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REPORT

Sustainable farming practices of the Chinese mitten crab (*Eriocheir sinensis*) around Hongze Lake, lower Yangtze River Basin, China

Qidong Wang, Jiashou Liu, Shengyu Zhang, Yuxi Lian, Huaiyu Ding, Xue Du, Zhongjie Li, Sena S. De Silva

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Abstract Results of a survey of 156 Chinese mitten crab (*Eriocheir sinensis*) grow-out farms around Hongze Lake (118.48–118.72°E; 33.36–33.38°N) are reported. Area farmed has remained relatively unchanged but production (59 932 *t* in 2012) increased steadily over the last 7 years, indicative of the viability and sustainability of the farming system that has gradually replaced intensive Chinese major carp polyculture around Hongze Lake. Results showed that production range was 135–2400 kg ha^{-1} $cycle^{-1}$ (mean 1144 ± 34). Crab yields correlated linearly to stocking density and conformed to a normal distribution curve, with 66.7 % of farms yielding 900 kg ha^{-1} $cycle^{-1}$ or more. Yield was negatively correlated to pond size and capture size ($p < 0.01$), and farms with macrophyte coverage rate lower than 30 % of water surface were significantly ($p < 0.05$) lower than those exceeding 30 %.

Keywords Chinese mitten crab · *Eriocheir sinensis* · Farming practice · Feed type · Macrophyte · Yield · Hongze lake

INTRODUCTION

China dominates global aquaculture production and recently (2011) accounted for 65.7 % of the global production of 76.3 million tonnes (FAO 2014). This predominance of Chinese aquaculture is evident from the fact that it contributed on average 58.5 % to the global total and 61.2 % to the global inland aquaculture production in the period from 1981 to 2011, respectively (Wang et al. 2014).

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In recent years, there have been an increasing number of critiques of Chinese aquaculture practices because of the perceived negative environmental impacts in particular (Xie and Yu 2007; Cai et al. 2012a; Herbeck et al. 2013). On the contrary, there are certain farming practices that are based on the application of improved traditional knowledge that enhance sustainability and have become increasingly popular, in some instances, even replacing traditional Chinese major carp polyculture practices. One such farming practice is that of the Chinese mitten crab (*Eriocheir sinensis* Milne-Edwards 1854) which is the subject of the present study.

Hongze Lake (118.48–118.72°E and 33.36–33.38°N), a 1597-km^2 lake with an average water depth of 1.77 m, is the fourth largest freshwater lake in China and a national natural wetland reserve, located on the western side of the Grand Canal (World Heritage Listed in 2014) in Jiangsu province, Eastern China (Ye et al. 2011; Yu and Hu 2013). Hongze Lake is also an important regulating reservoir of the South-to-North Water Diversion Project, which aims to divert water from the Yangtze River to alleviate water shortage in northern China (Li et al. 2011a).

Fisheries and aquaculture in the lake are important for the local economy and covers 28 fisheries towns and 162 villages, and an estimated 218 928 people were engaged in these activities in 2010. The most recent estimates (2012) indicate that aquatic production around Hongze Lake was 268 031 t (data provided by Hongze Lake Fisheries Management Committee Office—HLFMCO, 2012). During the last six decades, the fishery in Hongze Lake region has undergone a remarkable transformation from capture fishery dominance to aquaculture. Polyculture of Chinese carps was the major farming system around Hongze Lake until the 1990s. Rapid development of intensive aquaculture, primarily of Chinese major carps, threatened the sustainability of the Hongze Lake wetlands through eutrophication resulting from excessive use of fertilizer and feed (reviewed by Zhang et al. 2015). As such, there was a need to minimize the environmental impacts of aquaculture and alternatives introduced that would still provide livelihood and economic opportunities to the local communities engaged in fish farming. The environment-friendly alternative that was advocated by the authorities in the beginning in the early 1990s and embraced by the local community was the farming of Chinese mitten crab.

The culture of Chinese mitten crab can be considered as a unique crustacean farming system in comparison to the traditional cyprinid polyculture in Chinese freshwaters. The lowest net loading of total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and total suspended solids (TSS) have been observed in mitten crab farming compared to other farmed freshwater species, such as grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), river prawn (*Macrobrachium nipponensis*), shrimp (*Penaeus vanmamei*), and soft-shelled turtle (*Trionyx sinensis*) (Cai et al. 2012a). The contribution to low volumes and concentrations of pollutants in effluents of mitten crab farming are mainly attributed to the common practice of transplanting aquatic macrophytes to regulate water quality rather than through water exchange (Cai et al. 2012b). Therefore, mitten crab farming is considered to be relatively more environment-friendly than most other practices.

Although mitten crab is considered as an invasive species in Europe and America (Rudnick et al. 2003; Paunovic et al. 2004), it makes a significant contribution to the aquaculture sector in China (Chen et al. 2007). The recent trends (from 1990 to 2012) in production and value of mitten crab culture demonstrate the increasing importance of this species for the aquaculture sector in China (Fig. 1). Mitten crab has a high consumer demand that commands a price that places it amongst the higher range of aquatic products in China (Wang et al. 2007a, 2014; Li et al. 2011b). Globally, there are many recorded instances of cultured species and or species groups that are important to some nations and regions but considered as invasive and or pests by others, such as carp species (Billard 1999) and tilapias (Xie et al. 2001; De Silva et al. 2004). Mitten crab not only has a unique flavour, but is also an excellent source of minerals (particularly zinc, iron, copper and phosphorous), and high-quality protein and fatty acids (Chen et al. 2007; Guo et al. 2014; Shao et al. 2014). For many years, its market price has been rising steadily owing to the imbalance between supply and demand. Over the years, however, it has gradually become an affordable commodity to common people due to its increasing production as well as the increasing living standards of the Chinese people (Luo et al. 2008; Li et al. 2011b).

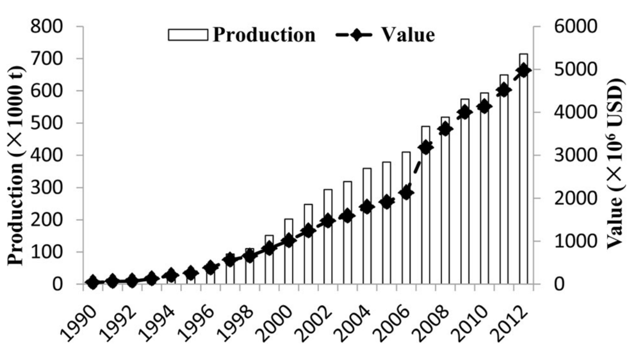

Fig. 1 Trends in production (×1000 *t*) and value (×10^6 USD) of Chinese mitten crab cultured from 1990 to 2012, China (based on data from FAO 2014)

The rise of mitten crab farming around Hongze Lake commenced in the early 1990s, and now constitutes the most important farming sector in this area. Pond farming of mitten crab became the dominant form because of its relatively independent culture system, favourable feed conversion rates, stable yields and harvest sizes. Although mitten crab culture has gained gradual prominence in freshwater aquaculture, there is very limited information on its sustainable farming practices. Furthermore, the grow-out farming operations of mitten crab in ponds around the lake also represent a unique ecosystem that is delicately balanced and sustainable. Cheng et al. (2008) summarized the trends in hatchery techniques and stock enhancement practices, and Sui et al. (2011) and Shao et al. (2013, 2014) reviewed larviculture and gonad quality in relation to fattening, respectively. The present paper attempts to fill the gap in our knowledge on grow-out operations of mitten crab aquaculture, a key growth area in Chinese freshwater aquaculture, which predominates in global aquaculture production (Wang et al. 2014). Hongze Lake was chosen as it is representative of mitten crab culture in China and is the area where the highest concentration of mitten crab farming occurs in the country. It is also representative of a farming practice, based on improvements from traditional knowledge that replaced intensive Chinese major carps polyculture practices on environmental grounds and is considered sustainable.

MATERIALS AND METHODS

Most of the mitten crab farms were reclaimed from the lowland area around Hongze Lake in the last three decades, and remain connected to the lake, drawing water from it. The issues related to reclamation of the wetland area in Hongze Lake for mitten crab farming have been dealt with in detail by Ruan et al. (2012).

The mitten crab farming area falls within the jurisdiction of six counties viz. Hongze, Xuyi, Huaiyin, Sihong, Siyang and

Sucheng. All the farms around Hongze Lake are registered with HLFMCO which provided the historical data on this sector. In addition, data on the farming practice was collected through farm visits and farmer interviews using structured questionnaires (Supplementary material). A total of 156 farms were surveyed and the locations of these are shown in Fig. 2. In each county, the numbers of farms investigated were based on the intensity of mitten crab farming. An attempt was also made to include as many districts as possible within each county. In a given locality, farmers were randomly chosen based on a list provided by the respective HLFMCO or Aquaculture Technology Extension Stations (ATES).

The survey was conducted by our research group between May 2011 and December 2012. In each instance, 3–4 interviewers, trained for this purpose, were involved. The responses at the interviews were primarily based on the records maintained by farmers, which in the majority of cases were very detailed for the recent years.

The survey data was inputted into MS Excel 2010 (Microsoft Corporation, USA), then exported to relevant statistical software packages such as SPSS 18.0 (SPSS Inc., Illinois, USA) for performing relevant statistical analyses. Where relevant, the means and standard errors are given in parentheses. In addition, where appropriate, regression analyses (linear, curvilinear and polynomial) were carried out to determine relationships between parameters and those relationships that showed the highest r^2 values were chosen and included here.

RESULTS AND DISCUSSION

Mitten crab is a catadromous species, defined as a species that spends most of its life in freshwater and migrates to seawater to breed (Herborg et al. 2003), and the stages of its culture in brackish and fresh water environments are schematically depicted in Fig. 3. The hatchery rearing of mitten crab occurs in brackish water. Post-metamorphosed crab larvae (megalopae) are nursed for approximately 1 year until they reach a weight of 5–10 g (for details see Cheng et al. 2008; Sui et al. 2011). These crabs, referred to as coin-sized in the industry in China, are grown in freshwater until they attain market size. The grow-out phase in freshwater lasts 8–10 months, and the practices of this phase forms the basis of the contents of this study.

Overall status of the sector around Hongze Lake

The farming of mitten crab around Hongze lake region began in the 1990s, and over the last three decades has

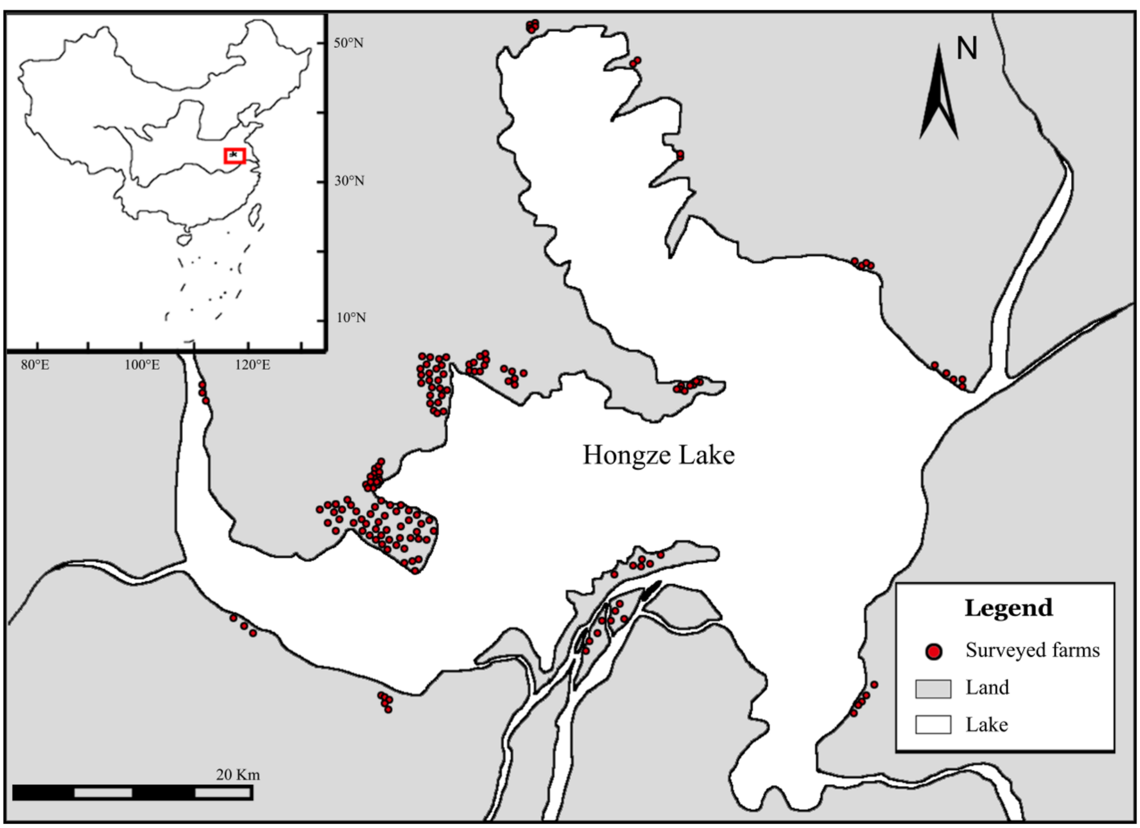

Fig. 2 The location of the mitten crab farms investigated around Hongze Lake

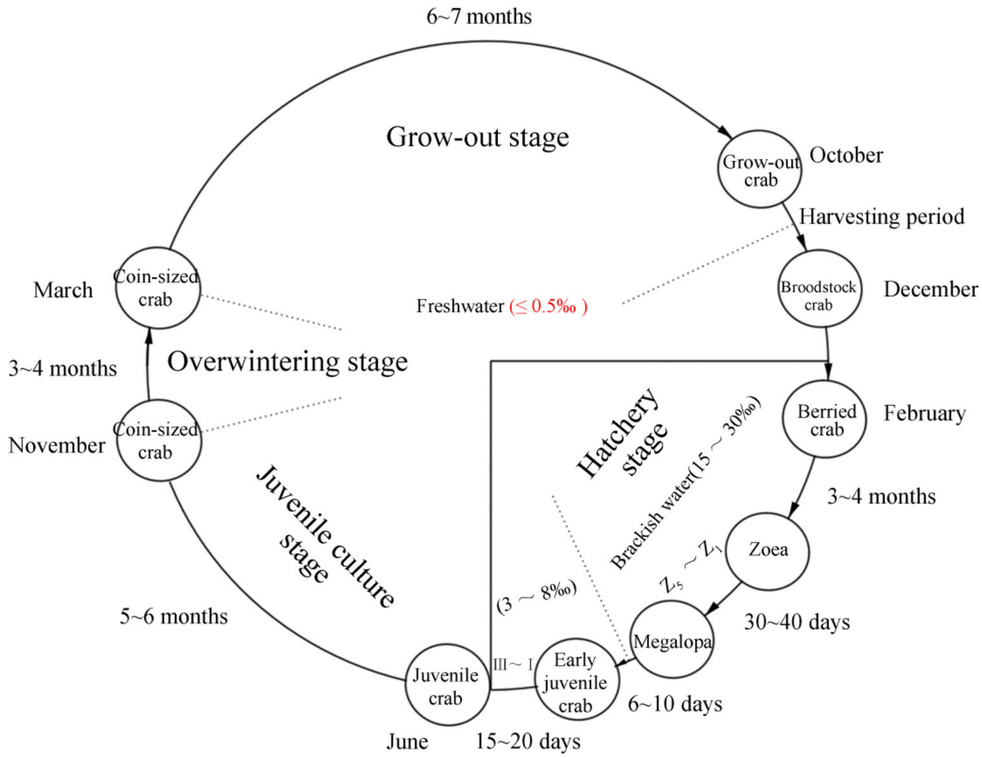

Fig. 3 A schematic representation of the life cycle of mitten crab and the relevant culture stages (modified after Wang et al. 2007; Sui et al. 2008)

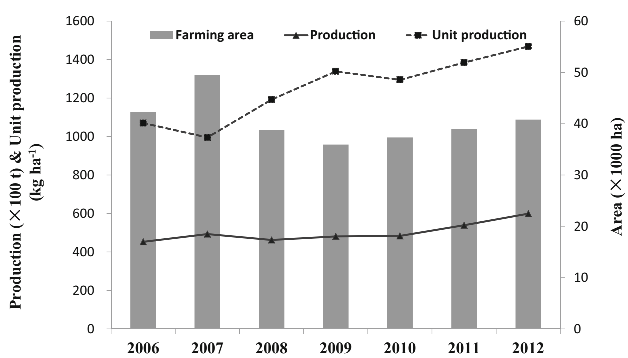

Fig. 4 Trends in mitten crab farming area, total and unit area production in Hongze Lake wetlands from 2006 to 2012; the data was provided by Hongze Lake Fisheries Management Committee Office—HLFMCO, 2012

been the major production sector in the lake region. From 2006 to 2012, the production of mitten crab from Hongze Lake region contributed an average of 9 % with respect to total mitten crab production in China, being the most intensely farmed area in the country (data from HLFMCO, 2012). The farming area of mitten crab has remained relatively static over the last seven years, but the total production and production per ha have increased steadily (Fig. 4). For example, between 2006 and 2012 (the period for which reliable data are available), the total production and the production per unit area increased, respectively, from 45 297 to 59 932 *t*, and 1070 to 1469 kg ha^{-1}.

In the early years of mitten crab farming, net pen culture system was adopted. In 2003, the area of net pen culture peaked at 41 200 ha and then decreased to 16 600 ha by 2008 (data from HLFMCO, 2012). This decline is thought to have been driven by the low economic returns from pen culture. Other reasons attributed to this decline were the reduction of the macrophyte cover in net pens, eutrophication and changes in sediment physical and chemical properties of the lake (Cui and Li 2005;Wang et al. 2014). Since 2006, pond culture began to dominate mitten crab farming practices around Hongze Lake, not only in the extent of the farming area, but also in unit production.

Farming practices

Farm operations

The mitten crab farming operations were rarely vertically integrated, i.e. all the life cycle stages are not cultured as a unit of single management in the same physical location. Of the 156 farms surveyed, only 3 farms nursed one-year-old juvenile crablets from larval stage. The rest of the farms purchased one-year-old crablets from culture operations in the coastal area for growing out. Here again, the trend reflects those of other farming systems in Asia such as striped catfish (*Pangasianodon hypophthalmus*) farming in the Mekong Delta where the grow-out, nursery and hatchery sectors are often operated as different entities (Phan et al. 2009; Bui et al. 2010).

Farm characteristics

The farm size and the water surface area of the 156 farms surveyed ranged from 0.21 to 7.17 ha (1.69 ± 0.11) and from 0.15 to 6.39 ha (1.32 ± 0.09), respectively. The number of ponds *per* farm and pond size ranged from 1 to 5 (1.69 ± 0.07) and 0.20 to 4.66 ha (1.00 ± 0.05), respectively.

The frequency distribution of farm size, water surface area, and pond size are shown in Fig. 5, and it is evident that farm size is highly positively skewed (skewness = 1.70), with 85.3 % farms being less than 3 ha, and only 2.6 % farms being equal or larger than 5 ha. It is evident that 65 % of the ponds are less than 1 ha, and only 8 % ponds are larger than 2 ha. Therefore, mitten crab farms around Hongze Lake can be categorized as smallholdings that are clustered together in an area conducive for farming. These observations are in accordance with most other aquatic animal farming sectors in Asia, such as for example shrimp farming in Southeast Asia (Kongkeo 1997), the giant freshwater prawn (*Macrobrachium rosenbergii* De Man) farming in Bangladesh (Wahab et al. 2012), and striped catfish (*Pangasianodon hypophthalmus*) farming in the Mekong Delta in Vietnam (Phan et al. 2009; De Silva and Phuong 2011).

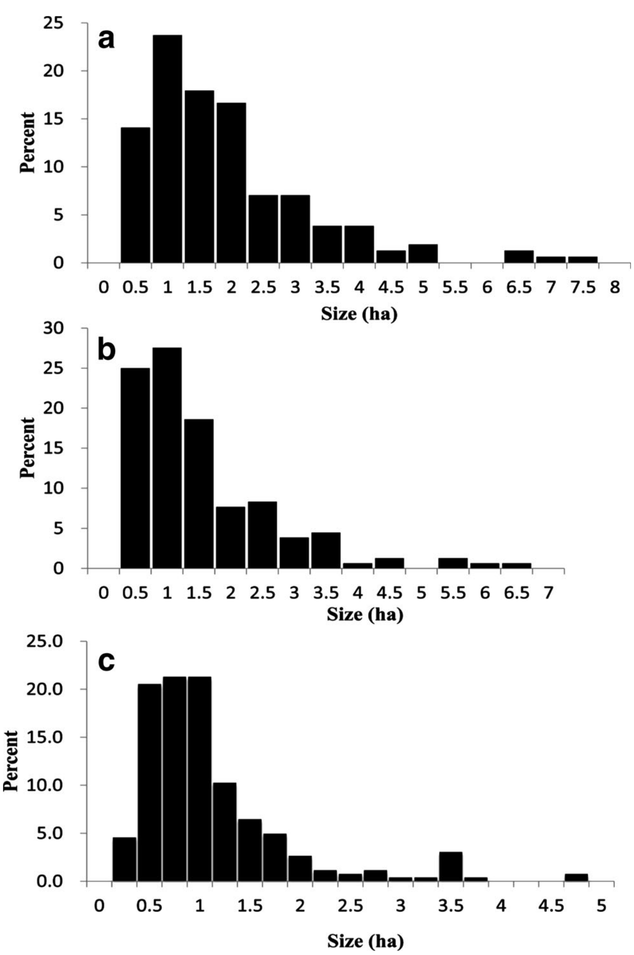

Fig. 5 Frequency distribution of **a** size, **b** water surface area, and **c** pond size of the mitten crab farms surveyed

Water supply, pond preparation and macrophyte transplanting

Of the 156 farms investigated, 93 % received water from creeks or canals connected to the lake and the rest directly from the lake itself. It should also be noted that 27 % farms pumped groundwater for replenishing during the dry season (June to August) and the proportion of farms adopting such a procedure tended to increase in the last 5 years. Only 21 % of farms screened the inflow water and almost none of the farms used sedimentation ponds.

All farms treated the pond bottom prior to filling up with water and stocking. After harvest, ponds were drained and fully exposed to prevailing sunlight for a period ranging from 15 to 55 days, usually in the months of December to January. During this fallow period, in general, one of the following four methods of sediment treatment was adopted: (1) remove sludge, dry in sunlight with addition of quicklime (CaO) (9 % of farms); (2) dry in sunlight with addition of quicklime (62 % of farms); (3) dry in sunlight and tilling with quicklime (24 % of farms); (4) only drying in sunlight (5 % of farms).

Following the above pond preparation, submerged macrophytes used for maintaining water quality and providing refuge during the mitten crab growth cycle, were transplanted back into ponds. The most commonly transplanted species included *Elodea canadensis* Michx. (EC) (90 % of farms), *Vallisneria natans* Hara (VN) (27.6 % of farms), *Ceratophyllum demersum* Lin (CD) (16 % of farms), *Hydrilla verticillata* (Linn. F.) Royle var. *rosburghii* Casp. (HV) (14 % of farms), and *Myriophyllum spicatum* L. (MS) (13 % of farm). Most farms (52 %) adopted a combination of the above species, but in varying combinations and proportions of species. Availability was also a key factor that constrained macrophyte species choices. Five to seven days before cultivation of macrophytes culture ponds were filled with water to a depth of 30 cm. Normally crab culture ponds were drained to a depth of 10–15 cm prior to transplanting macrophytes. For example, for species such as *E. Canadensis, C. demersum* and *H. verticillata,* the stem was cut into a few pieces of 10–15 cm. Each bunch of macrophytes with five to ten pieces of stem was planted evenly at an interval of 0.5–

0.6 m on the whole bottom of the ponds. Thereafter, the water depth was regulated based on the growth of macrophyte before stocking mitten crab.

Prior to stocking, farmers adopted a varying number of methods to eradicate all unwanted fish, crayfish and/or other aquatic animals. The most widespread methods used were application of quicklime (38 % of farms), Calcium hypochlorite ($Ca(ClO)_2$) (34 %), povidone-iodine ($(C_6H_9NO)_n \cdot xI$) (16 % of farms), teaseed cake (3 % of farms) and remaining 9 % of farms used other methods. The amounts and the number of times applied varied between farms and did not strictly follow any guidelines.

Stocking

The main stocking period was between February and April and the stocking size of mitten crab ranged from 2.1 to 16.7 g individual^{-1}, and averaged 5.9 (± 0.1 g individual^{-1}. Of the surveyed farms 58.6 % stocked mitten crab of 4–7 g individual^{-1}. Stocking densities used in grow-out mitten crab farming ranged from 5025 to 48 000 individuals ha^{-1} (24 232 ± 472), and primarily depended on the size and the availability of coin-sized crabs and the projected market price. Of the surveyed farms, 68.4 % stocked 15 000–30 000 individuals ha^{-1} mitten crab. Amongst all the surveyed farms, 84 % stocked only once in a calendar year and the rest stocked 2–3 times, often when driven by low survival rates of stocked coin-sized crab at the first stocking. High early mortalities resulted mainly from, for example, long-distance transportation, extreme climate (e.g. water shortage), incomplete disinfection or water pollution. All farms treated coin-sized crab prior to stocking, and the major treatments included application of salt (NaCl) (62 % of farms) and potassium permanganate ($KMnO_4$) (38 % of farms). The amounts of these chemicals applied varied between farms, but normally ranged from 0.3 to 6 % (g L^{-1}).

In general, freshwater aquaculture in China almost always utilizes models incorporating principles of polyculture: as a means of not only increasing productivity but also improving the utilization of feed resources, allochthonous and autochthonous, which in turn reduces nutrients in the effluent (Wang et al. 2014). The majority of the farms (92 %) stocked high-valued, carnivorous, mandarin fish (*Siniperca chuasti*) of average body length of 4–10 cm at densities ranging from 150 to 900 individuals ha^{-1}. These fish were expected to forage on the naturally recruited wild fish. It was also a very common practice for all the farms surveyed to stock silver carp (*Hypophthalmichthys molitrix* Valenciennes 1844) and/or big head carp (*Aristichthys nobilis* Richardson 1845) of average weight in the range of 50–250 g at a density range of 300–750 individuals ha^{-1}. These species feed on plankton and are known to facilitate maintenance of water quality. These practices are also utilized in turtle culture in China and known to be very effective (Wang et al. 2007b; Shi et al. 2008).

Water-quality management

Water-quality management is one of the key factors that determines the success or failure of mitten crab farming, as much as in other farming systems, and the overall ecosystem health (see for e.g. Ackefors and Enell 1994; Guo and Li 2003; Phan et al. 2009; De Silva et al. 2010). In general, four major methods were adopted to regulate water quality in mitten crab grow-out ponds, including regular water exchange and maintenance of macrophyte(s) that all the farms adopted, application of photosynthetic bacteria (PSB) (44 % of farms) and addition of quicklime (63 % of farms). It should be noted that bottom microporous aeration to improve water quality was becoming an emerging technique and 3 % of farms surveyed have adopted this practice. Only 34 % of farms surveyed exchanged water during the growth cycle, and 66 % replenished, but did not discharge effluent at the same time. In the former practice, during the first 3 months following stocking, water exchange frequency was variable from one to three times *per* month. In the latter months, especially from June to September, frequency was increased to one to two times per week. The rate of exchange for each time ranged from 5 to 30 %. In the latter practice, water was added to offset the loss from evaporation and seepage.

Most of farms discharged water into the surrounding canals (93 %) which were connected to the lake and the rest of farms discharged directly into the lake. None of the farms treated the discharged water.

Feed types and feed management

Amongst all the farms surveyed, 21 % used trash fish or low-valued fish, which were either small freshwater fish (e.g. *Carassius auratus* Linn., *H. molitrix*, *A. nobilis* obtained locally from the capture fisheries of Hongze Lake, or frozen low-valued marine fish purchased from local markets. Twenty three percent of farms used only commercial pellet feed. A combination of trash fish and commercial pellet feed were used by 56 % of farms, where the ratio of trash fish to commercial feed ranged from 0.1 to 33.0 (3.8 ± 0.6). In addition to the above, all the farms used small amounts of maize seed as a supplementary feed for about one month prior to harvest, based on the perception that it facilitated gonadal maturity (Li et al. 2011b). The market price of mitten crab is considerably higher for gravid females, and consequently precocious sexual maturity is favoured (Wang et al. 2007a; Li et al. 2011b).

In most farms, feed were broadcast twice a day, in the morning and afternoon, by hand over the whole pond. The feeding rate differed from farm to farm as well as from day to

Table 1 The compositions of a random selection of commercial feeds, as specified on bags, used in mitten crab grow-out operation around Hongze Lake. For all the parameters, the minimal values are given

Feed no.	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)	Fibre (%)
1	12.5	32	3.5	18	16
2	12	42	4	16	8
3	12	41	3.6	18	6
4	12	34	4	19	8
5	12	32	4	12	8
6	12.5	30	3.2	18	14
7	12.5	28	2.5	17	10
8	12.5	30	3	17	10
9	12.5	32	3.2	16	8

day within a farm, and in general approximated to about 3 % of the biomass of crabs in a pond. There were no strategies used to determine whether the food provided was consumed or not, as that employed in shrimp culture (i.e. use of feeding trays).

The quality of the commercial pellet feeds used for grow-out mitten crab culture was highly variable; for example the protein content ranged from 28 to 42 % (Table 1). The feed conversion ratio (FCR) (ratio of weight of food provided to increase in wet biomass) for the three feeding strategies during the growth cycle of mitten crab was significantly different ($p < 0.05$). It was evident that the average FCR recorded for trash fish was significantly better ($p < 0.05$) than for the other two feed types. Here, allowance was made for the moisture content of trash fish cf. 75 % (Xu et al. 2007; Hasan and Halwart 2009; Shao et al. 2013; Bunlipatanon et al. 2014). The FCR was calculated using the following formula:

FCR = (0.25 × total volume trash fish + total volume commercial feed + total volume maize seed)/total increased biomass of mitten crab.

The scatter plot of FCR for each feed type to yield (Fig. 6) indicated negative, exponential relationship between the two parameters. The specific relationships were

(a) Trash fish fed:

$$\mathrm{Y(yield)} = 2554.6 exp^{-0.249 \times X(FCR)}, \quad \left(R^2 = 0.364,\ p < 0.01\right)$$

(b) Trash fish and commercial feed fed:

$$\mathrm{Y(yield)} = 4229.9 exp^{-0.331 \times X(FCR)}, \quad \left(R^2 = 0.550,\ p < 0.01\right)$$

(c) Commercial feed fed:

$$\mathrm{Y(yield)} = 3880.8 exp^{-0.268 \times X(FCR)}, \quad \left(R^2 = 0.601,\ p < 0.01\right)$$

In general, however, it should be noted that the FCR for mitten crab, irrespective of the feed type used was considerably higher (therefore, poorer rate of food conversion) than those recorded for finfish farming practices (Lemarié et al. 1998; Gross et al. 2000; Yi et al. 2003; Phan et al. 2009; Bunlipatanon et al. 2014), and or for shrimp farming practices around the world (Hopkins et al. 1993; Briggs and Funge-Smith, 1994; Thakur and Lin, 2003; Sahu et al. 2013). It is therefore evident that considerable improvements have to be brought about in commonly used feeds and feed management in mitten crab culture. Perhaps such improvements will bring about significant cost reduction in mitten crab farming operations and also consequent improvements in nutrients discharge, and impact positively on the overall ecosystem health.

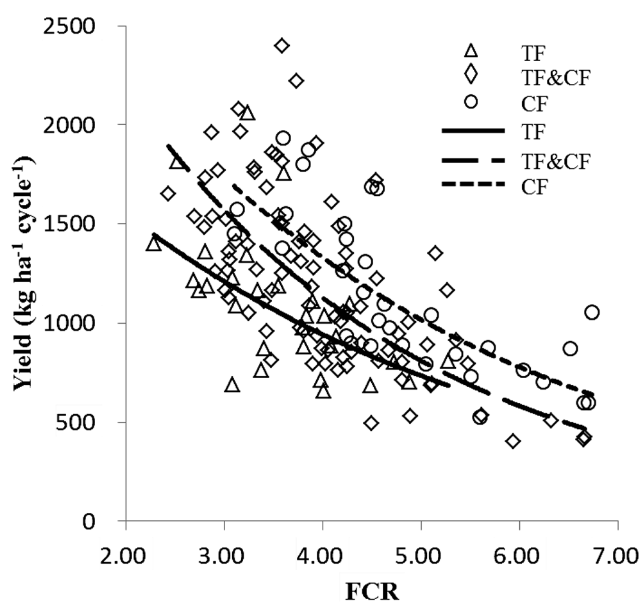

Fig. 6 Relationship between mean yield of mitten crab (kg ha^{-1} cycle^{-1}) and FCR of crabs fed with three kinds of feed (*TF* trash fish, *CF* commercial feed, *TF & CF* trash fish + commercial feed)

Chen et al. (1989) reported that mitten crab from Lake Taihu fed on hydrophytes, fishes, shrimps, mollusks, aquatic insects, and worms. Jin et al. (2003) observed that mitten crab in a natural lake in the Yangtze basin fed on macrophytes, algae, arthropods, oligochaetes, fish and detritus and the percent frequencies of occurrence of these items were 87.3, 82.0, 48.2, 28.2, 28.7 and 88.7 %, respectively. It is possible therefore that in the pond farming systems where macrophytes are grown, mitten crab is able to feed on macrophytes as well as aquatic invertebrates naturally occurring in the pond ecosystem. This may be one of the reasons for the relatively poor FCRs recorded in the mitten crab farming systems. It may be that there is over feeding and a considerable proportion of the food provided goes to waste.

As such, a well-planned study would provide suitable guidelines to determine the optimal range of feed input required, and would enable the farming system to be more profitable, and facilitate the improvement of the health of the lake ecosystem. Since the livelihoods of the many thousands of farmers are engaged in mitten crab farming, it is important that famers are provided with suitable and substantiated guidance on the most efficient and feasible form of feed to be used, to remain not only economically viable but also environmentally sustainable (Shao et al. 2013). This is in accordance with other farming sector in Asia, such as in the case of Asian seabass (*Lates calcarifer* (Bloch)) and tiger grouper (*Epinephelus fuscoguttatus* (Forsskal)) farming in Thailand (Bunlipatanon et al. 2014).

Production

Mitten crab farm yields ranged from 135 to 2400 kg ha^{-1} $cycle^{-1}$ (1144 ± 34). The frequency distribution of yield conformed to a normal distribution curve (Fig. 7), where 66.7 % of farms recorded yields of 900 kg ha^{-1} $cycle^{-1}$ or more. Normally, the extreme low yields occurred in few small farms that were owned and operated by new entrant farmers. The extreme high yields could be attributed to the outstanding operations across the production cycle, such as pond preparation, macrophyte maintenance, stocking, water management and feed management.

Mitten crab yield was positively and linearly correlated to stocking density (×1000 individuals ha^{-1}) ($p < 0.01$), negatively and linearly correlated to pond size and size at harvest ($p < 0.01$) (Fig. 8). However, the yield was neither correlated to stocking size nor farm size ($p > 0.05$).

Relationships of the yield to other parameters, such as the locality of farms, macrophyte types and combinations thereof, macrophyte coverage rate in the warm season (June, July and August), water source and feed types were

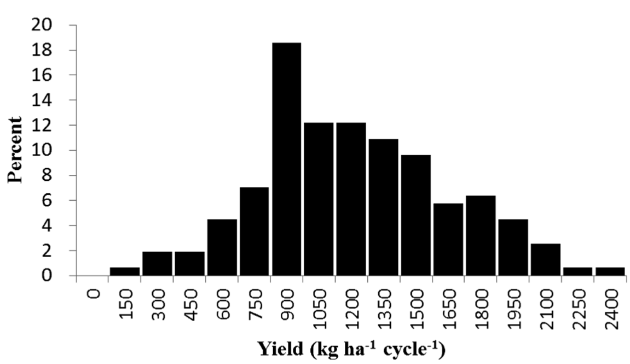

Fig. 7 Frequency distribution of mitten crab production of the farms surveyed around Hongze Lake

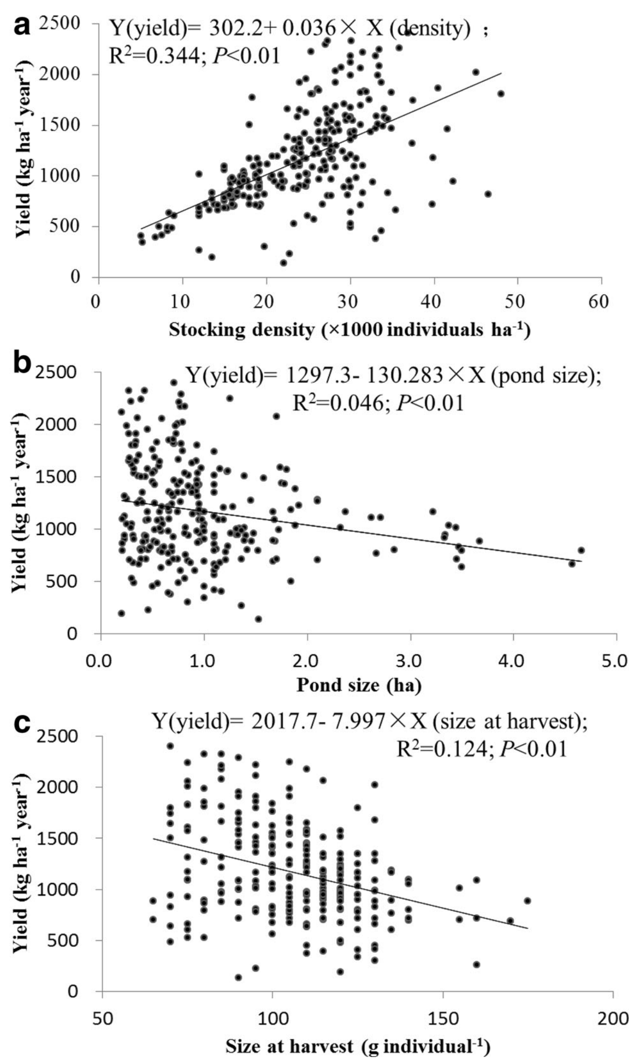

Fig. 8 Relationships between yield (kg ha^{-1} $year^{-1}$) and **a** stocking density (×1000 individuals ha^{-1}); **b** pond size (ha); **c** size at harvest (g $individual^{-1}$). In each case, the *lines* of best fit are drawn

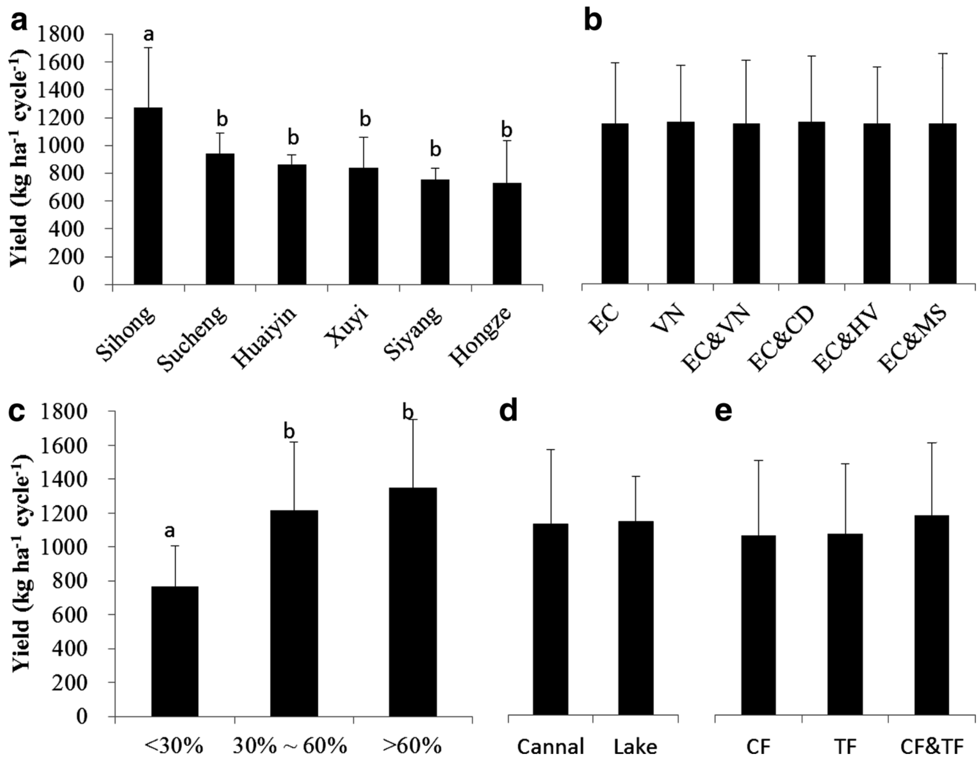

Fig. 9 Mean yields of mitten crab (kg ha^{-1} $year^{-1}$) for **a** different regions, **b** macrophyte combination types (EC, VN, EC & VN, EC & CD, EC & HV, EC & MS), **c** macrophyte coverage rates, **d** water source and **e** feed types (*CF* commercial feed, *TF* trash fish, *CF* + *TF* commercial feed + trash fish). *Lowercase* notations above bars indicate significant differences ($p < 0.05$)

also explored. As shown in Fig. 9a, the mean yield of mitten crab in farms from different counties was significantly different ($p < 0.05$). Amongst these, Sihong County dominated the mean yield, followed by Sucheng, Huaiyin, Xuyi, Siyang and Hongze. It is difficult to discern the reasons that lead to this trend. However, the resource availability perhaps was an important factor that contributed to the difference of mean yield. For example, the technology services (e.g. water-quality diagnosis and macrophyte breeding) and experience exchange will be more accessible in a highly dense area of crab farming, such as in Sihong county.

It is most likely that macrophytes play a key role in the course of growth of mitten crab, such as providing natural food and harbouring and facilitating the production of its favoured natural food types (Jin et al. 2003), and providing a refuge when moulting (Pan 2002; Wang et al. 2006). Although yields were not related to macrophyte types ($p > 0.05$) (Fig. 9b), this is an aspect that needs further investigation. The mean yields of mitten crab in farms with a macrophyte coverage rate less than 30 % of water surface area was significantly ($p < 0.05$) lower than those in farms with coverage higher than 30 % (Fig. 9c), providing evidence in support of the statement that macrophytes play a key role in the course of growth of mitten crab.

The mean yields of mitten crab did not differ significantly (Fig. 9d) from each other in relation to the water source ($p > 0.05$). Also, yields were correlated with neither water exchange frequency nor the volume exchanged per month.

The feeding strategy used in mitten crab farming is complicated as stated in "Feed types and feed management" section. However, the mean yields of mitten crab fed with different feed types did not differ significantly from each other ($p > 0.05$) (Fig. 9e). It is often alleged that the use of trash fish is more environmentally perturbing than the use of commercial pellet feed, even though direct scientific evidence in this regard is scant, and when available does not take into account the primary resource usage (Bunlipatanon et al. 2014).

Harvesting and marketing

In general, mitten crab is harvested from October to November. Average size at harvest ranged from 65 to 175 g individual^{-1} (106 ± 1). Net traps of approximately

Table 2 Cost–benefit analysis of mitten crab farming around Hongze Lake. *TF* trash fish, *CF* commercial pellet feed (in RMB ha^{-1}year^{-1}). For all values, the means ± SE are given

Cost items	TF (RMB ha^{-1} year^{-1})	TF&CF (RMB ha^{-1} year^{-1})	CF (RMB ha^{-1} year^{-1})
(a) Capital investment			
1. Fencing	2979 ± 55	2986 ± 40	3193 ± 83
2. Pump set	1001 ± 85	1018 ± 31	980 ± 57
3. Catchment tool	745 ± 55	790 ± 24	894 ± 65
4. Boats	960 ± 126	1127 ± 76	1374 ± 171
Total	5685 ± 198	5921 ± 104	6441 ± 236
(b) Fixed cost			
1. Land lease	12 500 ± 781	12 605 ± 387	12 717 ± 451
2. Deprecation	1137 ± 40	1184 ± 21	1288 ± 47
3. Interest	853 ± 30	888 ± 16	966 ± 35
Total	14 490 ± 791	14 680 ± 382	14 975 ± 452
(c) Operating cost			
1. Pond preparation	1568 ± 83	1580 ± 33	1576 ± 56
2. Crab seed	4025 ± 415	3792 ± 215	3222 ± 303
3. Fish fingerling	756 ± 49	650 ± 25	669 ± 36
4. Macrophyte	2562 ± 88	2468 ± 49	2542 ± 75
5. Snails	6033 ± 502	5805 ± 293	6257 ± 201
6. Feed	29 120 ± 2526	26 880 ± 1030	23 474 ± 1268
7. Fuel/electricity charges	1390 ± 66	1311 ± 34	1220 ± 51
Total	45 455 ± 2731	42 487 ± 1191	38 960 ± 1441
(d) Total cost (b+c)	59 947 ± 2873	57 168 ± 1203	53 935 ± 1559
(e) Total revenue	75 949 ± 4533	82 150 ± 2670	78 443 ± 4151
1. Revenue from crab	73 322 ± 4516	79 697 ± 2654	75 911 ± 4160
2. Revenue from fish	2628 ± 114	2453 ± 93	2532 ± 142
(f) Net profit	16 003 ± 2022	24 983 ± 1680	24 509 ± 2926

15 m length, are set in the night and hauled early morning. In general, about five such traps are laid in a 1-ha pond. All mitten crabs in a 1-ha pond could be harvested over a period of 7 days. Once the harvest is completed, ponds are drained to harvest the co-cultured fishes. Normally harvested silver carp, bighead carp and other small fish are frozen and used as trash fish for the next rearing cycle. However, the more highly valued mandarin fish is sold on capture.

In recent years, farmers have witnessed wide price fluctuations of mitten crab with the highest price occurring between October and February the following year. This leads to speculative action by some farmers (27 % of farms surveyed) to hoard harvested mitten crabs in net cages awaiting for escalation in prices.

Aquatic product vendors often negotiated with farmers based on quality tests and weight classification of mitten crab. Factors influencing price including the appearance (e.g. colour of abdomen, chelipedes loss or damage), degree of gonads maturity, and degree of muscle maturity were all included in such assessment. Often vendors undertook the transportation of mitten crab to market(s).

Farming communities

Mitten crab farming communities of Hongze Lake are relatively old, with the age of farmers ranging from 27 to 77 years, but 48.4 % of practitioners being 50 years or older. Meanwhile, only 16 % of farmers are under 40 years. The educational level of crab farmers ranged from illiterate (8 %), primary school (29 %), middle school (33 %), high school (28 %), to college or university (2 %). Almost all the farmers surveyed accumulated the farming technology from other farmers or through experience exchanges with others. It should be noted that the government, at the Provincial and or District levels, have made increasing efforts to improve farming techniques by organizing technical training, distributing free technical manuals and providing expert consultancy services. Fixed labour ranged from 1 to 6 (mean 2) people per farm. Female labour contributed 0–50 % (mean 43 %) of the farm labour forces and were involved in all the activities such as pond preparation, macrophyte transplanting, feeding, harvesting and marketing.

Cost–benefit analysis

The fixed cost of a mitten crab farm ranged from 10 138 to 29 023 RMB per ha per cycle (mean 14 710 ± 285 RMB ha^{-1} $cycle^{-1}$, 1 US $ = 5.97 RMB) with main costs being attributed to land lease (mean 86 %), depreciation (mean 8 %) and interest (mean 6 %). Operating costs ranged from 24 049 to 76 158 RMB per ha per cycle (mean 42 216 ± 929 RMB ha^{-1} $cycle^{-1}$). The operating cost for feeding trash fish (mean 45 455 ± 2731 RMB ha^{-1} $cycle^{-1}$) was higher than that for commercial feed (mean 38 960 ± 1441 RMB ha^{-1} $cycle^{-1}$) (Table 2). The annual revenue ranged from 43 969 to 146 444 RMB ha^{-1} $cycle^{-1}$ (mean 80 299 ± 2018 RMB ha^{-1} $cycle^{-1}$).

It is evident that the mean net profit ranged from 16 003 to 24 983 RMB ha^{-1} $cycle^{-1}$, for farms using trash fish alone, commercial pellet feed alone, and commercial pellet feed and trash fish (Table 2). In fact, there was no significant difference in the net profit between those farms that use only commercial pellet feed and or a combination of the latter with trash fish. As pointed out earlier, there is a need for a targeted study to evaluate the efficacies of using trash fish alone, trash fish and commercial pellet feeds and or commercial pellet feeds alone, the costliest recurring cost in mitten carb culture as in almost all aquaculture practices (Hasan and Halwart 2009). Such a study could lead to a rationalization of the type of feed use and the quantities thereof in mitten carb culture and could lead to increased economic viability and long-term sustainability of mitten crab farming in Hongze Lake wetlands, and indeed elsewhere in China also.

CONCLUSIONS

Mitten crab farming area has remained relatively static but total production and unit production have increased steadily over the last 7 years (the period for which reliable data are available), indicative of the viability and sustainability of the farming system. This trend in Hongze lake region, which has become a major mitten crab farming area in the country reflects the overall trends of mitten crab farming in China. Mitten crab farming in Hongze lake region has become an important source of income for many fishery communities and provides a livelihood for thousands of farmers. Meanwhile, the rapid development of the mitten crab farming sector in this region has cultivated and facilitated the development of other related industries and ancillary services, such as feed manufacture, crab seed production and transportation, macrophyte seed production, water-quality diagnosis and regulation services amongst others. It is also important to note that the mitten crab market chain provides for a large number of employment opportunities.

With mitten crab becoming a relatively high-valued species corresponding to 5–6 times of the farm gate price of that of major carp species, it is not surprising that nearly 90 % of farming water area in Hongze Lake region turned to mitten crab culture beginning in the 1990s, transforming the lake ecosystem and its surroundings. It is believed that the steady growth of mitten crab farming in Hongze lake region over the last two decades is an indication of its economic viability and overall sustainability.

Overall, the mitten crab farming sector in Hongze Lake region epitomizes the current status of aquaculture based on lake reclamation land, and also is representative of the culture of this species in China, in a manner making it a unique aquatic ecosystem. Mitten crab farming practices incorporate improved traditional practices making it environment-friendly overall with minimal TN, TP, COD and TSS levels in effluents compared to other aquaculture species (Cai et al. 2012a). Environmental friendliness of farming practices is known to be a key to sustainability for all forms of primary production and a paradigm that is being increasingly acknowledged as a necessity for meeting the food demands for an increasing population (Charles et al. 2015; Chartres and Noble 2015; Poppy et al. 2015).

It is believed that the above factors and the steady growth of the mitten crab farming in Hongze lake region over the last two decades is an indication of its economic viability and overall sustainability.

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REFERENCES

Ackefors, H., and M. Enell. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. *Journal Applied Ichthyology* 10: 225–241.

Billard, R. 1999. *The carp: Biology and culture*. New York: Springer-Praxis.

Briggs, M.R.P., and S.J. Funge-Smith. 1994. A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management* 25: 789–811.

Bui, T.M., L.T. Phan, B.A. Ingram, T.T.T. Nguyen, G.J. Gooley, H.V. Nguyen, P.V. Nguyen, and S.S. De Silva. 2010. Seed production practices of striped catfish, *Pangasianodon hypophthalmus* in the Mekong Delta region. *Vietnam. Aquaculture* 306: 92–100.

Bunlipatanon, P., N. Songseechan, H. Kongkeo, N.W. Abery, and S.S. De Silva. 2014. Comparative efficacy of trash fish versus compounded commercial feeds in cage aquaculture of Asian seabass (*Lates calcarifer*) (Bloch) and tiger grouper (*Epinephelus fuscoguttatus*) (Forsska). *Aquaculture Research* 45: 373–388.

Cai, C., X. Gu, Y. Ye, C. Yang, X. Dai, D. Chen, and C. Yang. 2012a. Assessment of pollutant loads discharged from aquaculture ponds around Taihu Lake, China. *Aquaculture Research* 44: 795–806.

Cai, C., X. Gu, H. Huang, X. Dai, Y. Ye, and C. Shi. 2012b. Water quality, nutrient budget, and pollutant loads in Chinese mitten crab (*Eriocheir sinensis*) farms around East Taihu Lake. *Chinese Journal of Oceanology and Limnology* 30: 29–36.

Charles, H., J. Godfray, and T. Garnett. 2015. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B*. doi:10.1098/rstb.2012.0273.

Chartres, C.J., and A. Noble. 2015. Sustainable intensification: Overcoming land and water constraints on food production. *Food Security*. doi:10.1007/s12571-015-0425-1.

Chen, B., N. Du, and H. Ye. 1989. Analysis on the feeding habit of the mitten crab *Eriocheir sinensis*. *Fisheries Science & Technology Information* 16: 2–5. **(In Chinese with English abstract)**.

Chen, D., M. Zhang, and S. Shrestha. 2007. Compositional characteristics and nutritional quality of Chinese mitten crab (*Eriocheir sinensis*). *Food Chemistry* 103: 1343–1349.

Cheng, Y., X. Wu, X. Yang, and A.H. Hines. 2008. Current trends in hatchery techniques and stock enhancement for Chinese mitten crab, *Eriocheir japonica sinensis*. *Reviews in Fisheries Science* 16: 377–384.

Cui, Y., and Z. Li. 2005. *Fishery resources and conservation of environment in lakes of the Changjiang River Basin*. Beijing: Science Press. **(In Chinese)**.

De Silva, S.S., R.P. Subasinghe, D.M. Bartley, and A. Lowther. 2004. Tilapias as alien aquatics in Asia and the Pacific: A review. FAO, Fisheries Technical Paper No. 453, Rome, Italy.

De Silva, S.S., B.A. Ingram, P.T. Nguyen, T.M. Bui, G.J. Gooley, and G.M. Turchini. 2010. Estimation of nitrogen and phosphorus in effluent from the striped catfish farming sector in the Mekong Delta, Vietnam. *Ambio* 39: 504–514.

De Silva, S.S., and N.T. Phuong. 2011. Striped catfish farming in the Mekong Delta, Vietnam: a tumultuous path to a global success. *Reviews in Aquaculture* 3: 45–73.

FAO. 2014. FishStatJ: A Tool for Fishery Statistical Analysis. (Available: http://www.fao.org/fishery/statistics/software/fishstatj/en).

Gross, A., C.E. Boyed, and C.W. Wood. 2000. Nitrogen transformations and balance in channel catfish ponds. *Aquacultural Engineering* 24: 1–14.

Guo, L., and Z. Li. 2003. Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China. *Aquaculture* 226: 201–212.

Guo, Y., S. Gu, X. Wang, L. Zhao, and J. Zheng. 2014. Comparison of fatty acid and amino acid profiles of steamed Chinese mitten crab. *Fisheries Science* 80: 621–633.

Hasan, M.R., and M. Halwart. 2009. Fish as feed inputs for aquaculture: practices, sustainability and implications. FAO, Fisheries and Aquaculture Technical Paper No. 518, Rome, Italy.

Herbeck, L.S., D. Unger, Y. Wu, and T.C. Jennerjahn. 2013. Effluent, nutrient and organic matter export from shrimp and fish ponds causing eutrophication in coastal and back-reef waters of NE Hainan, tropical China. *Continental Shelf Research* 57: 92–104.

Herborg, L.M., S.P. Rushton, A.S. Clare, and M.G. Bentley. 2003. Spread of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards) in Continental Europe: analysis of a historical data set. *Hydrobiologia* 503: 21–28.

Hopkins, J.S., R.D. Hamilton, P.A. Sandier, C.L. Browdy, and A.D. Stokes. 1993. Effect of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. *Journal of the World Aquaculture Society* 24: 304–320.

Jin, G., P. Xie, and Z. Li. 2003. Food habits of 2-year-old Chinese mitten crab (*Eriocheir sinensis*) stocked in Lake Bao'an, China. *Journal of Freshwater Ecology* 18: 369–375.

Kongkeo, H. 1997. Comparison of intensive shrimp farming systems in Indonesia, Philippines, Taiwan and Thailand. *Aquaculture Research* 28: 789–796.

Lemarié, G., J.M. Martin, G. Dutto, and C. Garidou. 1998. Nitrogenous and phosphorous waste production in a flow-through land-based farm of European seabass (*Dicentrarchus zubrux*). *Aquatic Living Resource* 11: 247–254.

Li, S., W. Guo, and B. Mitchell. 2011a. Evaluation of water quality and management of Hongze Lake and Gaoyou Lake along the Grand Canal in Eastern China. *Environmental Monitoring and Assessment* 176: 373–384.

Li, X., Z. Li, J. Liu, and S.S. De Silva. 2011b. Advances in precocity research of the Chinese mitten crab *Eriocheir sinensis*. *Aquaculture International* 19: 251–267.

Luo, Z., X. Tan, Y. Chen, W. Wang, and G. Zhou. 2008. Apparent digestibility coefficients of selected feed ingredients for Chinese mitten crab *Eriocheir sinensis*. *Aquaculture* 285: 141–145.

Pan, H. 2002. *Ecological culture of Chinese mitten crab*. Beijing: China Agriculture Science and Technology Press. **(in Chinese)**.

Paunovic, M., P. Cakic, A. Hegedis, J. Kolarevic, and M. Lenhardt. 2004. A report of *Eriocheir sinensis* (H. Milne Edwards, 1854) (Crustacea: Brachyura: Grapsidae) from the Serbian part of the Danube River. *Hydrobiologia* 529: 275–277.

Phan, L.T., T.M. Bui, T.T.T. Nguyen, G.J. Gooley, B.A. Ingram, H.V. Nguyen, P.T. Nguyen, and S.S. De Silva. 2009. Current status of farming practices of striped catfish, *Pangasianodon hypophthalmus* in the Mekong Delta. *Vietnam. Aquaculture* 296: 227–236.

Poppy, G.M., P.C. Jepson, J.A. Pickett, and M.A. Birkett. 2015. Achieving food environmental security: New approaches to close the gap. *Philosophical Transactions of the Royal Society B*. doi:10.1098/rstb.2012.0272.

Ruan, R., S. Xia, Y. Chen, Y. She, and M. Yan. 2012. Change of lake nearby Linhuai Town in west bank of Hongze Lake during 1979–2006. *Wetland Science* 10(3): 344–349. **(in Chinese with English abstract)**.

Rudnick, D.A., K. Hieb, K.F. Grimmer, and V.H. Resh. 2003. Patterns and processes of biological invasion: The Chinese mitten crab in San Francisco Bay. *Basic and Applied Ecology* 4: 249–262.

Sahu, B.C., S. Adhikari, and L. Dey. 2013. Carbon, nitrogen and phosphorus budget in shrimp (*Penaeus monodon*) culture ponds in eastern India. *Aquaculture International* 21: 453–466.

Shao, L., C. Wang, J. He, X. Wu, and Y. Cheng. 2013. Hepatopancreas and gonad quality of Chinese mitten crabs fattened with natural and formulated diets. *Journal of Food Quality* 36: 217–227.

Shao, L., C. Wang, J. He, X. Wu, and Y. Cheng. 2014. Meat quality of Chinese mitten crabs fattened with natural and formulated diets. *Journal of Aquatic Food Product Technology* 23: 59–72.

Shi, H., F.P. James, Z. Fan, M. Hong, and F. Yin. 2008. Evidence of massive scale turtle farming in China. *Oryx* 42: 147–160.

Sui, L., M. Wille, Y. Cheng, W. Wu, and P. Sorgeloos. 2011. Larviculture techniques of Chinese mitten crab *Eriocheir sinensis*. *Aquaculture* 315: 16–19.

Thakur, D.P., and C.K. Lin. 2003. Water quality and nutrient budget in closed shrimp (*Penaeus monodon*) culture systems. *Aquacultural Engineering* 27: 158–176.

Wahab, M.A., S.K. Ahmad-Al-Nahid, N. Ahmed, M.M. Haque, and M. Karim. 2012. Current status and prospects of farming the giant river prawn (De Man) in Bangladesh. *Aquaculture Research* 43: 970–983.

Wang, H., H. Wang, X. Liang, and Y. Cui. 2006. Stocking models of Chinese mitten crab (*Eriocheir japonica sinensis*) in Yangtze lakes. *Aquaculture* 255: 456–465.

Wang, W., Y. Cheng, and Y. Li. 2007a. Biology of Chinese mitten crab. *Fisheries Science & Technology Information* 34: 25–28. **(in Chinese)**.

Wang, M., J. Ma, and Q. Shao. 2007b. Study on aquaculture technology of soft shelled turtle. *Reservoir Fisheries* 27: 24–26. **(In Chinese)**.

Wang, Q., L. Cheng, J. Liu, Z. Li, S. Xie, and S.S. De Silva. 2014. Freshwater aquaculture in PR China: trends and prospects. *Reviews in Aquaculture* 5: 1–20.

Xie, B., and K. Yu. 2007. Shrimp farming in China: Operating characteristics, environmental impact and perspectives. *Ocean and Coastal Management* 50: 538–550.

Xie, Y., Z. Li, W.P. Gregg, and D. Li. 2001. Invasive species in China—An overview. *Biodiversity and Conservation* 10: 1317–1341.

Xu, Z., X. Lin, Q. Lin, Y. Yang, and Y. Wang. 2007. Nitrogen, phosphorus, and energy waste outputs of four marine cage-cultured fish fed with trash fish. *Aquaculture* 263: 130–141.

Ye, C., C. Li, B. Wang, J. Zhang, and L. Zhang. 2011. Study on building scheme for a healthy aquatic ecosystem of Lake Hongze. *Journal of Lake Sciences* 23: 725–730. **(In Chinese with English abstract)**.

Yi, Y., C.K. Lin, and J.S. Diana. 2003. Hybrid catfish (*Clarias macrocephalus C. gariepinus*) and Nile tilapia (*Oreochromis niloticus*) culture in an integrated pen-cum-pond system: Growth performance and nutrient budgets. *Aquaculture* 17: 395–408.

Yu, K., and C. Hu. 2013. Changes in vegetation coverage of the Hongze Lake national wetland nature reserve: A decade-long assessment using MODIS medium-resolution data. *Journal of Applied Remote Sensing*. doi:10.1117/1.JRS.7.073589.

Zhang, Y., A. Bleeker, and J. Liu. 2015. Nutrient discharge from China's aquaculture industry and associated environmental impacts. *Environmental Research Letters*. doi:10.1088/1748-9326/10/4/045002.

AUTHOR BIOGRAPHIES

Qidong Wang is an Assistant Professor (PhD) of the Institute of Hydrobiology, Chinese Academy of Sciences. His research focuses on environmental impacts of aquaculture actives and sustainable farming systems.
Address: State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
Address: National Research Centre for Freshwater Fisheries Engineering, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
e-mail: wangqd@ihb.ac.cn

Jiashou Liu is a Professor of Fisheries Ecology in the State Key Laboratory of Freshwater Ecology and Biotechnology of the Institute of Hydrobiology, the Chinese Academy of Sciences. His research interests include impacts of different aquaculture farming practices on water quality in reservoirs and sustainable fisheries and environmental management.
Address: State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
Address: National Research Centre for Freshwater Fisheries Engineering, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
e-mail: jsliu@ihb.ac.cn

Shengyu Zhang has a Master's Degree and is a deputy director at Hongze Lake Fisheries Management Committee Office. His work focuses on in wetland environment protection.
Address: Hongze Lake Fisheries Management Committee Office, East Huanghe Road, Huaian 223002, People's Republic of China.
e-mail: hzhzsy@126.com

Yuxi Lian is a doctoral candidate at the Institute of Hydrobiology, Chinese Academy of Sciences and the University of the Chinese Academy of Sciences. His work focuses on the application of hydroacoustics in fish resources and protection.
Address: State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
Address: University of the Chinese Academy of Sciences, 19 Yuquan Road, Beijing 100049, People's Republic of China.
e-mail: lianyx@ihb.ac.cn

Huaiyu Ding is a Professor of Aquaculture in the College of Life Science, the Huaiyin Normal University, Huaian 223300, P. R. China. His main field of expertise is in crustacean aquaculture.
Address: College of Life Science, Huaiyin Normal University, 111 West Changjiang Road, Huaian 223300, People's Republic of China.
e-mail: huaiyu-ding@163.com

Xue Du is a doctoral candidate at the Institute of Hydrobiology, the Chinese Academy of Sciences and the University of the Chinese Academy of Sciences. Her work focuses on the zooplankton, lake eutrophication and lake wetland sustainability science.
Address: State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
Address: University of the Chinese Academy of Sciences, 19 Yuquan Road, Beijing 100049, People's Republic of China.
e-mail: beautyduxue@sina.com

Zhongjie Li (✉) is a Professor of Fisheries Ecology in the State Key Laboratory of Freshwater Ecology and Biotechnology, the Institute of Hydrobiology, the Chinese Academy of Sciences. His research interests include various aspects of sustainable aquaculture and lake wetlands management.
Address: State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, Hubei, People's Republic of China.
e-mail: zhongjie@ihb.ac.cn

Sena S. De Silva is an Honorary Professor at the Deakin University, Victoria, Australia.
Address: School of Life & Environmental Sciences, Deakin University, Warrnambool, VIC 3280, Australia.
e-mail: sena.desilva@deakin.edu.au