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Population Structures and Diets of Two Species of *Pisodonophis* (Ophichthidae) from the Southwest Coast of Taiwan

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Abstract

This study was used to lift nets and trap net fishing at intertidal zone of lagoon and estuarine regions of southern Taiwan. From July 2013 to July 2018, a total 420 specimens of *Pisodonophis* were analyzed, the average total body length (TL) and average body weight (W) of *P. boro* eels are 68.4 ± 11.9 cm and 140.4 ± 86.1 g (N = 194), respectively. Typically, *P. cancrivorus* eels are smaller (TL = 52.8 ± 9.2 cm) and lighter (W = 107.9 ± 73.7 g [N = 119]) than *P. boro* eels. The natural logarithmic linear relationships between the TL and W of *P. boro* and *P. cancrivorus* are respectively expressed as $\ln(W)_b = 2.4405 \ln(TL) - 5.4448$ ($R^2 = 0.796$, N = 194) and $\ln(W)_c = 3.2168 \ln(TL) - 8.2027$, ($R^2 = 0.934$, N= 119). *P. cancrivorus* typically preys on shrimp, crab, and fish; lab assessment revealed that the frequencies of occurrence of these foods in their guts were 49%, 21%, and 15%, respectively (N = 100). The main catch months of *P. boro* were during the rainy season, and that of *P. cancrivorus* were the winter season in Taiwan. The average W values of *P. boro* from Jhuoshuei and Puzih estuaries were 343.2 ± 218.8 g (N = 91) and 140.4 ± 86.1 g (N = 194), respectively. Furthermore, the results of the study revealed that the Puzih estuary is overfished. We suggest that fishery management units should develop some protection measures for the conservation of aquatic ecosystems in estuarine regions. For example, the *P. boro* weighing less than 113 g will be released back to the estuary.

Keywords

Pisodonophis boro, *P. cancrivorus*, Population Structure, Diet, Overfishing, Taiwan

1. Introduction

The family Ophichthidae (Anguilliformes) consists of approximately 323 species grouped into 62 genera; 67 species belonging to 24 genera have been recorded at estuaries in Taiwan [1] [2] [3] [4] [5].

The distribution of rice-paddy eel ((*Pisodonophis boro* (Hamilton, 1822)) and longfin snake-eel (*P. cancrivorus* (Richardson, 1848)) extends from the Indo-West Pacific region including the Red Sea, East Africa, India, Indonesia, Taiwan Area, Japan, Korea, Philippines, and Polynesia to Australia [6] [7] [8] [9]. Although the biology, morphology, and fecundity of snake-eels [10] [11] [12] and the diet, migration, habitat, and swimming behavior of *P. boro* and *P. cancrivorus* have been reported [13] [14] [15] [16], few studies have investigated their population structure in the southwest coast of Taiwan [17].

Length-weight relationship (LWR) has been used to convert lengths into biomass for management and evaluation of fish in various areas [9] [18] [19]. Furthermore, the estimated LWRs of four species of snake eel juveniles from India were reported to be 3.6 - 58.5 cm [9]. Lampang *et al.* (2021) [20] studied the body size distribution and ovarian histology of *P. boro* from Thailand. *P. boro* eels use mangrove mudflats as homing habitats for feeding, breeding, and migration during the breeding season [21].

Fishermen fish for *P. boro* on tidal mudflats by setting 5 to 20 lift and trap nets overnight, which trap snake eels hunting for food at night. Another method for catching snake eels is looking in and around the holes that they dwell in. At the southern bank of Jhuoshuei estuary, fishermen catch eels individually; however, in other estuaries and lagoons, a group of two or more fishermen fish for snake eels. Fishermen who are fishing alone are willing to release small snake eels that weigh less than 3 tw-tael (Taiwan weight unit, about 112.5 g) unless they are dead. However, when fishing in groups, fishermen are unwilling to release small snake eels because no law mandates them to do so.

Therefore, the objective of this study is to provide information for fishery assessment using the LWR, fishing methods and attitudes, and management as well as to compare populations of the same species from different regions.

2. Materials and Methods

We collaborated with seven local fishermen who helped us fish samples were used lift nets and trap net fishing at intertidal zone of lagoon and estuarine regions of southern Taiwan (120˚05'04.9"E - 20˚15'50.4"E, 23˚16'18.7"N - 23˚50'46.2"N) [22]. The sampling sites including the Puzih estuary (November 2014-July 2018), Jhuoshuei (Zhuoshui) estuary (July 2013-July 2015), and Beimen lagoon (October 2017-July 2018). collected overnight.

The Jhuoshuei estuary is a bare sandy beach approximately 470 ha, the Puzih estuary and lagoon of are approximately 500 ha and 650 ha, Beimen lagoons is approximately 100 ha, with mangroves covering 14 ha of its riverbank and mudflats [22] [23]. The gravel in the sample areas of the Jhuoshuei estuary was coarse (0.15 - 0.25 mm [38.4%], followed by 0.25 - 0.60 mm [24.5%]). The grain size of

the sand in the Puzixikou sample area was fine (0.063 - 0.15 mm [43.0%], followed by 0.15 - 0.25 mm [36.2%]) [22]. The area and the grain size of the intertidal zone not only affect the habitat of *P. boro* and, *P. cancrivorus*, but also affect the abundance of their food.

We collected *P. boro* and *P. cancrivorus* between November 2014 and July 2018 from the first sampling site Puzih estuary of Taiwan's southwest coast. Then, we collected *P. boro* eels only between November 2013 and July 2015 from the second sampling site Jhuoshuei estuary. The main difference of *P. boro* and, *P. cancrivorus* in external form is the head and tail [3]. The main difference of P. boro and, P. cancrivorus in external form is the triangle head and rouge tail of the former. All 94 specimens of *P. cancrivorus* and 13 specimens of *P. boro* were stored in a freezer at 0˚C and assessed at the laboratory of the Department of Environmental Engineering, Kun-Shan University. The TL values of these specimens were recorded to the nearest 0.1 cm by using digital calipers. The W values of these specimens were recorded to the nearest 0.1 g by using a digital scale. Live *P. boro* eels are typically used for preparing medicinal liquor in East Asia and they are priced at 600 $/kg in Taiwan. Therefore, measurements were performed by reducing their activity at low temperatures (<15˚C) so there is a large error, its TL with 5 cm, and W with 5 g at the scene.

The natural logarithmic linear relationship between TL and W was calculated according to the linear equation $\ln(W) = a \ln(TL) + b$, where Ln is the natural logarithm, a is the slope, and b is the intercept [18] [20] [24] [25]. Compare the slope value of the LWR linear equation of the *P. boro* and, *P. cancrivorus*.

The stomach and gut contents of 119 specimens of *P. cancrivorus* and 11 specimens of *P. boro* were examined after thawing. All stomach and gut contents (fish otoliths and bones, crab claws, shrimp heads and tails, and shell hinge teeth elements) were preserved in 75% ethanol and subsequently washed, compared and identification [4] [26] [27] [28]. The data are presented as mean ± standard deviation.

3. Results

From July 2013 to July 2018, a total of 420 specimens were analyzed, comprising 288 specimens of *P. boro* (Hamilton, 1822) and 132 specimens of *P. cancrivorus* (Richardson, 1848) from the Southwest coast of Taiwan.

3.1. The LWR of *Pisodonophis* Spp. from Puzih Estuary

From November 2014 to July 2018, at the first sampling site, Puzih estuary of Taiwan's southwest coast, the average TL of *P. cancrivorus* was 52.8 ± 9.2 cm (range: 34.0 - 82.0 cm) and the average W was 107.9 ± 73.7 g (range: 20.5 - 555.0 g, N = 119); the average TL of *P. boro* was 68.4 ± 11.9 cm (range: 47.3 - 143.0 cm) and the average W was 140.4 ± 86.1 g (range: 41.3 - 1012.5 g, N = 194) (**Figure 1**). *P. cancrivorus* was smaller than *P. boro*. The natural logarithmic equations of *P. cancrivorus* $\ln(W)_c = 3.2168 \ln(TL) - 8.2027$ ($R^2 = 0.9341$, N = 119) and that of *P. boro* $\ln(W)_b = 2.4405 \ln(TL) - 5.4448$ ($R^2 = 0.796$, N = 194) (**Figure 2**)

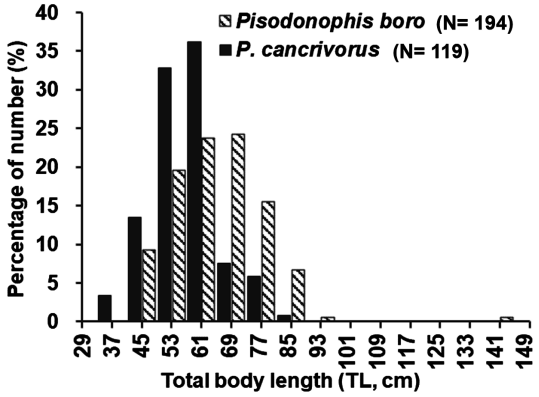

Figure 1. Distribution of the total body length of *Pisodonophis boro* (N = 194) and *P. cancrivorus* (N = 119) from the Puzih estuary of Taiwan's southwest coast between November 2014 and July 2018.

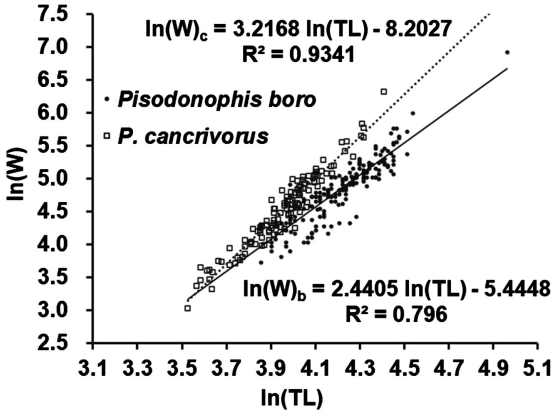

Figure 2. Natural logarithmic linear relationships between total body length (cm) and weight (g) of *Pisodonophis boro* (N = 194) and *P. cancrivorus* (N = 119) from the Puzih estuary of Taiwan's southwest coast between November 2014 and July 2018.

indicated positive linear relationships between the natural logarithms of TL and W for both *P. boro* and *P. cancrivorus*. Furthermore, *P. boro* is thinner than *P. cancrivorus*.

3.2. Monthly Population Changes of *Pisodonophis* Spp. from the Southwest Coast of Taiwan

From the total sampling sites of Taiwan's southwest coast, for *P. cancrivorus*, 59 (44.7%), 25 (18.9%), 23 (17.0%), and 17 (12.9%) specimens were collected in November, January, December, and October, respectively (N = 132) (Figure 3). These months constitute the winter season in Taiwan. For *P. boro*, 81 (28.1%), 75 (26.0%), 49 (17.0%), and 20 (6.9%) specimens were collected in July, September, June, and August, respectively (N = 132) (Figure 3). These months constitute the rainy season in Taiwan.

3.3. Diet of *Pisodonophis* Spp.

In total, 119 guts of *P. cancrivorus* and 11 guts of *P. boro* were examined; 100

specimens of *P. cancrivorus* and 3 specimens of *P. boro* had food in their guts, whereas the guts of the 27 specimens were empty. In total, 123 food items were retrieved. *P. boro* prey on shrimp (N = 3). *P. cancrivorus* prey on shrimp, crab, fish, and mollusks with frequencies of occurrence of 49%, 21%, 15%, and 2%, respectively (N = 100).

The family levels of these prey items were identified. Shrimp: Palaemonidae and Penaeidae; crab: Grapsidae, Ocypodidae, and Portunidae; fish: Gerreidae and Leiognathidae; and shell: Laternulidae.

3.4. Overfishing of *Pisodonophis boro*

In the Jhuoshuei estuary during November 2013 to July 2015, the average W of *P. boro* was 343.2 ± 218.8 g (range: 75.0 - 1, 350 g) (N = 91). The average W of *P. boro* from Puzih estuary was 40.9% of that of the Jhuoshuei estuary. The Jhuoshuei estuary accounted for 39.6% of specimens weighing more than 300 g, whereas the Puzih and other estuaries accounted for only 2.1% (Figure 4). Obviously, Puzih and other estuaries were overfishing of *P. boro*.

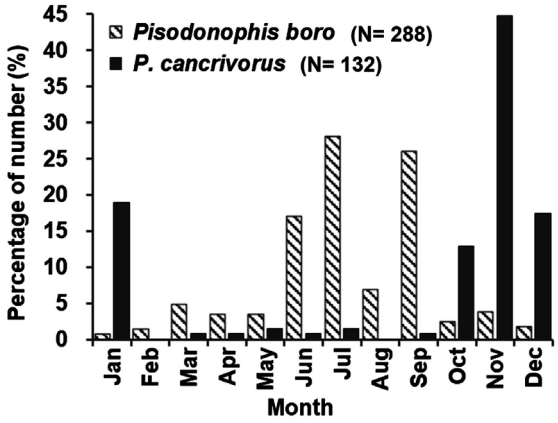

Figure 3. Monthly changes in numbers of *Pisodonophis boro* (N = 288) and *P. cancrivorus* (N = 132) from the southwest coast of Taiwan between July 2013 and July 2018.

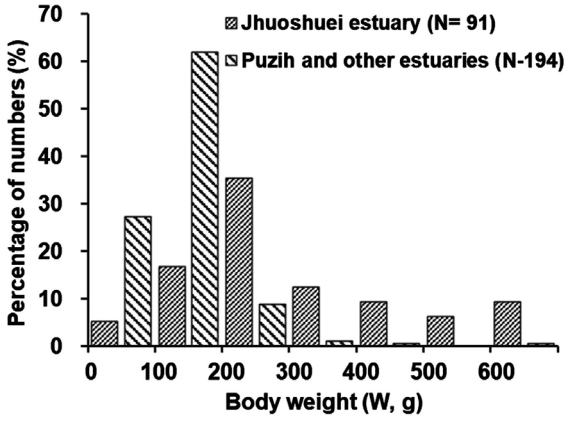

Figure 4. Distribution of the weight (g) of *Pisodonophis boro* at the Jhuoshuei estuary from November 2013 to July 2015 and at the other estuaries of Taiwan's southwest coast from November 2014 to July 2018.

4. Discussion

Although studies have reported that eels use mangrove mudflat habitats for breeding and feeding [21], the result of this study revealed eels thrive on the bare sandy beaches of the Jhuoshuei estuary and other habitats in Taiwan. Therefore, in addition to mangrove habitats, the size of the beach sand and whether food is abundant, are crucial habitat selection criteria.

The LWR of *P. boro* from the southwest coast of Taiwan is described by $\ln(W)_b = 2.4405 \ln(TL) - 5.4448$, which differs from that provided in FishBase [1]. Because *P. boro* is a crucial ingredient in medicinal wine in East Asia, they are overfished. The presented values, which its weight was larger than 3 tw-tael (Taiwan weight unit, about 112.5 g) can provide guidelines for the conservation of continental aquatic ecosystems in estuarine regions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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