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RESEARCH ARTICLE

Co-culture of roughskin sculpin (*Trachidermis fasciatus*) with common carp, medaka and freshwater shrimp

Yufeng LIU, Huiguang FU (✉)

Ocean College, Agricultural University of Hebei, Qinhuangdao 066003, China

Abstract **Co-culture of roughskin sculpin and common carp, roughskin sculpin and medaka, and roughskin sculpin and freshwater shrimp were carried out in three earthen ponds from late May till late October of 2009 in a suburb of Qinhuangdao, Hebei Province, China. In the sculpin/medaka and sculpin/shrimp co-culture ponds, aquatic plants (cattail and reed) composing approximately 25% of the pond area were settled. Commercial feed was administered in all the three ponds for the three forage animals: common carp, medaka and freshwater shrimp. In the sculpin/carp co-culture pond, though common carp grew properly with a yield of 4550 kg per hm^2, the sculpin gradually decreased in number, and eventually only a few were left. In the sculpin/medaka co-culture pond, the pelagic medaka and benthic roughskin sculpin made full use of the water column of the pond, with the former breeding continuously to provide fry and juveniles for the latter to prey on, yielding 61.4 kg roughskin sculpin per hm^2 and 1550 kg medaka per hm^2. In the sculpin/shrimp co-culture, adult freshwater shrimp were also bred to supply fry and juveniles for the growing roughskin sculpin to prey on, yielding 46.4 kg roughskin sculpin per hm^2 and 304 kg shrimp per hm^2, less than that in the sculpin/medaka co-culture, as both freshwater shrimp and roughskin sculpin lived in the same niches, i.e. the pond bottom and the plant stems and leaves, with the open water column left vacant. Further improvements were also proposed.**

Keywords co-culture, roughskin sculpin, forage fishes, medaka, common carp, freshwater shrimp

Introduction

Roughskin sculpin has been a luxurious food fish in China since the Tang Dynasty, praised as ‘the first famous fish in south-east China’ by Qianlong, the Great Emperor in the Qing Dynasty, and as one of ‘the four most famous fishes in China’ in recent years. Furthermore, roughskin sculpin is closely related with Chinese literature, as the fish was frequently mentioned by ancient famous literatures in many traditional poems and novels. Catadromous *Trachidermis fasciatus* used to be broadly distributed in the shores of the Bohai Sea, Yellow Sea, and East China Sea. However, nowadays the fish is only fragmentally found in the Bohai Sea and the Yalujiang River (Liu and Qin, 1987; Mao and Xu, 1991; Wang et al., 2001; Zhang, 2006), perhaps because of environmental changes, obstruction in migratory routes and pollution (Wang, 1994). The traditional capture of roughskin sculpin used to be netting at its catadromous migration routes in the autumn (Wang, 1994), and consumption was limited because of the fairly high price. As the fish resources declined, both commercial capture and consumption have been impossible since the 1980s, when the first aquatic animal protection law was set in China. Pilot aquaculture of roughskin sculpin with fry captured from the wild was practiced with limited successes (Shanghai Fishery Office, 1975; Ye, 1999), but thereafter it was impractical and forbidden because of the inadequate wild fry available and the protection policy.

After accumulating knowledge on the spawning and embryonic development (Shao et al., 1980; Takita and Chikamoto, 1994; Takeshita et al., 1997; Onikura et al., 2002; Onikura et al., 2007) and the diet and distribution of the larvae and juveniles (Onikura et al., 1999; Islam et al., 2007) of the fish, artificial breeding of wild broodstock and fry culture in the hatchery succeeded (Fu et al., 2010). However, weaning the fry from rotifer and *Artemia nauplii* to pellet feed

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Correspondence: Huiguang FU
E-mail: fuhuiguang@yeah.net

resulted in considerably low survival (our unpublished observations). Aquaculture of this fish species has to depend on live food. After some experimental culture of the sculpin in indoor concrete ponds in our hatchery, we carried out aquaculture of *Trachidermis fasciatus* in outdoor earthen ponds in 2009. Here we report our results of the pond culture of roughskin sculpin together with three forage animals, namely, common carp, medaka and freshwater shrimp.

Materials and methods

Pond preparation

Three rectangular (70 m×42 m, 0.29 hm^2) earthen ponds in the eastern suburb of Qinhuangdao were drained, and exposed to sunlight in early April 2009. The ponds were then fertilized with manure (750 kg/hm^2) and filled with freshwater from a nearby canal to an average depth of 0.6 m in mid-April. Water transparency in the ponds was maintained at a range of 20–40 cm, with chemical fertilizers (urea and diammonium phosphate) used in case of necessity.

Stocking

Freshwater shrimp (*Macrobrachium nipponense*, 6.7±2.1 cm (mean±SD) in body length) captured from the Luanhe River Basin were stocked at a rate of 4500 individuals per hm^2 in Pond 1 on April 26.

Medaka (*Oryzias latipes*, 2.3±0.6 cm in body length) netted from a nearby swamp were stocked in Pond 2 at a density of approximately 9000 individuals per hm^2 on April 28.

Roughskin sculpin juveniles (42-day-old since hatching, 1.5±0.3 cm in body length), which had been reared in seawater and acclimated to freshwater in our college-run hatchery, were stocked in each of the three ponds at a density of 15000 individuals per hm^2 on May 27.

Common carp fry at swim-up stage (supplied by Laolongwan Fishfarm in Luanxian County, China) were stocked at a density of 1200000 individuals per hm^2 in Pond 3 on June 5.

Feeding and administration

In Pond 1 and Pond 2, feeding of commercial feed began on May 5, and gradually increased in dose during the rest of the culture period. Audio-conditional feeding with whistles was used for medaka. In Pond 1, trays with feed were set to detect the consumption of feed by the shrimps. The details of feeding doses during the whole culture period are shown in Table 1.

In Pond 3, soybean milk was sprayed into the pond at a rate of 200 L (made from 15 kg soybean) per hm^2 daily for 5 d (from June 6 to June 10), and then reduced to 30–40 L per hm^2 for 10 d (from June 11 to June 21). Audio-conditional (by using whistles) feeding of commercial feed was carried out from June 23 until the end of the culture period. The feeding rates during the whole culture period are shown in Table 1.

In Pond 1 and Pond 2, cattail (*Typha angustifolia*) and reed (*Phragmites communis*) were left to grow and expand until they occupied approximately 25% of the total pond area, then they were restricted in the same area by cutting off the excess. In Pond 3, following routine carp culture, all the grass was cut off.

Water depth in all the three ponds was increased from 0.6 m to 1.2 m in early July and then maintained at the same level for the rest of the culture period.

A paddle aerator (3 kW) was set in each of the three ponds in late May, and operated when DO (dissolved oxygen) of the pond water decreased below 4 mg/L.

Observations of pond water, fish, shrimp and other aquatic animals were carried out in the early morning and afternoon daily.

Sampling

Trap nets, which were cylindrical, 40 cm in diameter and 30 cm in height, were set at both marginal and inner sites of the ponds in the late afternoon and taken out the next morning to sample fishes, shrimps and other aquatic animals weekly. Sampled fishes and shrimps were measured for body length and then released in situ, and at a monthly interval, 4–6 roughskin sculpin were anatomized to examine the contents in the stomach. Planktons were sampled by plankton nets in the early morning and examined under a light microscope weekly.

Monitoring of water physicochemical parameters in the ponds

Transparency, ammonia, nitrate, nitrite, sulfide and pH in each pond were measured weekly, with temperature and DO done in the morning and evening daily.

Harvesting

In late October, after cutting off cattail and reed in Pond 1 and Pond 2, the fishes and shrimps were harvested by pulling nets across the ponds first, and then collecting manually after the ponds had been drained. Roughskin sculpin, common carp, medaka and shrimps were weighed separately. The yields in each pond were calculated and expressed as kg/hm^2.

Results

Stocking

Three days after the stocking of shrimp, medaka, roughskin

Table 1 Feeding rates (kg per hm^2 daily) in the three ponds during the whole cultural period

Treatments	May 5–20	May 21–June 10	June 11–30	July 1–Aug. 5	Aug. 6–Oct. 5	Oct. 6–Oct. 15
Pond 1	30	50	60	60	60	50
Pond 2	30	75	85	85	85	60
Pond 3	–	Soybean milk	90	90	90	70

sculpin juveniles and carp fry, no significant mortalities were observed, only a few dead fish or shrimp were found on the sites where they were released.

Feeding

Both common carp and medaka were soon acclimated to audio-conditioned feeding with the whistle, gathering at the sites where feed was sprayed. In all the three ponds, roughskin sculpin were never found to eat commercial feed. In Pond 1 (co-culture of roughskin sculpin and shrimp), examination of trays showed there was always some feed left, confirming almost satiated feeding. The commercial feed used in Pond 1 was lower than that in each of the other two ponds (see Table 1).

Observations and sampling

Dominant zooplanktons showed progressive changes in, at first, rotifers, then copepods and then cladocerans since the fishes and shrimps were stocked. Less zooplanktons were observed in Pond 3 after common carp fry were stocked, but, to some extent, was gradually restored with the administration of soybean milk.

Sampling with trap nets showed that egg-carrying female shrimps and egg-carrying female medaka appeared in early June, shrimp fry and medaka fry a few days later, but all the 'pregnant' females disappeared in August, and then reappeared in early September. The sampling also showed progressive growth of roughskin sculpin and common carp, and changes in the age composition of freshwater shrimp and medaka (Table 2). In Pond 3, no roughskin sculpin were sampled from early July. Other samples taken together with the farmed fishes were also backswimmers, damselfly nymphs, dragonfly nymphs and occasionally tadpoles (in middle and late June) and diving beetles. The biomass of damselfly nymphs and dragonfly nymphs in the vegetated ponds (Pond 1 and Pond 2) was significantly higher than that in the weed-free pond (Pond 3).

Cattail and reed progressively grew into dense beds, occupying approximately 25%–30% of the whole pond area in both Pond 1 and Pond 2. In the cattail and reed beds, roughskin sculpin, shrimps, damselfly nymphs, and dragonfly nymphs were often found sitting on the leaves and stems, with medaka hovering in between.

Roughskin sculpin were observed sitting either on the pond bottom or on the plants, but seldom moving about. They were often found being attacked by common carp, shrimps and tadpoles, but not by medaka. However, conversely, attacks and predation of roughskin sculpin upon other animals were seldom observed.

Table 2 Body length (cm) of farmed roughskin sculpin, medaka and freshwater shrimp during the experimental period.

Treatments	Sampling time	Roughskin sculpin	Common carp	Freshwater shrimp	Medaka
Pond 1	June 16	2.3±0.4	–	6.9±2.4	–
	July 2	3.5±0.9		1.9±1.1	
	August 1	5.9±1.3		2.9±1.3	
	September 2	8.2±2.3		3.2±2.0	
	October 3	10.6±4.5		3.4±2.4	
	October 25	11.4±5.3		3.8±2.3	
Pond 2	June 16	2.2±0.5	–	–	3.1±1.1
	July 2	3.4±0.7			1.1±1.3
	August 1	6.1±1.7			1.8±1.2
	September 2	7.8±2.5			1.5±1.2
	October 3	10.1±4.1			1.5±1.9
	October 25	10.9±5.4			2.1±0.8
Pond 3	June 16	2.2±0.4	0.9±0.2	–	–
	July 2	3.4±0.6	2.3±0.6		
	August 1	–	3.8±1.1		
	September 2	–	4.5±1.9		
	October 3	–	5.9±2.4		
	October 25	–	6.4±3.7		

Note: Data are expressed as mean±standard deviation. The difference in roughskin sculpin between Pond 1 and Pond 2 are statistically insignificant. No roughskin sculpin were sampled in Pond 3 from August 1. A mixture of adults and juveniles were sampled and measured for both freshwater shrimp and medaka from July 2.

The anatomy of the stomach from roughskin sculpin sampled from the trap nets showed that most of the stomachs were empty, but occasionally contained shrimp legs and carapaces, remains of damselfly nymphs, fish skeletons and skulls, including the identical skulls of roughskin sculpin with recognizable bony spines.

Monitoring of water physicochemical parameters in the ponds

Water temperatures in the ponds were approximately 18–23°C in late April and early May, gradually increasing to 20–25°C in middle and late May, reached a peak of 28–31°C in August, and then decreased to 22–28°C in September, to 12–16°C in late October. In all the three ponds, pH varied from 7.8 to 8.1, salinities were undetectable most of the time, except for a minor value of 0.3 ppt in early and mid-April, and

DO was never below 4 mg/L, with aerators operating in case of need. Though more chemical fertilizer was used in Pond 1 and Pond 2, transparencies in the two vegetated ponds (Pond 1 and Pond 2), on the whole, were more than that in Pond 3 (Table 3). Nitrite and sulfide were undetectable in most measurements, with some exceptional sublethal levels on cloudy and/or rainy days.

Harvesting

By pulling the nets across the ponds, most of the common carp and medaka, some shrimps, and a little amount of roughskin sculpin were harvested. Most roughskin sculpin were collected manually after draining the ponds. A reasonable yield of common carp, but as few as only 7 roughskin sculpin was obtained in Pond 3. The yields in all the three ponds are shown in Table 4.

Discussion

The difficulties in pond culture of roughskin sculpin, as revealed in this study, came from its specific attributes, i.e., refusal of commercial feed, small size with limited feeding gap, slow growth, cannibalism, inactive benthic way of life, and a poor understanding of the fish biology.

Common carp was first selected as a forage fish in roughskin sculpin culture, as the widespread carp culture in China would give convenience, economic efficiency and technical ease. Co-culture of wild carnivorous fishes with carps has becoming popular in China in recent decades, as traditional carp culture decreases in profit, while wild carnivorous fishes increase in price. A few wild carnivorous fishes, such as Chinese catfish (*Silurus asotus*), Chinese snakehead (*Channa argus*) and mandarin fish (*Siniperca chuatsi*) were successfully cultured, using Chinese carps as forage fishes. It is a pity that roughskin sculpin cannot be cultured in the above model of carnivorous fishes. In this study, roughskin sculpin grew well in the early culture period, as zooplanktons and planktonic carp fry served well as the live feed. However, roughskin sculpin had not been found when sampling in early July, which clearly demonstrated that few roughskin sculpin were left at that time, while in the same sampling, common carps reached the mean length of up to 2.3 cm, certainly exceeding the feeding gap of roughskin sculpin (with the mean body length of 3.4 cm). Not only are common carps unsuitable for roughskin sculpin co-culture, but other carps being cultured will not be the candidate forage fish, as they all grow too quickly for slow-growing sculpin's prey. The minor amount of roughskin sculpin left in the pond at harvesting time might have lived on other forage animals (e.g., aquatic insects), the stunted carp individuals, or cannibalism. There might be a possible improvement if a successive supply of carp fry can meet the slow-growing sculpin's predation. However, commercial production of carp fry after June is unavailable. Moreover, darkness and other possible undesirable physicochemical parameters, such as silt and decay of surplus feed and feces on the bottom, and the common carp's scavenging of the pond bottom for feed definitely threaten the roughskin sculpin, a typical bottom dweller. Therefore, the co-culture of roughskin sculpin with carps seems unpromising.

As marine shrimps were the main prey for adult roughskin sculpin in the littoral zone (our unpublished observations), the techniques of freshwater shrimp culture (Cao, 2004) was modified for the co-culture of the shrimp and roughskin sculpin in this study. Adult freshwater shrimp were stocked in late April, bred in early June, and then shrimp fry appeared, when roughskin sculpin had been feeding on zooplanktons, mainly cladocerans, for a half month and were ready to change to a bigger foodstuff. Thereafter, the old shrimp broodstock died, offsprings matured and were bred, forming shrimp populations composed of two or three generations that provided live food in a variety of sizes for roughskin sculpin.

Table 3 Water physicochemical parameters in different ponds during the culture period

Treatments	Transparency	Ammonia/ammonium	Nitrate	Nitrite	Sulfide
Pond 1	24–47	0.1–0.5	0.1–0.8	0–0.001	0–0.001
Pond 2	25–43	0.1–0.6	0.1–0.8	0–0.001	0–0.001
Pond 3	18–30	0.1–1.1	0.1–0.9	0–0.015	0–0.010

Note: Ammonia/ammonium, nitrate, nitrite and sulfide were expressed as mg/L, and transparency as centimeter.

Table 4 Yields, survivals and mean bodyweights of roughskin sculpin, common carp, medaka, and freshwater shrimp harvested in the three coculture ponds

Treatments	Roughskin sculpin	Common carp	Medaka	Freshwater shrimp
Pond 1	46.2 kg/hm^2, 13.2%, 23.2g in mean bodyweight	–	–	304 kg/hm^2, 3.7 g in mean bodyweight
Pond 2	61.4 kg/hm^2, 18.0%, 22.8 g in mean bodyweight	–	1500 kg/hm^2, 2.2 g in mean bodyweight	–
Pond 3	Only 7 individuals left, 0, 13.9g in mean bodyweight	4550 kg/hm^2, 19.1%, 20.8 g in mean bodyweight	–	–

Note: Survival is not expressed in shrimp and medaka, as it is meaningless for these two species to be reproduced during the culture period.

However, this cultural model vacated the open water column of the pond and thus reduced productivity; meanwhile, it caused the two benthic animals, forage shrimp and predatory roughskin sculpin, to be in the same niches: the pond bottom and weed beds, facilitating the sculpin's predation, but suppressing the shrimps. As a result, there were not enough shrimp left to support roughskin sculpin during the later culture periods. Therefore, additional shrimp monoculture to supply forage shrimp for the co-culture is necessary, which means fairly high costs, as the monoculture of freshwater shrimp is expensive with a yield of as low as approximately 900 kg per hm^2 annually.

In light of the ecological studies on medaka in a marsh (Li and Fu, 2009), medaka were chosen as the forage fish in the roughskin sculpin culture. An adult medaka is only approximately 3 cm in body length, an ideal size as a prey for adult and late juvenile roughskin sculpin. Furthermore, in accordance with the report that medaka never bite animal carcass (Baidu Animal Atlas, http://hi.baidu.com), the fish were never found to offend sluggish roughskin sculpin. Like freshwater shrimp, medaka were successively bred in the pond, allowing roughskin sculpin to shift their prey from zooplanktons to medaka fry; and the fish's short inter-generation time creating a population of two or three generations in the summer and autumn gave roughskin sculpin a good selection of sizes to prey on. Living in the upper and middle water layers, medaka, together with benthic roughskin sculpin, made an efficient use of the whole water column in the pond, and thus increased the production. Medaka's habit of hovering in the water weed and moving towards shallow pond margins made themselves accessible to the preying roughskin sculpin. This co-culture model is thus sustainable, with sufficient forage fish available for roughskin sculpin. The surplus medaka left in the pond can be used in the following culture of roughskin sculpin in seawater in the next winter and spring, an essential step to produce sculpin broodstock, for amphidromous medaka can be easily acclimated to seawater together with roughskin sculpin.

The aquatic plants (reed and cattail) in the ponds not only supplied dwelling places for shrimps and breeding sites for medaka, but also provided a favorable niche for benthic roughskin sculpin to escape from the dirty pond bottom, or increased their living space, by providing additional floors, when the pond bottom was desirable for dwelling. The failure in co-culture of rouhgskin sculpin and common carp might partially result from the lack of plants in the ponds. Theoretically, an increase in weed area in the ponds would increase the living space for benthic roughskin sculpin and forage animals, and thus would increase production. However, too much weed in the ponds will exhaust nutrients in water, resulting in the disappearance of planktons feeding medaka fry and shrimp fry. Therefore, 20%–30% of total pond area was recommended for freshwater shrimp culture (Cao, 2004). The optimum plant ratio for the co-culture of roughskin sculpin with medaka and freshwater shrimp needs further experiments. A disadvantage of reed and cattail in the ponds is that they provide egg-laying sites for dragonfly and damselfly, so that more dragonfly nymphs and damselfly nymphs were found in the vegetated ponds (Pond 1 and Pond 2) than those in the plant-free pond (Pond 3), which naturally compete for living places with roughskin sculpin and might attach the fish, although younger nymphs might provide prey. Other water plants (e.g., emerged weeds) or artificial materials (e.g., plastic tubes in octopus culture) are recommended for roughskin sculpin culture.

There was a considerable mortality in roughskin sculpin in the ponds but the dead fish were seldom found floating on the water surface. Unlike most cultured fishes, roughskin sculpin are benthic fish, without a swimming bladder, having a higher density than water. When they die, they remain lying on the pond bottom, and are torn up and eaten by cannibals (as we observed in the indoor concrete ponds in the hatchery) and, presumably, also by carnivorous insects. Furthermore, roughskin sculpin sampled by trap nets in the ponds had empty stomachs, occasionally with little remains of victim's skeletons, while most of the fish sampled from the lower littoral zone of the sea in early spring had full stomachs (our unpublished observations). The explanation may be that this fish species is active in the pre- and spawning season even without the need for hunting, while during growing-up stage, they are active only when they are hungry enough to hunt, but they sit on the substrata (pond bottoms and plant stems and leaves) most of the time. These findings should be considered in the further improvement of culture techniques.

In conclusion, the roughskin sculpin/freshwater shrimp and roughskin sculpin/medaka were successfully co-cultured, allowing further studies on the production of broodstock in the second generation. However, the survival and production of roughskin sculpin were fairly low. These might have resulted from the inadequate food supply, predation and/or aggression from carnivorous insects, cannibalism, and an unfavorable environment during some culture periods. Further studies on the optimum vegetation ratio in ponds, availability of artificial substrata, selection and stocking regime of forage animals, and appropriate arrangement of the co-culture together with monoculture of forage fish or shrimp are necessary to improve the techniques for roughskin sculpin culture.

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