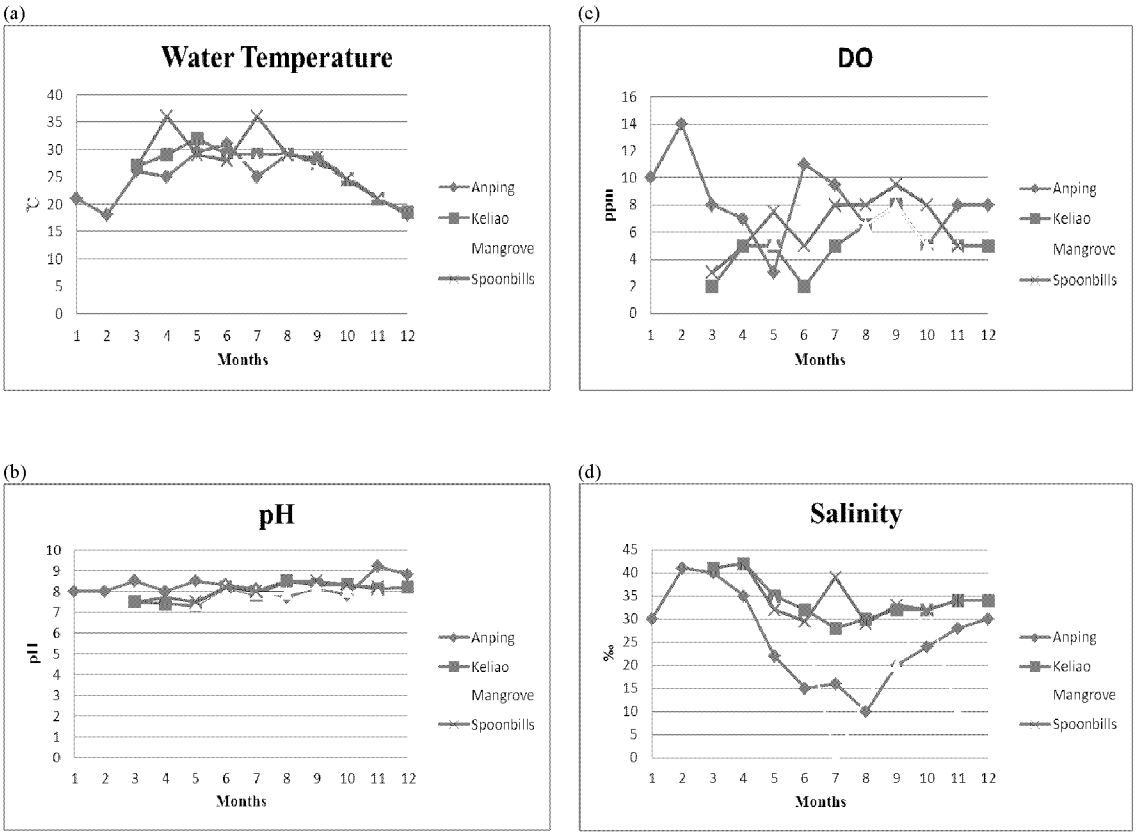


Figure 4 Changes of Environmental Factors for mudskipper (**Periophthalmus modestus**) in (a) water temperature (b) pH (c) dissolved oxygen, and (d). salinity. Blue line is Anping, brown line is Keliao, green line is Spoonbills area, and black line is Mangrove.