EVALUATION OF *Q/B* VALUES OF DEMERSAL FISH SPECIES IN THE PEARL RIVER ESTUARY, CHINA

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Abstract. The *Q/B* value is defined as the food consumption (*Q*) by a population over a period of time (conventionally a year) relative to its biomass (*B*). The *Q/B* values of 85 fish species were calculated by two empirical models based on the fish caught during three fishery resource surveys from April 2020 to April 2021 in the Pearl River Estuary, as well as determination of the mean annual habitat temperature (T_c), asymptotic weight (W_∞), the aspect ratio of caudal fin (*A*) and referencing the food types. The results showed that among the demersal fish species in the Pearl River Estuary, 20 small-scale fish species swimming by caudal fin propulsion have an average *Q/B* value of 14.12 and an average food consumption of 177.06 kg/km^2·a; while 42 medium-large-scale fish species swimming by caudal fin propulsion have an average *Q/B* value of 11.70 and an average food consumption of 745.29 kg/km^2·a. The average *Q/B* value of 8 small-scale fish species swimming not by caudal fin propulsion is 16.29, and their average food consumption was 119.73 kg/km^2·a. The average *Q/B* value of 15 medium-large-scale fish species swimming not by caudal fin propulsion is 12.75, and their average food consumption is 134.64 kg/km^2·a. The *Q/B* values and food consumption of these 85 demersal fish species can be useful for constructing Ecopath (trophic) models and studying the nutrient structure of marine ecosystems in the Pearl River Estuary and even the northern South China Sea.
Keywords: *empirical models, caudal fin, small-scale fish species, medium-large-scale fish species, food consumption*

Introduction

One of the most important parameters required to estimate the energy flow of marine ecosystems is the food consumption of fish. This is a significant metric to quantitatively evaluate the ecosystem's carrying capacity, the relationship between predator and prey, and it would also provide the basis for establishing an energy model of marine ecosystems. The *Q/B* value has been defined as the food consumption (*Q*) by a population over a period of time (conventionally a year) relative to its biomass (*B*) (Polovina, 1984; Pauly, 1989). The *Q/B* value linking fish food consumption with biomass becomes an important input parameter for the construction of Ecopath (trophic) models (Polovina, 1984; Christensen and Pauly, 1993). In addition, the *Q/B* value, used in conjunction with other growth models [e.g. , Bayesian length-at-age models (Smart and Grammer, 2021; Mukherji et al., 2021), "*Wiff*"-growth-function models (Wiff et al., 2015)], is an important tool for comprehensively understanding the life history of fish. Furthermore, in more practical settings, *Q/B* value can be used to determine the ecological carrying capacity of

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fishery resources, facilitating the development of effective management plans (Stabler et al., 2018; Xu et al., 2022).

The *Q/B* value of fish species can be calculated by laboratory experiments or long-term observational data in natural waters (Garcia and Duarte, 2002). However, both require a large amount of time as well as suitable facilities. In the absence of laboratory measurements or observational data, *Q/B* values to be used as input parameters for models or other studies were often replaced by arbitrary guesses (Palomares and Pauly, 1998). Based on extensive investigations of fish food consumption, researchers (Palomares and Pauly, 1989, 1998; Pauly and Christensen, 1990) proposed that the empirical models to calculate *Q/B* values of fish species with different swimming styles revealed correlations between the *Q/B* values and the asymptotic weight, habitat temperature, caudal fin aspect ratio, and food type consumed. Many studies have verified the accuracy of these empirical models in different locations, and those empirical models have been widely used (Garcia and Duarte, 2002; Kavanagh et al., 2004; Gubiani et al., 2012; Behzadi et al., 2018; Schmitt et al., 2021; Wang et al., 2021). However, there are few systematic studies on the *Q/B* value of fish species in specific sea areas. As an indispensable input parameter of the Ecopath (trophic) model, *Q/B* value is estimated by empirical models or by referring to other models (Christensen and Walters, 2004; Bhavan et al., 2021; Montero et al., 2021; Xu et al., 2022). Therefore, lacking an accurate *Q/B* value is one of the main factors that affects the accuracy of the Ecopath (trophic) model. Gubiani et al. (2012) explored *Q/B* values of 135 fish species sampled across thirty reservoirs in the State of Paraná, Ouyang and Guo (2010) calculated the *Q/B* values of 103 fish species in the East China and the Yellow China Seas using empirical models. However, there have been no detailed reports or systematic studies of the *Q/B* values of fish species in the Pearl River Estuary or in the northern South China Sea.

Due to various factors such as overfishing, marine environmental pollution as well as other disturbances by human activities, fishery resources in the Pearl River Estuary have been declining for the past 20 years (Xu et al., 2021). Consequently, the fishery resources obtained has not been meeting the needs of the Guangdong-Hong Kong-Macao Greater Bay Area nearby. The main spatial ecological groups of fish in the Pearl River Estuary are demersal and near-demersal fish, which account for 64.21% of the species (Li, 2018). Benthic feeding taxa are the dominant taxa in the Pearl River Estuary (Zhou et al., 2021), therefore, this study will focus on demersal and near-demersal fish. To restore the fishery resource in the Pear River Estuary, it is necessary to evaluate the ecological carrying capacity of fishery resources, in which the *Q/B* values of fish species is the core issue that needs to be resolved. To this end, this study considered the Pearl River Estuary as the core area for fishery resource surveys, and used data from the trawl surveys to study and calculate the *Q/B* values of the main demersal fish. This provided a basic parameter for in-depth study at the trophic level and energy flow characteristics in the Pearl River Estuary, and even in the northern South China Sea marine ecosystem.

Materials and methods

Samples collection

All the fish were evaluated in this article were collected form the Pearl River Estuary. The Pearl River Estuary is located in the north of the South China Sea, south of Hong Kong, west of Macau, and southeast of Zhuhai City. The width of the Pearl River Estuary is approximately 150 km from east to west, and the area is approximately 6000 km^2.

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Located at 21°30′N, 113 °00'E and 22°30′N, 114°30'E, the Pearl River Estuary is the maritime barrier of the Guangdong-Hong Kong-Macao Greater Bay Area (*Fig. 1*). There are more than 100 small islands, such as Wanshan Island, Dongao Island, and Wailingding Island in this area, forming the Wanshan Archipelago. The water depth of this region ranges between 20-30 m. The study area was located in the south of the Pearl River Estuary, where rich nutrients flow into the sea from the upper reaches, providing sufficient nutrition for the production of marine phytoplankton. Being rich in bait resources of phytoplankton and zooplankton, the study area has formed the largest natural marine fishing ground (the Pearl River Estuary Fishing Ground) in the northern South China Sea. In 2015, the National Marine Ranching Demonstration Zone of Wanshan island adjacent area was approved as the first national marine ranching demonstration zones, covering an area of 312.00 km^2. In 2018, the National Marine Ranching Demonstration Zone of Miaowan island adjacent area was approved as the fourth national marine ranching demonstration zone, covering an area of 9.83 km^2. Artificial reef habitats were constructed in early 2011 in the Wanshan-National Marine Ranching Demonstration (Chen and Chen, 2020), and the Miaowan-National Marine Ranching Demonstration Zone deployed artificial reefs approximately 10 years ago (Xu et al., 2022). Artificial reefs have been shown to attract and concentrate fish biomass, overall, improving species richness to a greater extent than control sites (Scott et al., 2015; Yuan et al., 2021; Nguyen et al., 2022). Additionally, total fish production tends to be higher on artificial reefs than on natural reefs (Granneman and Steele, 2014), highlighting their effectiveness. Thus, surveys around artificial reefs can allow for more fish to be caught. The investigation of the fishery resource trawl surveys in the study area are mainly concentrated in the Wanshan-National Marine Ranching Demonstration, the Miaowan-National Marine Ranching Demonstration Zone, and the sea area adjacent to the Wailingding Island, where most fish in the Pear River Estuary are attracted and concentrated.

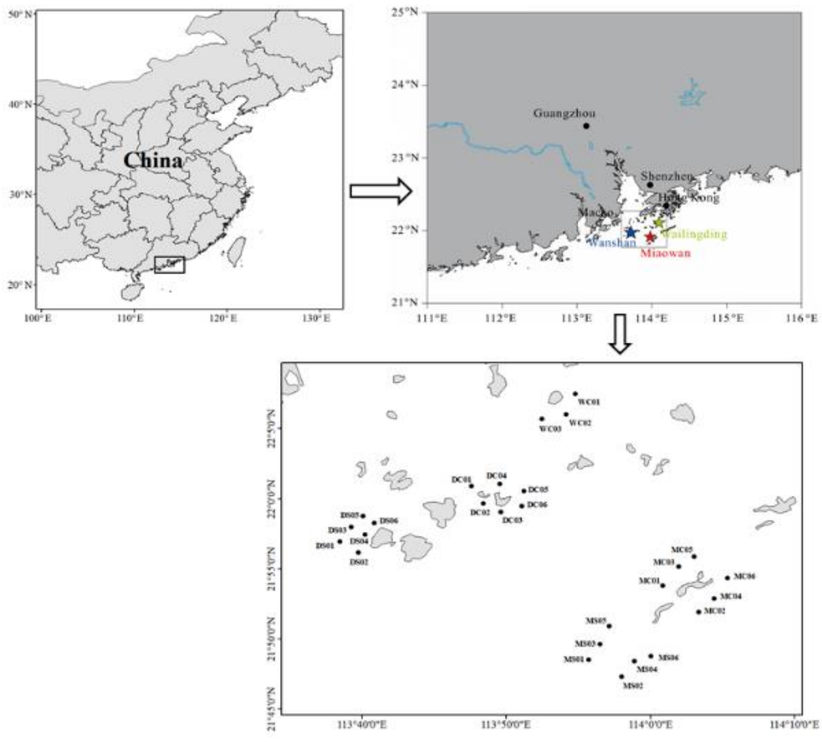

Figure 1. *The location of the Pearl River Estuary and the fishery sampling site*

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Fishery resource trawl surveys were carried out in the Wanshan Archipelago, including the three areas of Wanshan, Miaowan, and Wailingding Island adjacent area in the Pearl River Estuary. In the study area, six trawl stations (DS01, DS02, DS03, DS04, DS05, and DS06) were set up in the artificial reef area near Wanshan Island; and 6 trawl stations (DC01, DC02, DC03, DC04, DC05, and DC06) were set up in the non-artificial reef area near Wanshan Island. Furthermore, there were six trawl stations (MS01, MS02, MS03, MS04, MS05, and MS06) set up in the artificial reef area, and six trawl stations (MC01, MC02, MC03, MC04, MC05, and MC06) set up in the non-artificial reef area near Miaowan Island. There were three trawl stations (WC01, WC02, and WC03) set up in the control area near Wailingding Island (*Fig. 1*, *Table A1*). Three trawl surveys were conducted in the spring of 2020 (April), the winter of 2020 (November and December), and the spring of 2021 (April).

The net used during the course of this study is a two-piece bottom trawl, each trawl with long 6.0 m and wide 4.0 m, and the mesh of the dragnet is 24 mm. Each survey station trawled for 1 h, and the trawl speed remained approximately at 5.556 km/h. When the demersal fish samples were caught, they were cryopreserved and brought back to the laboratory for species identification. In the laboratory, each fish sample was identified to the species level, and the body length and weight of the fish samples were measured, biomass density was calculated, and each sample was photographed to estimate their caudal fin aspect ratio. The bottom water was collected to determine the in situ water temperature during the trawl survey in the Nov. 2020 and Apr. 2021; the bottom water temperature was measured again in July 2020 (*Table A1*). Across the three surveys, the bottom water temperature of the Pearl River Estuary was determined to be 23°C±2°C, indicative of there being little seasonal variation in bottom water temperature of the Pearl River Estuary. Thus, the temperature of the bottom water could represent the mean annual habitat temperature, a parameter used in the calculation of *Q/B* values. In the present study, well-preserved fish were selected for accurate weight and caudal fin aspect ratio measurements. The information regarding the bottom water temperature and the number of fish species that were caught is shown in *Table A1*.

Methods

To estimate the *Q/B* values, two empirical models were used: *Eq.1* is employed for fish species that use their caudal fin as the (main) swimming organ of propulsion (Palomares and Pauly, 1998). *Eq.2*, based on Pauly and Christensen (1990) and Guo and Tang (2004), is employed for fish species that do not use their caudal fin as the (main) swimming organ of propulsion. These are expressed in the following form:

$$\mathrm{Log}Q/B=7.964-0.204\log W_{\infty}-1.965\,T'+0.083A+0.532h+0.398d \qquad \text{(Eq.1)}$$

$$\mathrm{Log}Q/B=6.37-1.5045\,T'-0.168\log W_{\infty}+0.14f+1.276F_t \qquad \text{(Eq.2)}$$

where *Q/B* is the annual food consumption/biomass ratio of each fish population; W_{∞} is the asymptotic weight (wet weight, in g) of the fish in the population in question; T_c is the mean annual habitat temperature for the fish population in question (in °C); T' is the mean annual habitat temperature for the fish population in question expressed as $T'=1000/[T_c$ (℃) +273.15]; *A* is the aspect ratio of the caudal fin of the fish species (expressed as $A=h^2/s$, where *h* is the height of the caudal fin and *s* is the surface area of the caudal fin) and a measure of the swimming and metabolic activity of the fish. *h* and *d*

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in *Eq.1* are binary variables for types of food consumed (h=1, d=0 for herbivores; h=0, d=1 for detritivores; h=0, d=0 for carnivores); f in *Eq.2* is a feeding type variable (1 for apex and/or pelagic predators and/or zooplankton feeders, and 0 for other feeding types); F_t in *Eq.2* is the feeding type (0 for carnivores and 1 for herbivores and/or detritivores).

Asymptotic weight (W_∞) indicates the mean weight that the fish would reach if they were to grow indefinitely (Palomares and Pauly, 1998). Asymptotic weight (W_∞) could be obtained from asymptotic length using length-weight relationships in cases where the parameters were available (Garcia et al., 1999), or it could be estimated by maximum weight by the *Eq.3* (Garcia and Duarte, 2002; Ouyang and Guo, 2010). In this paper, asymptotic weight (W_∞) was estimated by the *Eq.3*:

$$W_\infty = W_{\max}/0.86 \quad \text{(Eq.3)}$$

The measurement method of the height (h) and area (s) of the caudal fin of different shapes follows the theory proposed by Palomares et al. (1998), extending to the narrowest part of the caudal peduncle.

The mean annual habitat temperature (T_c) is the average values of the fish habitat temperature within a year. In this study, the average temperature (i.e., 22.25°C) of the bottom water samples at each trawl station in the summer of 2020 (July) and the winter of 2020 (November and December) was recorded to characterize the mean annual habitat temperature (T_c).

Identify the types of food consumed by adult fish by referring to the published literature (Palomares and Pauly, 1989, 1998; Huang and Zhang, 2008; Ouyang and Guo, 2010; Zhang and Chen, 2005; Zhang, 2005) to assign the value to parameters h, d, f, and F_t.

Results

Q/B values of small-scale fish species swimming by caudal fin propulsion

The *Q/B* values of 20 small-scale fish species swimming by caudal fin propulsion in the Pearl River Estuary are generally between 9.04 and 21.14, with a mean value of 14.12 (*Table 1*). The *Q/B* values of samall -scale fish species swimming by caudal fin propulsion in the Pearl River Estuary are usually larger than 11, which means those small-scale fish species need to consume more than 11 unit bait to increase 1-unit biomass. Taking W_∞, A and *Q/B* for *k*-means clustering, the result shows that the small-scale fish species in the Pearl River Estuary can be divided into two main groups (*Fig. 2a*), namely, cluster 1 and 2, which consist of 8 and 12 fish species, respectively (*Table A2*).

Q/B values of medium-large-scale fish species swimming by caudal fin propulsion

Table 2 shows the *Q/B* values of 42 medium-large-scale fish species swimming with a caudal fin method of propulsion in the Pearl River Estuary. These medium-large-scale fish species swimming by caudal fin propulsion are the main economic species of the Pearl River Estuary fishery resources, and their *Q/B* values are generally between 5.65 and 19.69, with an average value of 11.70. Taking W_∞, A and Q/B for *k*-means clustering, the result shows that the medium-large-scale species in the Pearl River Estuary can be divided into three main groups (*Fig. 2b*), cluster 1 includes 30 species, cluster 2 includes 11 species, and cluster 3 includes 3 species (*Table A3*).

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Table 1. *Q/ B values of small-scale fish species swimming by caudal fin propulsion in the Pearl River Estuary*

Species	W∞	h	d	A	Q/B
Monocentrus japonicus	1.74	0	0	0.75	21.14
Apogonichthys ellioti	6.86	0	0	1.01	16.80
Thrissa kammalensis	6.98	0	0	1.04	16.83
Oxyurichthys tentacularis	10.47	0	0	0.43	13.79
Apogonichthys lineatus	11.63	0	0	1.08	15.28
Minous inermis	12.79	0	0	0.99	14.74
Opistognathus evermanni	12.79	0	0	1.50	16.24
Gnathagnus elongatus	13.95	0	0	1.56	16.14
Parachaeturichthys polynema	19.77	0	0	0.45	12.16
Apogon quadrifasciatus	22.09	0	0	1.16	13.62
Brachypleura novaezeelandiae	22.09	0	0	1.29	13.96
Myersina filifer	24.42	0	0	1.03	13.01
Apogonichthys ellioti	24.42	0	0	0.77	12.38
Brachypterois serrulata	28.02	0	0	1.25	13.20
Oxyurichthys papuensis	39.07	0	0	0.80	11.32
Polycaulus uranoscopa	43.02	0	0	0.91	11.33
Trachurus japonicus	48.49	0	0	2.18	14.10
Trypauchen vagina	88.60	0	0	0.50	9.04
Callionymus richardsoni	34.88	0	0	0.63	11.21
Leiognathus brevirostris	16.28	0	0	1.70	16.07

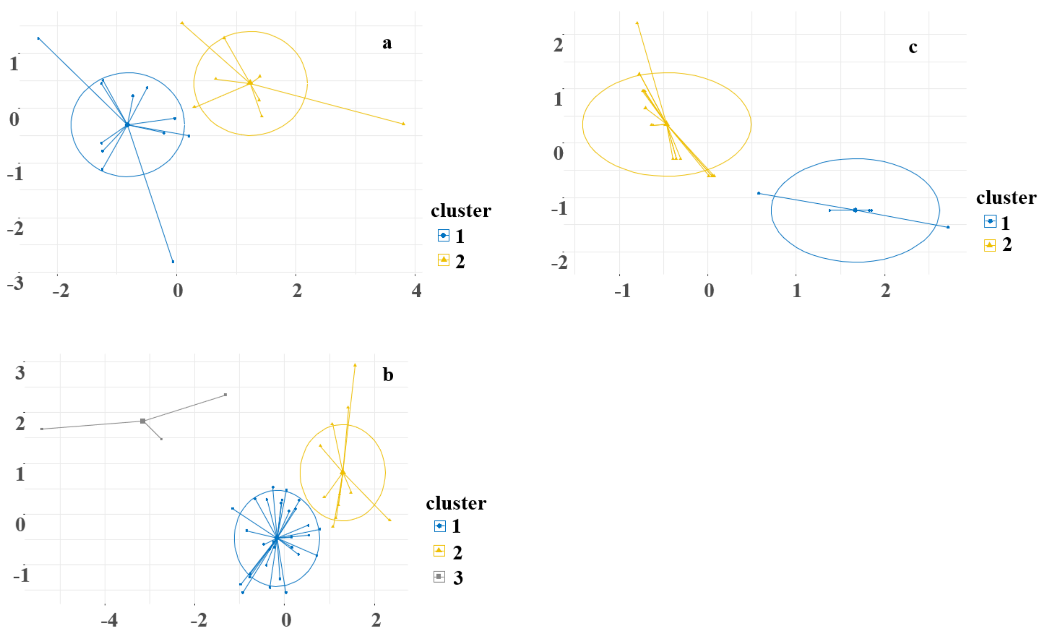

Figure 2. *k-means clustering of Q/B values of the demersal fish species in the Pearl River Estuary. a, small-scale fish species swimming by caudal fin propulsion; b, medium-large-scale fish species swimming by caudal fin propulsion; c, fish species swimming not by caudal fin propulsion*

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Table 2. *Q/ B values of medium-large-scale fish species swimming by caudal fin propulsion in the Pearl River Estuary*

Species	W∞	h	d	A	Q/B
Upeneus japonicus	3.49	0	0	1.12	19.69
Pleuronichthys cornutus	15.12	0	0	1.25	14.97
Priacanthus macracanthus	15.12	0	0	0.87	13.92
Hapalogenys nigripinnis	16.28	0	0	1.37	15.08
Parapercis sexfasciata	18.60	0	0	1.55	15.19
Paramonacanthus nipponensis	22.09	0	0	0.41	11.80
Parargyrops edita	22.09	0	0	1.72	15.15
Onigocia tuberculatus	22.09	0	0	1.26	13.88
Hapalogenys mucronatus	27.91	0	0	0.94	12.45
Terapon theraps	27.91	0	0	1.20	13.08
Hapalogenys nitens (Richarodson)	32.56	0	0	1.72	14.00
Osteomugil ophuyseni	33.72	0	0	1.35	12.95
Sebastiscus marmoratus	39.53	0	0	1.07	11.89
Argyrosomus pawak	43.02	0	0	0.53	10.54
Parapercis pulchella	47.67	0	0	1.22	11.77
Psenopsis anomala	65.12	0	0	1.62	11.93
Chelidonichthys spinosus	67.44	0	0	1.74	12.12
Epinephelus fasciatomaculatus	69.77	0	0	0.86	10.17
Apistus carinatus	69.77	0	0	1.10	10.65
Gerres filamentosus	69.77	0	0	2.97	15.22
Epinephelus bleekeri	76.74	0	0	1.60	11.49
Sillago japonica	78.84	0	0	1.18	10.54
Lepidotrigla alata	80.12	0	0	1.08	10.31
Polynemus sextarius	81.40	0	0	2.47	13.40
Pelates quadrilineatus	82.56	0	0	2.77	14.15
Johnius belengeri	101.16	0	0	0.70	9.14
Pennahia argentata	101.16	0	0	1.15	9.96
Grammoplites scaber	102.91	0	0	0.49	8.75
Onigocia macrolepis	104.65	0	0	0.75	9.17
Saurida undosquamis	108.14	0	0	3.56	15.58
Argyrosomus aneus	109.30	0	0	1.72	10.94
Saurida tumbil	110.47	0	0	1.76	11.00
Upeneus tragula	111.63	0	0	1.90	11.27
Harpodon nehereus	121.28	0	0	0.60	8.64
Nemipterus japonicus	162.79	0	0	1.76	10.16
Gastrophysus spadiceus	162.79	0	0	1.93	10.50
Epinephelus awoara	189.53	0	0	1.32	9.06
Uranoscopus oligolepis	213.95	0	0	1.75	9.59
Saurida elongata	313.95	0	0	1.57	8.57
Drepane punctata	662.79	0	0	2.92	9.52
Sparus latus	1000.00	0	0	2.05	7.42
Platycephalus sp.	2023.26	0	0	1.38	5.65

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Q/B values of demersal fish species swimming not by caudal fin propulsion

The *Q/B* values of demersal fish in the Pearl River Estuary that do not use their caudal fin as the (main) swimming organ of propulsion genrally vary between 9.37 and 20.73, with an average value of 13.98 (*Table 3*). There are 15 medium-large-scale fish species and 8 small-scale fish species in *Table 3*, and their average *Q/B* values are 12.75 and 16.29. Taking W_∞, Q/B for *k*-means clustering, the result shows that the demersal fish species in the Pearl River Estuary can be divided into three main groups (*Fig. 2c*), namely, cluster 1, 2, and 3, which consist of 30, 11, and 3 fish species, respectively (*Table A4*).

Table 3. *Q/ B values of demersal fish species swimming not by caudal fin propulsion in the Pearl River Estuary*

Species	W∞	f	Ft	Q/B
Cynoglossus abbreviatus	60.47	1	0	13.11
Cynoglossus lineolatus	24.53	1	0	15.26
Cynoglossus macrolepidotus	337.21	1	0	9.82
Cynoglossus puncticeps	26.63	1	0	15.05
Muraenesox cinereus	277.91	1	0	10.15
Uroconger lepturus	3.95	1	0	20.73
Dysomma anguillaris	66.28	1	0	12.91
Pisoodonophis cancrivorus	333.72	1	0	9.84
Gymnothorax reticularis	106.16	1	0	11.93
Strophidon sathete	176.63	1	0	10.95
Lepturacanthus savala	111.05	1	0	11.84
Pseudorhombus cinnamoneus	113.95	1	0	11.79
Tephrinectes sinensis	446.51	1	0	9.37
Pseudorhombus oligodon	111.28	1	0	11.83
Arnoglossus tenuis	14.42	1	0	16.68
*Engyprosopon grandisquama**	8.14	1	0	18.36
*Soleaovata Richardson**	60.47	1	0	13.11
*Aseraggodes kobensis**	14.65	1	0	16.64
*Crossorhombus kobensis**	16.40	1	0	16.32
Zebrias quagga (Kaup) *	55.00	1	0	13.32
*Halieutaea stellata**	7.79	1	0	18.50
*Arnoglossus aspilos**	13.95	1	0	16.77
*Octopus ocellatus**	11.63	1	0	17.29

* Represents the small-scale fish species

Food consumption

The *Q/B* values of 4 fish types in the Pearl River Estuary (*Fig. 3*), showing that the *Q/B* values of the fish species that do not use their caudal fin as the (main) swimming organ of propulsion are generally higher than those of fish species swimming with a caudal fin method of propulsion, and the *Q/B* values of small-scale fish species are generally higher than those of medium-large-scale fish species. Fitting the asymptotic weight (W_∞) and *Q/B* values of 85 demersal fish species in the Pearl River Estuary, the relationship between *Q/B* values and W_∞ is shown in *Figure 4*. The fitting empirical

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relationship between *Q/B* values and the asymptotic weight (W_∞) of demersal fish is as follows:

$$Q/B = 22.65 * W_\infty^{-0.2013} + 2.106 \quad \text{(Eq.4)}$$

The coefficient of determination (R-square) in *Eq.4* is 0.8117, and the root mean squared error (RMSE) is 1.36. As *Eq.4* is based on the *Q/B* values and asymptotic weights (W_∞) of 85 demersal fish species present in the Pearl River Estuary (*Fig. 4*), it is only recommended to apply *Eq.4* for fish species in the Pearl River Estuary when the other parameters are not available.

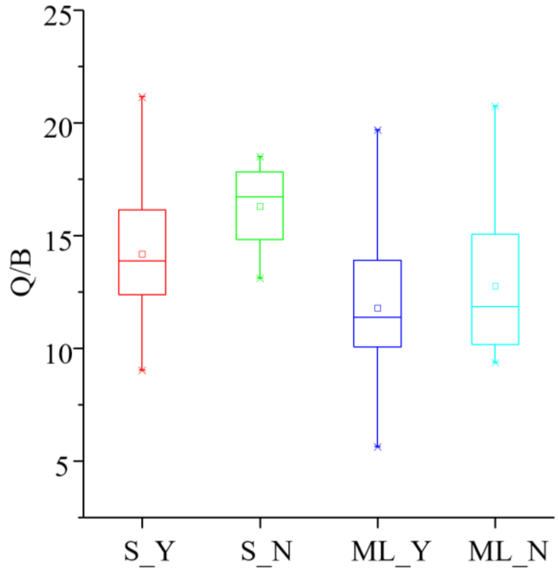

Figure 3. *Q/B values of four fish types in the Pearl River Estuary. S_Y, small-scale fish species swimming by caudal fin propulsion; ML_Y, medium-large-scale fish species swimming by caudal fin propulsion; S_N, small-scale fish species swimming not by caudal fin propulsion; ML_N, medium-large-scale fish species swimming not by caudal fin propulsion*

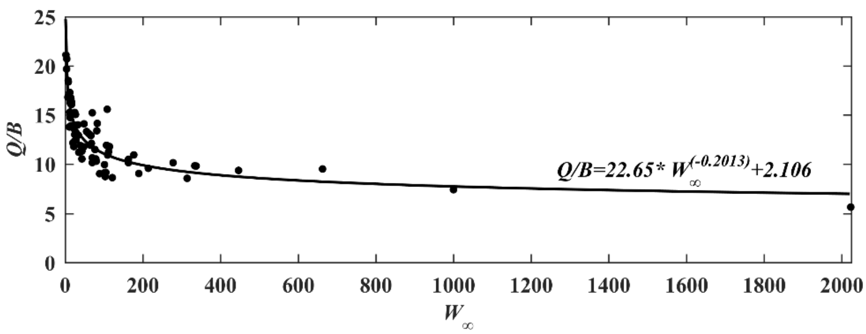

Figure 4. *Relationship between Q/B and* W_∞ *in fish species present in the Pearl River Estuary*

Based on the biomass density of the four types of fish in the Pearl River Estuary, their food consumption can be calculated based on the assumption that the food availability is not limited (*Table 4*). In the Pear River Estuary, medium-large-scale fish species

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swimming with a caudal fin method of propulsion have the largest food consumption, consuming 745.29 $kg/km^2 \cdot a$; the small-scale fish species swimming with a caudal fin method of propulsion have the second highest food consumption at 177.06 $kg/km^2 \cdot a$; the food consumption of medium-large-scale fish species swimming do not propelled with a caudal fin is 134.64 $kg/km^2 \cdot a$, which is lower than the small-scale fish species swimming with a caudal fin method of propulsion; the food consumption of small-scale fish species swimming do not propelled with a caudal fin is the lowest, just consuming 119.73 $kg/km^2 \cdot a$.

Table 4. *Q/B value and food consumption of four fish types in the Pearl River Estuary*

Types	S_Y	ML_Y	S_N	ML_N
Mean of Q/B	14.12	11.70	16.29	12.75
Biomass density (kg/km^2)	12.54	63.70	7.35	10.56
Food consumption ($kg/km^2 \cdot a$)	177.06	745.29	119.73	134.64

S_Y, small-scale fish species swimming by caudal fin propulsion; ML_Y, medium-large-scale fish species swimming by caudal fin propulsion; S_N, small-scale fish species swimming not by caudal fin propulsion; ML_N, medium-large-scale fish species swimming not by caudal fin propulsion

The *Q/B* values of small-scale fish in the Pearl River Estuary are generally above 10.0, indicating that they consume a large amount of food to increase their biomass. As noted in the trawl surveys, there are a large number of small-scale fish in the Pearl River Estuary, and they, in turn, are the food source for many medium- large scale fish. These small-scale fish play a significant role in maintaining energy transfer in marine ecosystems.

Discussion

The *Q/B* value is calculated by the empirical models from parameters of asymptotic weight (W_∞), mean annual habitat temperature (*T'*), caudal fin aspect ratio (*A*), and feeding type parameters. Therefore, obtaining accurate parameters is the main method for improving the accuracy of *Q/B* values. The asymptotic weight (W_∞) must comply with the recent data from field surveys. Our research team went to the study area three times in a survey year (from April 2020 to April 2021) to carry out the trawl surveys and obtain the fish samples. Therefore, the data on fish species in this study reflects the current fishery situation of the Pearl River Estuary accurately. Briefly, the current situation can be accurately reflected by using the maximum weight of the fish samples from April 2020 to April 2021 to estimate the asymptotic weight (W_∞) to calculate *Q/B* values of the fish species in the Pearl River Estuary.

The mean annual habitat temperature (*T'*) is another important parameter for calculating the *Q/B* values. In order to calculate the mean temperature of the habitat, our research team went to the trawl survey stations in summer (August 2020) and winter (November and December 2020) to collect the bottom water samples and measured the temperature on-site, which minimized the error of the habitat temperature and improved the reliability of *Q/B* values. Palomares and Pauly (1998) proposed that measuring the height and surface area of the caudal fin to calculate the aspect ratio of the caudal fin (*A*) should follow the natural shape when the fish are swimming when applying the empirical model. However, it is difficult for the caudal fin to extend to the natural swimming form for some fish species after cryopreservation (e.g. *Callionymus richardsoni* and

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Oxyurichthys tentacularis), which can negatively affect the accuracy of *Q/B* values. In addition, in this study, we measured the aspect ratio of the caudal fin (*A*) with samples from the same species but different in body lengths (e.g., *Drepane punctata*, *Saurida tumbil, and Gastrophysus spadiceus*), the results show that there are slight differences in the caudal fin aspect ratio (*A*) among samples from a same species. There are also differences between the caudal fin aspect ratio (*A*) of fish species in the Pearl River Estuary and in the East China Sea and the Yellow China Sea (Ouyang and Guo, 2010). Therefore, how to improve accuracy in determining the caudal fin aspect ratio (*A*) of fish species to consequently improve the accuracy of *Q/B* value, is the method that need to be further explored in the future. Many studies have been published on the feeding types of fish species in the South China Sea (Zhang, 2005; Zhang and Chen, 2005; Huang and Zhang, 2008). Thus, it is reasonable to judge the feeding types and assign the value to parameters *h*, *d*, *f*, and F_t by referring to published literature.

Fish in marine ecosystems generally prey on organisms with smaller body sizes than their own. Body size is the main factor that affects the biomass, abundance, trophic level, and the relationship between predators and prey (Dickie et al., 1987; Trebilco et al., 2013). Fish eating low-energy food consume more food than fish eating high-energy foods. Compared with large fish, small-scale fish consume more food (Dickie et al., 1987). The relationship between the food consumption of high-trophic level fish and the biomass of their prey is mutually restrictive. When the biomass of prey is much greater than the food consumption required by the predator, the continuous growth of the fish ecology can be maintained. The biomass density of small-scale fish species in the Pearl River Estuary is lower than that of medium-large-scale fish species, and the food consumption of medium-large-scale fish is higher than that of small-scale fish species (*Table 4*). It indicates that the biomass of small-scale fish species in the Pearl River Estuary may not be able to maintain the food demand of the medium-large-scale fish species. Consequently, the larvae of some medium-large-scale fish species may be predated. As a result, the economic value of fishery resources may be reduced.

The biomass density in this study was determined to be lower than that in the published data of the Pearl River Estuary (Li et al., 2012; Li, 2018). This is probably because trawling occurs in spring (April 2020 and 2021) and winter (November 26 to December 7, 2020), while the highest fishery resource density is in summer and is at its lowest in spring and winter (Li et al., 2012). In addition, the structure of fishery resources in the Pearl River Estuary has undergone significant changes, with dominant species and economic species gradually transitioning from fish to shrimps and crabs in the past 30 years (Xu et al., 2021). Fish have also been characterized by miniaturization and low quality, and the small and medium-sized general economic species have gradually replaced the traditional large and high-quality economic species (Tang et al., 2022). Tang’s (2022) study showed that the number and diversity of fishery resources in bottom trawls were lower than in trammel net surveys, which may be another reason for the low biomass in this study.

Ouyang and Guo (2010) calculated the *Q/B* values of 88 fish species swimming with a caudal fin method of propulsion and 15 fish species swimming not by caudal fin propulsion in the East China Sea and the Yellow China Sea using the same empirical model. The *Q/B* values of fish species in the Pearl River Estuary was higher than those in the East China Sea and the Yellow China Sea. Gubiani et al. (2012). calculated the *Q/B* values of 135 fish species from 31 reservoirs in six river basins throughout the State of Paraná, Brazil by the Palomares (1998) empirical model, and the results showed that the

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average *Q/B* values of carnivorous fish is 8.79. The average *Q/B* values of carnivorous fish species swimming by caudal fin propulsion is 12.48 in the Pearl River Estuary, which indicates that the *Q/B* values of fish species in the Pearl River Estuary are higher than those in the reservoirs in the State of Paraná, Brazil. Compared to the East China Sea and the Yellow China Sea, reservoirs in the State of Paraná, Brazil, there are two main reasons for the high *Q/B* values of fish species in the Pearl River Estuary. First, the asymptotic weight (W_∞) of fish species was lower in the Pearl River Estuary. Second, the mean annual habitat temperature (T_c) was higher in the Pearl River Estuary.

In the statistical analysis of fishery resources by Christensen et al. (2014), the fish biomass has declined in the last century. The fishing effort of marine fisheries in China ranks among the highest in the world. The coastal waters along the Pearl River Delta are fishing hotspots with large fishing efforts (Chen and Yao, 2020). The catch rate of the Pear River Estuary fish has dropped due to the factors like over-exploitation, pollution, and changes in the marine environment. Consequently, fish species composition shows a biological performance of small-scale, relatively younger age trend and early sexual maturity (Li and Chen, 2000). In fishery resources, small-scale fish species and/or the larvae of large-scale fish species have an absolute dominance (Yan et al., 2016). The asymptotic weight (W_∞) applied in the empirical models to calculate the *Q/B* values in this study is based on trawl surveys in the Pearl River Estuary in the past year, which shows a relatively younger age compared with the historical data. Comparing the asymptotic weight (W_∞) of the same fish species in the Pearl River Estuary with the East China Sea and the Yellow China Sea, the asymptotic weight (W_∞) of the fish species in the Pear River Estuary are generally lower than those in the East China Sea and Yellow China Sea, which is the main factor leading to higher *Q/B* values for fish species in the Pearl River Estuary.

Fish are ectothermic organisms, and their body temperature is generally 0.5~1.0 ℃ higher than the habitat temperature. Temperature is one of the most important and direct environmental factors affecting the metabolic rate of fish. Temperature can affect fish excretion rate by affecting the metabolic rate of fish tissues (Leung et al., 1999; Yan et al., 2008), and the oxygen consumption rate of fish increases within a suitable temperature range (Das et al., 2004). The food consumption rate increases with increasing temperature (Regier and Holmes, 1990), thus temperature affects the biomass of fish species (Yoseda et al., 2006). Fish will instinctively maximize growth and reproduction by using excess energy (Ouyang and Guo, 2008); therefore, metabolic efficiency will increase with increasing temperature, while the remaining energy will reduce concomitantly, which leads to a reduction in fish biomass and an increase in the *Q/B* values of fish species. The mean annual habitat temperature (T_c) of fish species in the Pearl River Estuary, the East China Sea, and the Yellow China Sea, reservoirs in the State of Paraná of Brazil are 22.25℃, 10–19℃ and 20.27℃, respectively. High temperature is another important factor that causes the *Q/B* values of demersal fish species in the Pearl River Estuary to be generally higher than those in the other two water areas.

Conclusion

This study based on three trawl surveys of fishery resources in the Pearl River Estuary, calculated the *Q/B* values of 85 demersal fish species using the *Q/B* value empirical models. The parameters for the *Q/B* value estimating by empirical models are reasonable, and the results are relatively reliable in this study. The *Q/B* values calculated in this study

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can provide basic parameters for the study of marine fishery resources ecological carrying capacity model, and marine ecosystem energy flow models such as the Ecopath (trophic) model in the Pearl River Estuary and even the northern South China Sea.

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Data availability. All data generated or analyzed during this study are included in this published article.

Ethics approval. All activities were performed according to Chinese laws and regulations. No ethical conflicts exist in the realization of this work.

Consent for publication. All authors have reviewed and approved the present version to be published.

Competing interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX

Table A1. *The sample collection information of GPS position, temperature and the number of caught fish species*

site	GPS position		Apr. 2020		Nov. 2020		Apr. 2021	
	longitude(°E)	latitude(°N)	T (°)*	N	T (°)	N	T (°)	N
DS01	113.64056	21.94917	22.1	13	21.8	8	25.2	23
DS02	113.66250	21.93611	/	9	21.6	14	25.1	22
DS03	113.65417	21.96611	/	9	22	9	24.7	18
DS04	113.67000	21.95722	22.2	9	21.4	8	24.2	20
DS05	113.66778	21.97917	22.4	12	21.4	11	24.9	27
DS06	113.68056	21.97083	/	10	21.3	10	25.2	12
DC01	113.79306	22.01528	22.3	11	22.4	11	25	17
DC02	113.80694	21.99444	/	10	22.7	13	24.8	20
DC03	113.82722	21.98389	22.3	13	22.7	10	24.6	16
DC04	113.82583	22.01750	/	10	22.4	11	25.2	17
DC05	113.85361	22.00917	22.3	15	22.5	17	24.7	17
DC06	113.85139	21.99111	/	12	22.8	11	25	13
MS01	113.92861	21.80833	22.3	15	22.8	32	24.3	16
MS02	113.96694	21.78861	/	15	22.9	25	23.5	10
MS03	113.94222	21.82722	/	23	23	15	24.4	18
MS04	113.98194	21.80667	22.2	12	21.2	24	23.8	10
MS05	113.95278	21.84861	22.4	15	21	17	24.7	10
MS06	114.00111	21.81278	/	15	21.1	19	23.9	9
MC01	114.01472	21.89639	22.8	21	22.1	17	24	14
MC02	114.05611	21.86528	/	12	22.7	18	24	19
MC03	114.03278	21.91944	/	7	22.1	13	24	16
MC04	114.07389	21.88139	21.9	10	22.7	13	24.1	14
MC05	114.05083	21.93139	22.8	10	22.2	18	24.2	13
MC06	114.08972	21.90528	/	9	22.8	18	24.2	4
WC01	113.91361	22.12444	/	/	22.5	4	24.6	22
WC02	113.90278	22.10028	/	/	22.3	12	23.9	31
WC03	113.87472	22.09472	/	/	22	17	24.2	16

T(°) means the temperature, N means the number of caught fish species, "*" Represents the temperature were measured in July 2020. "/" indicates no detection data

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Table A2. *Clusters result of small-scale fish species swimming by caudal fin propulsion in the Pearl River Estuary by k-means clustering*

Cluster	Species
Cluster 1	*Oxyurichthys tentacularis* *Parachaeturichthys polynema* *Myersina filifer* *Apogonichthys ellioti* *Oxyurichthys papuensis* *Polycaulus uranoscopa* *Trypauchen vagina* *Callionymus richardsoni*
Cluster 2	*Monocentrus japonicus* *Apogonichthys ellioti* *Thrissa kammalensis* *Apogonichthys lineatus* *Minous inermis* *Opistognathus evermanni* *Gnathagnus elongatus* *Apogon quadrifasciatus* *Brachypleura novaezeelandiae* *Brachypterois serrulata* *Trachurus japonicus* *Leiognathus brevirostris*

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Table A3. *Clusters result of medium-large-scale fish species swimming by caudal fin propulsion in the Pearl River Estuary by k-means clustering*

Cluster	Species
Cluster 1	*Priacanthus macracanthus*
	Paramonacanthus nipponensis
	Onigocia tuberculatus
	Hapalogenys mucronatus
	Terapon theraps
	Osteomugil ophuyseni
	Callionymus richardsoni
	Sebastiscus marmoratus
	Argyrosomus pawak
	Parapercis pulchella
	Psenopsis anomala
	Chelidonichthys spinosus
	Epinephelus fasciatomaculatus
	Apistus carinatus
	Epinephelus bleekeri
	Sillago japonica
	Lepidotrigla alata
	Johnius belengeri
	Pennahia argentata
	Grammoplites scaber
	Onigocia macrolepis
	Argyrosomus aneus
	Saurida tumbil
	Upeneus tragula
	Harpodon nehereus
	Nemipterus japonicus
	Gastrophysus spadiceus
	Epinephelus awoara
	Uranoscopus oligolepis
	Saurida elongata
	Priacanthus macracanthus
	Paramonacanthus nipponensis
	Onigocia tuberculatus
	Hapalogenys mucronatus
	Terapon theraps
	Osteomugil ophuyseni

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Cluster	Species
	Callionymus richardsoni
	Sebastiscus marmoratus
	Argyrosomus pawak
	Parapercis pulchella
	Psenopsis anomala
	Chelidonichthys spinosus
	Epinephelus fasciatomaculatus
	Apistus carinatus
	Epinephelus bleekeri
	Sillago japonica
	Lepidotrigla alata
	Johnius belengeri
	Pennahia argentata
	Grammoplites scaber
	Onigocia macrolepis
	Argyrosomus aneus
	Saurida tumbil
	Upeneus tragula
	Harpodon nehereus
	Nemipterus japonicus
	Gastrophysus spadiceus
	Epinephelus awoara
	Uranoscopus oligolepis
	Saurida elongata
Cluster 2	*Upeneus japonicus*
	Pleuronichthys cornutus
	Hapalogenys nigripinnis
	Leiognathus brevirostris
	Parapercis sexfasciata
	Parargyrops edita
	Hapalogenys nitens (Richarodson)
	Gerres filamentosus
	Polynemus sextarius
	Pelates quadrilineatus
	Saurida undosquamis
Cluster 3	*Drepane punctata*
	Sparus latus
	Platycephalus sp.1

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Table A4. *Clusters result of demersal fish species swimming not by caudal fin propulsion in the Pearl River Estuary by k-means clustering*

Cluster	Species
Cluster 1	*Cynoglossus macrolepidotus* *Muraenesox cinereus* *Pisoodonophis cancrivorus* *Strophidon sathete* *Tephrinectes sinensis*
Cluster 2	*Cynoglossus abbreviatus* *Cynoglossus lineolatus* *Cynoglossus puncticeps* *Uroconger lepturus* *Dysomma anguillaris* *Gymnothorax reticularis* *Lepturacanthus savala* *Pseudorhombus cinnamoneus* *Pseudorhombus oligodon* *Arnoglossus tenuis* *Engyprosopon grandisquama* *Soleaovata Richardson* *Aseraggodes kobensis* *Crossorhombus kobensis* *Zebrias quagga (Kaup)* *Halieutaea stellata* *Arnoglossus aspilos* *Octopus ocellatus*

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