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Freshwater aquaculture in PR China: trends and prospects

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Abstract

It is acknowledged that China is the mainstay in global aquaculture, contributing for example, 65.7 (of 76 321 310 t) and 63.6 (of 38 994 913 t) per cent to total global and freshwater aquaculture production, respectively, in 2011, significantly increasing the corresponding contributions from 36.1 and 38.5% of the global total (7 359 881 t) and global freshwater (2 342 706 t) aquaculture production in 1980. Overall, aquaculture production in China in turn has enabled to reduce our dependence on food fish supplies from a hunted to a farmed origin, like all the other staples. However, there are very few accounts on different subsectors of aquaculture in China and even less on variations in aquaculture developments within the country. This review attempts to trace the development trends in inland aquaculture in China in time and space and includes aspects on production, types and modes of culture, species cultured and marketing. It is evident that though inland aquaculture is practised in most provinces of China, the great bulk of it occurs in the area that lies approximately between 110 and 120 °E and 19 and 35 °N, in the Yangtze and Pearl River basins. The review also addresses emerging issues on freshwater aquaculture and possible ways of achieving sustainability in the long term.

Key words: alien species, freshwater aquaculture, monoculture, polyculture, production, value.

Introduction

Aquaculture, in spite of millennia old practice transformed into a significant food production sector in the course of the last three to four decades only, and it currently accounts for over 50% of the global food fish consumption (Subasinghe *et al.* 2009). Food fish needs and the changes in the food fish production sector, from a developed country dominance to a developing country dominance, in contrast to the continued developing country dominance of the aquaculture sector have been dealt with previously (Delgado *et al.* 2003; De Silva 2012). In all instances, when aquaculture development over the years and its increasing importance as a food sector (see for example Tacon *et al.* 2009; Aquaculture Service 2011; Subasinghe *et al.* 2012) that have helped to change the food fish supplies from a hunted to a farmed origin, as in the case of all of our other staples (De Silva 2012), are dealt with notable key salient points emerge. These are the following:

- Aquaculture has recorded the highest annual growth rate of all primary production sectors over the last three decades.
- Aquaculture is a significant contributor to the nutrition, accounting for approximately 30% of the daily animal protein consumption in developing nations.
- The bulk of aquaculture production is finfish and freshwater aquaculture predominates globally.
- The main production centres of aquaculture are in the Asia-Pacific region, and
- PR China has continued to lead the global aquaculture production over the last few decades and indeed in the modern era of aquaculture developments in the world, with an increasing share over the years. For example, PR China has accounted for 36.1 and 38.5% of the global total (7 359 881 t) and global freshwater (2 342 706 t) aquaculture production in 1980, respectively, and increased the corresponding contributions to 65.7 (of 76 321 310 t) and 63.6 (of 38 994 913 t) per cent in 2011.

In spite of the significant importance of freshwater aquaculture in China to global food security and to the socio-economy, the sector has not been the subject of an extensive review. This does not, however, preclude the fact that there is an enormous quantum of literature on specific aspects of Chinese aquaculture, including the growing concerns on environmental impacts for instance (see for example Qin *et al.* 2007; Pan *et al.* 2012). Aquaculture in China had been dealt with in the past in detail. However, most of this documentation on aspects of aquaculture was done in the early years of China's 'opening up' (Li 1988, 1992, 1994; Lin 1991). Edwards (2004) dealt with traditional Chinese aquaculture and its impact outside China and followed up (Edwards 2006) with a brief treatment on recent developments in Chinese inland aquaculture. Such documentation has been also supplemented with reviews on some specific aspects on Chinese aquaculture, such as on cage and pen culture (Chen *et al.* 2007), the role of exotic species (Liu & Li 2010; Lin *et al.* 2013) and a synopsis of farming practices in one of the major freshwater aquaculture-producing province, Hubei (Edwards 2012, 2013).

During the last two to three decades, it is universally accepted that China has grown in leaps and bounds in many spheres of human endeavour, including in primary production. It has become the global leader in the production of many staples and a net exporter of commodities such as rice; aquaculture developments have not been an exception in this regard either.

However, in spite of the major developments in aquaculture in China and its increasing contribution to the global food fish supplies, there had not been a major attempt to review and evaluate this progress. As such this paper attempts to review the trends in freshwater aquaculture in mainland China and focus on some of the more recent developments in this regard. It should also be noted that in view of the great diversity of freshwater aquaculture practices in China, it will be futile to attempt to review all these. What is endeavoured here is to illustrate with suitable examples, where appropriate, and to emphasize the different modes of practices and the ranges in production in relation to some selected practices of major cultured species.

Data sources and scope of the review

Statistical information of freshwater aquaculture in China in relation to that globally was accessed from the FAO database (FAO 2014). As for details on the production in relation to different freshwater environments and species cultured, these were accessed from the China Fisheries Yearbooks from 1980 to 2012 (FDMA 1981–2012). With regard to the value of freshwater aquaculture produce differentiation between wild caught and cultured were available only from 2003 onwards. In addition, for other information provided in this review an extensive survey of the available literature in Chinese and in English languages on freshwater aquaculture in China was evaluated.

In this analysis, freshwater mollusc production was not taken into account for two reasons. Firstly, the freshwater mollusc production did not exceed 0.5×10^6 t in any 1 year in the period 1981–2012, and secondly the information provided in the above mentioned data sources accessed did not provide details on species cultured and/or on environments and/or culture systems.

Freshwater aquaculture in China

Freshwater aquaculture in the global context

Overall, global and regional trends in freshwater aquaculture have been reviewed recently (Aquaculture Service 2011; Aquaculture Service and Network of Aquaculture Centres in Asia-Pacific 2011). Globally, over the years since aquaculture became a significant contributor to the food fish basket, freshwater aquaculture has played and continues to play a dominant role (Fig. 1). Freshwater aquaculture accounted for 51.1% of the global aquaculture production of 76 321 310 t in 2011, and its contribution averaged 45.3% over the period 1981–2011. However, if seaweed production was excluded, the proportionate contribution from the latter would be considerably higher. It is also evident from Figure 1 that China predominate global freshwater aquaculture production, and its contribution to the latter has continued to increase and currently (2011) accounts for 63.6% of the global total of 38 994 913 t. Furthermore, the contribution from China to global freshwater aquaculture production peaked in the early 1990s, and over the period 1981–2011 averaged 61.2%. As such the importance of the freshwater aquaculture to global aquaculture and the predominance of Chinese contribution to the former are evident.

Centres of freshwater aquaculture within China

Production trends

Of the 31 provinces and municipalities in the mainland of China, only in 24 provinces did the inland aquaculture production exceed 25 000 t year^{-1} in the period 1981–2010. Based on 5-year averages in production from 1981 to 2010, the leading 15 freshwater aquaculture-producing provinces in China accounted for over 92% of the country's production. Over the same period, the top eight freshwater aquaculture-producing provinces accounted for over 82% of the national production (Fig. 2). The leading freshwater aquaculture-producing provinces over the period 1981–2010 were Anhui, Guangdong, Hainan, Hubei, Hunan, Jiangsu and Jiangxi. Zhejiang province, on the other hand, was among the top five producers in the period from 1981 to

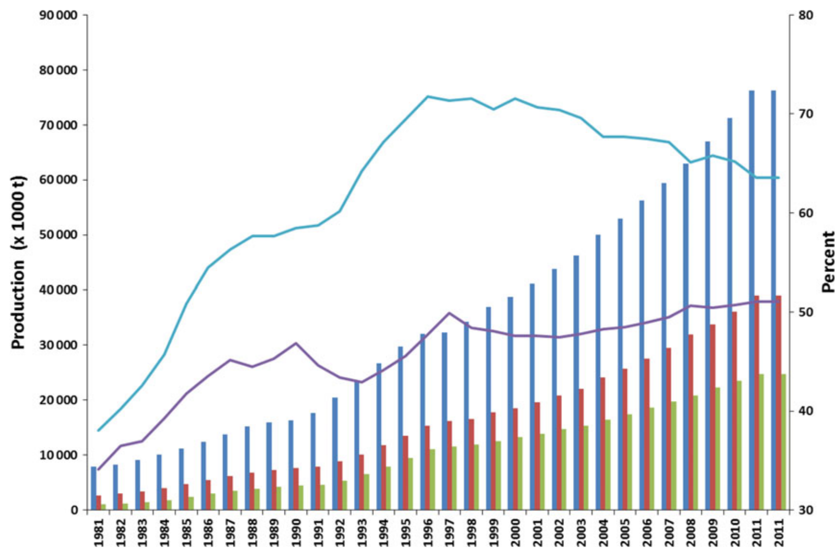

Figure 1 Total and global freshwater, and Chinese freshwater aquaculture production (in ×1000 t) and the per cent contribution of freshwater aquaculture to the global total and that of China to the global freshwater aquaculture production (based on FAO FishStatJ, 2014). (▬) Global (Total), (▬) Global (FwAqP), (▬) China (FwAqP), (▬) % GlobalFwAqP to Global Total, (▬) % China FwAqP to Global FwAqP.

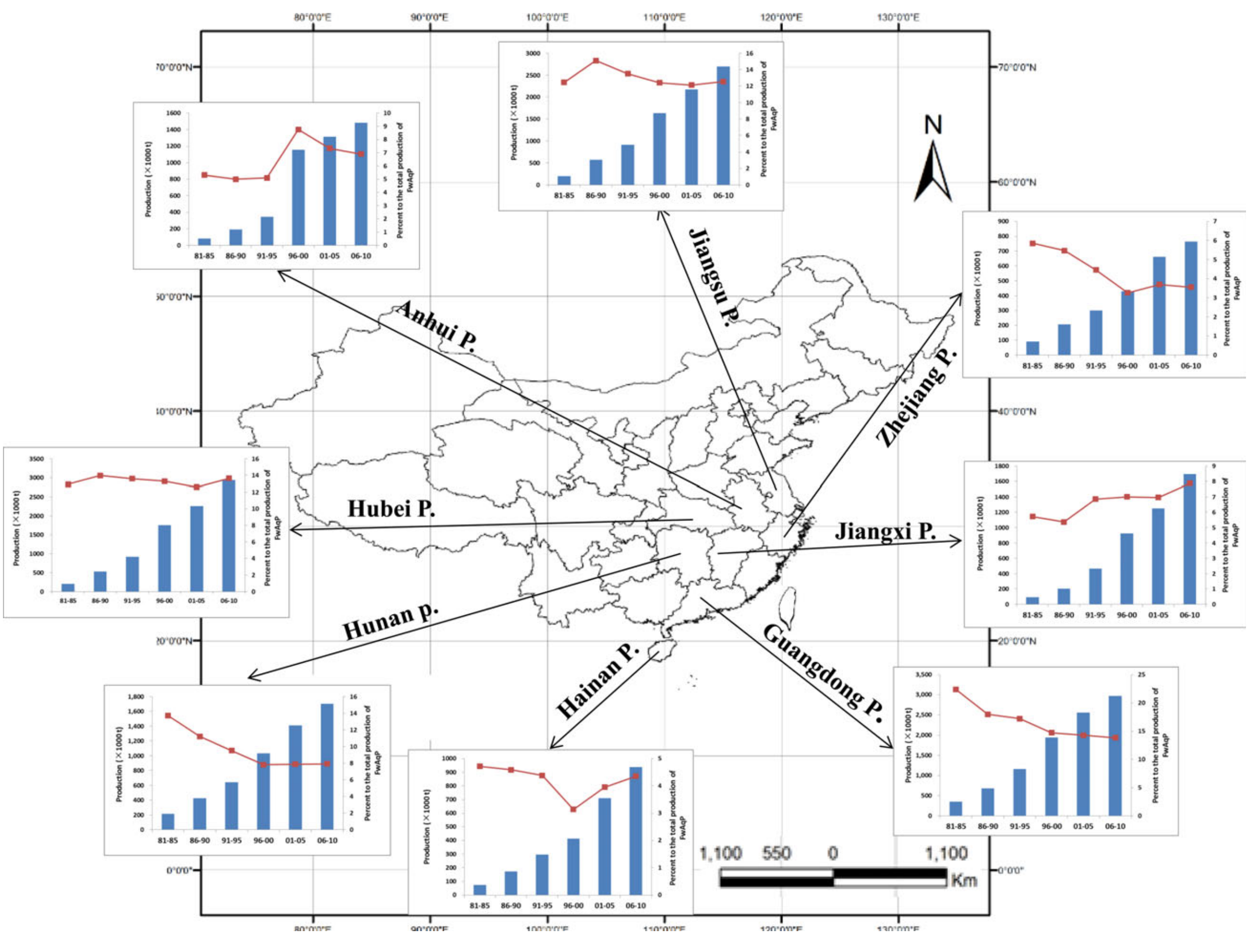

Figure 2 The average production (×1000 t) per year for each five-year period from 1981 to 2010 of those provinces that were among the top ten freshwater aquaculture-producing provinces in China for the whole of the above period, together with the per cent contribution to nation's total freshwater aquaculture production.

1990 and became less important in the period after 1990. All these provinces lie approximately between 110 and 120 °E and 19 and 35 °N, well within the tropical and subtropical belt (Fig. 2). Importantly, all these provinces, except Hainan, lie either in the Yangtze River basin and/or the Pearl River basin (Guangdong only), where water availability is, at least thus far, not being a limiting factor. For example, the provinces in the Yangtze River Basin accounted for 54.7% of the inland aquaculture production in China.

It is also evident from Figure 2 that in all eight leading aquaculture-producing provinces production has continued to increase through the last two decades. However, in some provinces, notably Guangdong, Hunan and Zhejiang the relative contribution to the overall freshwater aquaculture production has declined. This indicates the shifts in production in the country. For example, the contribution to national production increased markedly in Hainan Province since the 1990s, triggered off with the development of Nile tilapia culture in the province (Liu & Li 2010). Similarly, Hubei Province has witnessed an upsurge resulting from increased production of the indigenous mitten crab (*Eriocheir sinensis* (H. Milne-Edwards 1854)) and the exotic crayfish (*Procambarus clarkii* (Girard 1852)). Such shifts in culture practices impact on the national production. Shifts in the relative importance of individual provincial contribution are to be expected in the future also, particularly in the region 110–120 °E and 19–35 °N in view of the favourable climatic regimes for aquaculture, the ingrained traditions and water availability.

Trends in value of produce

Monetary value of freshwater aquaculture for the period when data were available (from 2003 onwards) for the top seven provinces is shown in Figure 3. The total value of freshwater aquaculture produce in China increased from RMB 143.2 billion in 2003 to RMB 419.5 billion in 2012 (6 RMB = 1 US; i.e. approximately 23.9 billion US to 62.0

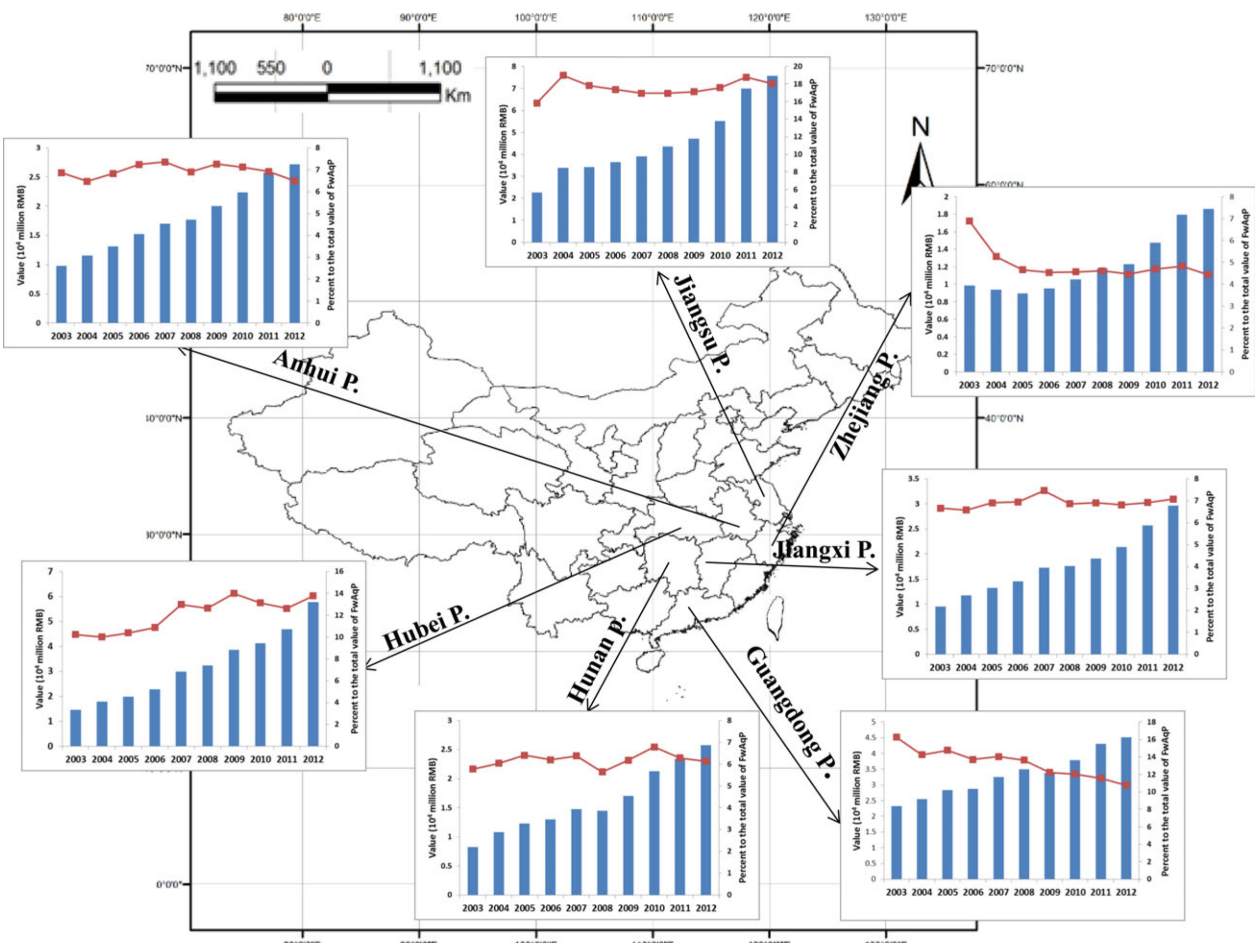

Figure 3 Trends in monetary value in RMB (in 10^4 million; RMB 6.25 = 1 US$) from freshwater aquaculture production for the seven leading provinces in China from 2003 to 2012.

billion US$), which is equivalent to nearly 19.3% increase in monetary value per year. Here, again the monetary value of freshwater aquaculture produce tended to increase in the leading seven provinces (Fig. 3). However, the monetary contribution to the total value of national freshwater aquaculture produce tended to decrease only in Guangdong and Zhejiang province where as in the other five the changes were minor and increased slightly overall (Fig. 3). Perhaps, the highest proportionate increase occurred in Hubei province, almost coincident to the increase in production of the two relatively high-valued species viz. the indigenous mitten crab and the exotic crayfish.

Forms of freshwater aquaculture

In China, all natural (rivers and lakes) and man-made water bodies such as reservoirs and ponds are used for aquaculture. Overall, pond aquaculture is the most predominant (Fig. 4a). Freshwater aquaculture pond area has increased over the years, particularly so from 1991 onwards, while that of reservoir area used for aquaculture purposes has declined slightly. Perhaps, an equally steep increase in an area similar to pond acreage has occurred in paddy field aquaculture (also referred to as rice-fish culture), since the 1990s, which is a very old and a traditional form of aquaculture in China (Li 1988, 1992; Miao 2010), but being gradually adopted for the culture of high-valued species such as crayfish and mitten crab (Miao 2010).

In reservoirs, lakes and rivers, the commonest aquaculture practice in China is net cage culture. There is a huge diversity in the size, material used for net cages and equally a diversity of the species cultured. The species commonly cultured in net cages are indicated in Table 1, and the species choice varies on water temperature and regional consumer preferences and also export potential. For example, the exotic channel catfish (*Ictalurus punctatus* (Rafinesque 1818)) is almost exclusively cultured in net cages in reservoirs in the north-western part of Hubei province where temperature is favourable for growing this species, primarily targeting the lucrative export market.

On the other hand, the trends in the total production from the different environments did not necessarily reflect the area used (Fig. 4b). For example, pond aquaculture yielded the highest production and increased up to almost eight times of that in the early 1990s (1 744 024 t average for 1991–1995 to 15 002 785 t average for 2006–2010). In contrast aquaculture production in reservoirs, for similar time periods, increased from 206 832 t to 2 556 932 t.

Species cultured

Although China is endowed with a rich finfish fauna consisting of 302 genera, 920 species of which 613 are endemic

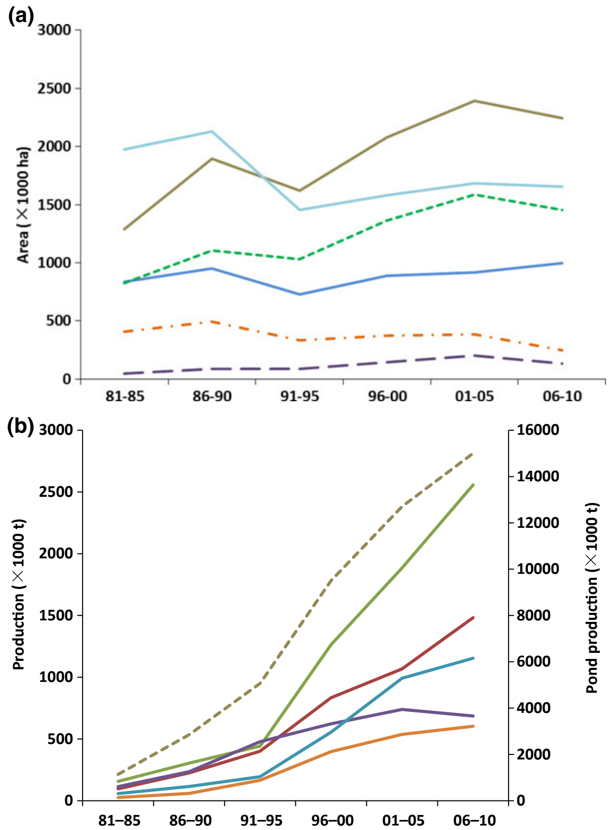

Figure 4 (a) The average area (thousand ha) for five-year periods from 1981 to 2010 of each environmental type used for freshwater aquaculture production . (b) Average production in ×1000 t over 5-year periods from 1981 to 2010 for each of the freshwater environmental types. Please note the production in ponds is indicated on the right-hand scale. (a) (—) Pond, (—) Lake, (—) Reservoir, (-·-) River, (----) Paddy, (– –) Other; (b) (—) Lake, (—) Reservoir, (—) River, (—) Paddy, (—) Others, (----) Pond.

(Kang *et al.* 2014) and many species are cultured, but only 20 finfish species, three crustacean species and one reptile species cultured exceeded a production of 25 000 t/year in any year from 2003 to 2012. Among the above, four finfish and two crustacean species are alien to China. The role of alien species in Asian aquaculture and that of Chinese aquaculture has been dealt with previously by De Silva *et al.* (2006), Liu and Li (2010) and Lin *et al.* (2013), respectively, and also from a food production and biodiversity view point (De Silva *et al.* 2009).

Overall, therefore, although China is the world leading freshwater aquaculture-producing nation, perhaps contrary to the popular belief, and in comparison with the number of species and families that are cultured globally (336 species belonging to 115 families; Bartley *et al.* 2009), the freshwater aquaculture production dominance in China is based on number of species or species groups, around 30.

Table 1 List of major species cultured in freshwaters (only species that exceeded 25 000 t year^{-1}, for any year from 1980 to 2012 are included) in China including relevant taxonomic information, the major provinces of culture and the culture systems utilized. All information except latter is based on data provided in China Fisheries Year Books, 1981–2013. Information on the culture systems utilized is based on the experiences of the authors

Order/Family/Species	Latin name	Major province	Culture systems
Cypriniformes/Cyprinidae			
Black carp	*Mylopharyngodon piceus* (Richardson 1846)	JS, ZJ, AH, JX, HB, HN, GD	Cc, Pc, CBF
Grass carp	*Ctenopharyngodon idellus* (Valenciennes 1844)	JS, ZJ, AH, FJ, JX, SD, HEN, HB, HN, GD, GX, SC, YN, NX, XJ	Pc, Cc, CBF
Silver carp	*Hypophthalmichthys molitrix* (Valenciennes 1844)	TJ, HEB, LN, JL, HLJ, JS, ZJ, AH, FJ, JX, SD, HEN, HB, HN, GD, GX, CQ, SC, YN, NX, XJ	Pc, Cc, CBF
Big-head carp	*Aristichthys nobilis* (Richardson 1845)	HEB, LN, JL, HLJ, JS, ZJ, AH, FJ, JX, SD, HN, HB, HN, GD, GX, CQ, SC, YN	Pc, Cc, CBF
Common carp	*Cyprinus carpio* (Linnaeus 1758)	TJ, HEB, SX, IM, LN, JL, HLG, JS, ZJ, AH, FJ, JX, SD, HEN, HB, HN, GD, GX, CQ, SC, GZ, YN, SX, NX, XJ	Pc, Cc, CBF
Crucian carp	*Carassius auratus* (Linnaeus 1758)	TJ, HEB, LN, HLJ, SH, JS, ZJ, AH, FJ, JX, SD, HEN, HB, HN, GD, GX, CQ, SC	Pc, Cc, CBF
Bream	1. *Megalobrama amblycephala* (Yih 1955) 2. *Parabramis pekinensis* (Basilewsky 1855) 3. *Megalobrama terminalis* (Richardson 1846)	JS, ZJ, AH, JX, HEN, HB, HN, GD, SC	Pc, Cc, CBF
Cypriniformes/Cobitidae			
Loach	*Misgurnus anguillicaudatus* (Cantor 1842)	JS, AH, JX, HB	Pc
Siluriformes/Siluridae			
Catfish	*Parasilurus asotus* (Linnaeus 1758)	LN, JX, SD, HB, HN, GD, GX, SC	Pc, Cc
Siluriformes/Ictaluridae			
Channel catfish	*Ictalurus punctatus* (Rafinesque 1818)	JX, HB, HN, SC	Cc
Siluriformes/Bagridae			
Yellow catfish	*Tachysurus fulvidraco* (Richardson 1846)	JX, HB	Pc, Cc, CBF
Symbranchiformes/Symbranchidae			
Paddy eel	*Monopterus albus* (Zuiew 1793)	AH, JX, HB, HN,	Pc, Cc
Perciformes/Serranidae			
Mandarin fish	*Siniperca chuatsi* (Basilewsky 1855)	JS, AH, JX, HB, GD	Pc, Cc, CBF
Perciformes/Lateolabracidae			
Bass	*Lateolabrax japonicas* (Cuvier 1828)	JS, GD	Pc, Cc
Perciformes/Channidae			
Snakehead	*Channa argus* (Cantor 1842)	JS, ZJ, AH, JX, SD, HB, HN, GD	Pc, Cc
Perciformes/Cichlidae			
Nile tilapia	*Oreochromis niloticus* (Linnaeus 1758)	FJ, GD, GX, HAN, YN	Pc
Anguilliformes/Anguillidae			
Eel	*Anguilla japonica* (Temminck & Schlegel 1846)	FJ, GD	Pc, Cc
Characiformes/Serrasalmidae			
Pirapatinga	*Piaractus brachypomus* (Cuvier 1818)	GD, GX	Pc
Decapoda/Grapsidae			
Chinese mitten crab	*Eriocheir sinensis* (H. Milne-Edwards 1854)	LN, JS, AH, SD, HB	Pc, CBF, PeC, PfC
Decapoda/Astacidae			
Crayfish	*Procambarus clarkii* (Girard 1852)	JS, AH, JX, HB	Pc, PfC
Decapoda/Penaeidae			
Shrimp	*Penaeus vannamei* (Boone 1931)	TJ, HEB, SH, JS, ZJ, FJ, SD, GD	Pc
Testudines/Trionychidae			
Soft-shelled turtle	*Trionyx sinensis* (Wiegmann 1835)	JS, ZJ, HB	Pc

Provinces: AH-Anhui P., CQ-Chongqing, FJ-Fujian P., GD-Guangdong P., GX-Guangxi P., GZ-Guizhou P., HAN –Hainan P., HEB-Hebei P., HLJ-Heilongjiang P., HEN-Henan P., HB-Hubei P., HN-Hunan P., JS-Jiangsu P., JX-Jiangxi P., LN-Liaoning P., NX-Ningxia P., SD-Shandong P., SH-Shanghai, SX-Shanxi P., SC-Sichuan P., TJ-Tianjin P., XJ-Xinjiang P., YN-Yunnan P., and ZJ-Zhejiang P. Culture systems: Cc-Cage culture; CBF-Culture-based fisheries; PfC-Paddy field culture; Pc-pond culture; PeC-Pen culture.

These numbers are still considerably higher than that in any other country. This relevance of the dependence on a relatively small number of species/species groups in terms of sustainability of the sector has been highlighted (Lin *et al.* 2013) and will be dealt with in detail later.

Over the years carps, consisting of seven species that include the Chinese major carps: big-head carp (*Aristichthys nobilis* (Richardson 1845)), silver carp (*Hypophthalmichthys molitrix* (Valenciennes 1844)), grass carp (*Ctenopharyngodon idellus*), mud carp (*Cirrhinus molitorella* (Valenciennes 1844)), and black carp (*Mylopharyngodon piceus* (Richardson 1846)), together with common carp (*Cyprinus carpio* (Linnaeus 1758)) and crucian carp (*Carassius auratus* (Linnaeus 1758)), have dominated Chinese freshwater aquaculture. It is also evident from Table 1 that cyprinid culture is the most widespread and is practised in many provinces throughout China, compared with other species/species groups, most of which tended to be cultured in a smaller number of provinces.

Production of carps increased from 13 106 394 t in 2003 to 17 163 183 t in 2012. However, the per cent contribution of cyprinids to total freshwater aquaculture production in China for this period decreased from 73.9 to 64.9 (Fig. 5a). This indicates that other cultured species were also gaining in significance over this time period. Figure 5b shows the trends in production of six carp species over the same period. Among these, it is evident that grass carp (3 492 585–4 781 698 t) was the most predominant, followed by silver carp, common carp, bighead carp, crucian carp and black carp in that order. In effect, it could be considered that grass carp production is the highest among any species cultured globally. It is also important to point out that the production of carp species generally considered as the ‘poor man’s’ fish continued to increase in spite of the often acknowledged very significant improvements in per capita income and living standards in China. However, in this regard, there are exceptions among carp species, such as the black carp which always has commanded a relatively high price even in local markets. Perhaps, this is a reflection of the fact that the carp species continue to be a very important component of the Chinese cuisine and continue to be relished as an affordable food fish source. Another reason is for its high food conversion ratio as a herbivore (Wang 2014). Principles of carp culture have been reviewed previously (De Silva *et al.* 2012a) and included aspects such as reproduction and induced breeding, diseases, culture systems and genetic improvement.

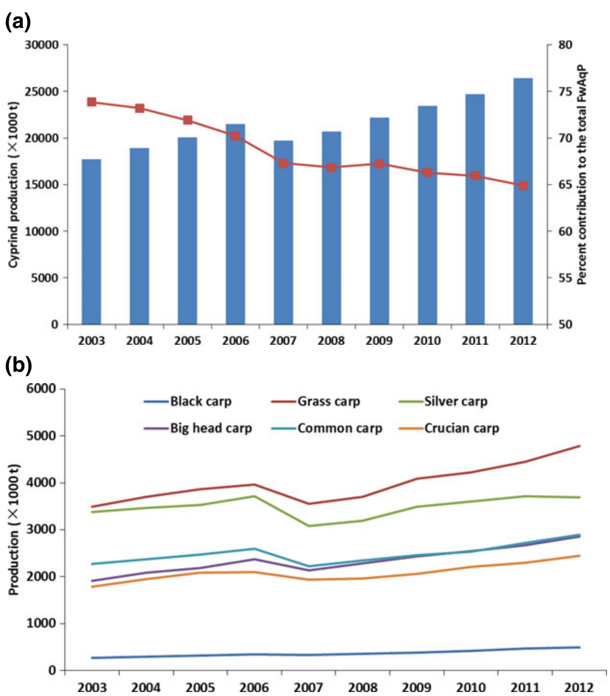

Figure 5 (a) Trends in production of cyprinid species from 2003 to 2012 and the per cent contribution of the group to the total freshwater aquaculture production; (b) The trends in production of the six major cyprinid species contributing to freshwater aquaculture production in China. (—) Black carp, (—) Grass carp, (—) Silver carp, (—) Bighead carp, (—) Common carp, (—) Crucian carp.

Apart from the cyprinids, there are a number finfish species and/or species groups that contribute (in excess of 25 000 t year^{-1}) to freshwater aquaculture production in China (Fig. 6). Of this group, the most predominant is the cichlid fish, alien to Asia, the Nile tilapia (*Oreochromis niloticus* (Linnaeus 1758)). The aquaculture production of this species outweighed all others markedly and accounted for more than three times that of snakehead (*Channa argus* (Cantor 1842)) the next leading species. Also importantly, all of these species/species groups have shown a consistent increase in production in the last decade, perhaps with the exception of the alien species channel catfish (*Ictalurus punctatus* (Rafinesque 1818)) which has tended to plateau in the last few years. Notably, this group of fish includes mostly omnivores and strict carnivores, especially snakehead and mandarin fish (*Siniperca chuatsi* (Basilewsky 1855)). It is known that the latter species feed on live fish only (Li *et al.* 1998, 2013) and attempts to wean it on artificial feeds have been not entirely effective in commercial farming (Liang *et al.* 2001). As such and more often than not its culture is associated with that of forage species such as mud carp. The increased production, and therefore, emphasis on the culture of carnivorous species such as the mandarin fish is primarily driven by the local consumer demand, coupled to the aspirations of the increasing middle class which desires to indulge in high-priced produce.

The relative contribution of the finfish species/species groups shown in Figure 6 to the total freshwater aquaculture production in China increased from 14.3% in 2003 to

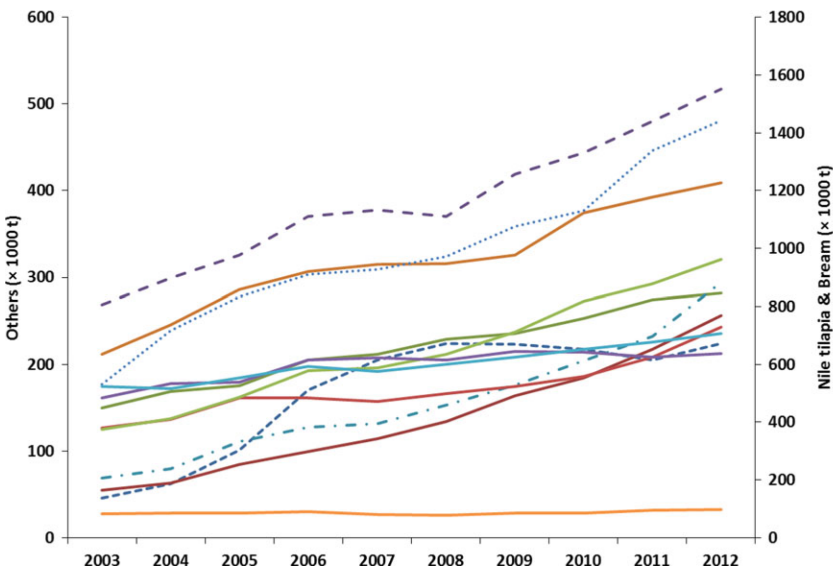

Figure 6 Production trends of major species/species groups contributing (over 25 000 t in any year) to freshwater aquaculture production in China. (----) Channel catfish, (—) Yellow catfish, (—) Mandarin fish, (-·-) Loach, (—) Catfish, (······) Snakehead, (—) Bass, (—) Paddy eel, (—) Eel, (– –) Nile tilapia, (—) Bream, (—) Pirapatinga.

19.2% in 2012. In contrast to the finfish species cultured, only three crustacean species are of notable significance in freshwaters aquaculture in China, and of these two are alien to the country (Fig. 7). Interestingly, two of these species are euryhaline, the exotic, white-legged shrimp (*Penaeus vannamei* (Boone 1931)), which unlike elsewhere is grown intensively in freshwater in a number of provinces such as Guangdong and the indigenous, catadromous mitten crab (*E. sinensis),* which is grown/farmed almost exclusively in freshwaters. The production of these three crustaceans increased from 715 941 t in 2003 to 1 959 948 t in 2012, and the corresponding contribution to freshwater aquaculture production increased from 4.0 to 7.4% (Fig. 7).

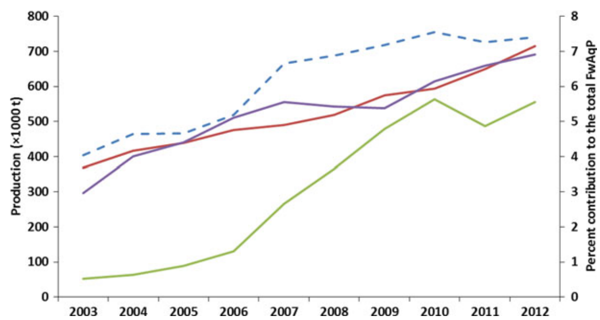

Figure 7 Trends in production of the three major crustacean species and the per cent contribution of these to the total freshwater aquaculture production in China. (—) Chinese mitten crab, (—) Crayfish, (—) Shrimp, (---) %.

The history of penaeid aquaculture is a mix of successes and failures, also referred to as boom and bust cycles, as a food source, economically and environmentally (Primavera 1998; Benzie 2009). All in all it is a much sought after seafood item, and currently in excess of 70% of the shrimp sold and consumed globally is farmed (Benzie 2009). SE Asia dominates global shrimp aquaculture, and the region has witnessed a see-sawing of dominance of different species over the 40-year history of shrimp aquaculture, and the pros and cons in this regard have been dealt with on numerous occasions (Wyban 2007; Benzie 2009; Kongkeo & Davy 2010). What is important to note is that the great bulk of shrimp farming, in particular the penaeid shrimps, occurs in brackish water ponds, in salinities ranging from 5 to 15 ppt the preferred salinity range for growth of penaeid shrimp, across SE Asia and also S America, with perhaps the exception in China.

White-legged shrimp was introduced to China in 1988 and cultured in brackish water ponds in southern coastal provinces (Guangdong, Guangxi and Hainan). Freshwater culture of white-legged shrimp was developed in 1999 which was the starting point (Li 2009). The production of white-legged shrimp cultured in freshwater increased from 296 312 t in 2003 to 690 727 t in 2012. And the per cent contribution of the species cultured in freshwater to the total aquaculture production for this period averaged 50.4%. Now, the major white-legged shrimp inland-producing provinces are Guangdong, Jiangsu, Zhejiang, Fujian, Shandong, Shanghai and Tianjin. An overwhelming majority of white-legged shrimp production is from pond farming systems. In the last decades, shrimp farming has experienced the change from exclusive monoculture to polyculture with fish, mollusc, crab, and so on. In inland freshwater white-legged shrimp ponds, the average stocking density is 1.53 million larvae ha^{-1}, and the average production is 2973 kg ha^{-1}, and the feed conversion coefficient is 2.32 (He *et al.* 2006).

Perhaps, the trend of freshwater culture of white-legged shrimp in China is driven by the fact that in general the preferred size for local consumption of shrimp is 5–10 g as opposed to above 20 g elsewhere in Asia and in the west. Consequently, with white-legged shrimp culture in freshwater, which is generally lower than in saline water, a minimum of three production cycles could be obtained and farmers attain economic viability.

The other most important species cultured in freshwater is the soft-shelled turtle (*Trionyx sinensis* (Wiegmann 1835)) (Table 1). According to Shi *et al.* (2008) the sale of turtle for food was valued in the region of 750 million US$ with *Pelodiscus sinensis* (*T. sinensis*) accounting for more than 90% of turtle sales.

Turtle farming in China has also been controversial, when in the past it was considered that nearly 11 IUCN listed species were wild caught and mixed with farmed turtle and sold as farmed (Shi *et al.* 2008). However, the situation has changed over the years, and now turtle culture is dominated by that of *T. sinensis*. The production of soft-shelled turtle cultured in freshwater increased from 143 816 t in 2003 to 331 424 t in 2012, which is equivalent to nearly 13% increase in production per year. The major producing provinces of soft-shelled turtle are Zhejiang, Jiangsu and Hubei. In recent years, with the increase of stocking density and feed input, deterioration of water quality and disease outbreaks resulted in quality decline of soft-shelled turtle, and consequently, the market prices showed a decreasing trend. However, the market price of wild caught soft-shelled turtle, which was considered as of higher nutritional value and better taste, still remained high (Wang *et al.* 2007). To maintain good water quality in turtle farming system and reduce the risk of disease outbreak, it is a very common practice in soft-shelled turtle pond culture to transplant macrophytes, release snails (2250 kg ha^{-1}) and stock silver carp and big-head carp (total density of 15000 individuals ha^{-1} of 100 g $individuals^{-1}$) (Wang *et al.* 2007; Shi & Zhao 2009; Tian *et al.* 2012). Furthermore, to make comprehensive use of added feed, most farmers adopt to stock yellow catfish (*Tachysurus fulvidraco* (Richardson 1846)) at a density of 3000 individuals ha^{-1} of 5 g $individuals^{-1}$ or other omnivorous species (e.g. crucian carp or shrimp). In general, commercial feed was mainly used in soft-shelled turtle culture. In addition, the cocultured silver carp and big-head carp were also captured and used as trash fish to feed soft-shelled turtle during the rearing period. Normally, a stocking density of 6000 individuals ha^{-1} of soft-shelled turtle with a stocking size of 150 g $individual^{-1}$ was adopted in culture operations, and a production of about 3500 kg ha^{-1} of turtle could be obtained (Shi & Zhao 2009). In addition, it is very common to build a few platforms in the culture ponds which are convenient for turtles to sun bathe with a view of eradicating parasites and other pathogenic bacteria.

Culture techniques/systems

The culture and/or the farming techniques in freshwater aquaculture in China are very diverse and wide ranging, and it will be almost impossible to review this enormous variations. In Figure 8, an attempt is made to capture and summarize the range of diversity in the culture systems that operate in freshwaters in China, with appropriate examples. Perhaps one of the likely reasons that enable China to dominate freshwater aquaculture is the wide adoption of polyculture practices, across board, with increasing introduction of new species into such systems that enable the economic returns to be maintained.

Pond culture

In essence, the carp farming systems, for example, are almost always carried out as a polyculture activity, where the constituent species have different food habits and preferences and ensure the utilization of all the available food resources in the pond ecosystem (Lin 1991), a principle known from very ancient times in China and also reciprocally applied effectively in respect of the polyculture of Indian major carp species such as *Labeo rohita* (Hamilton 1822), *Catla catla* (Hamilton 1822) and *Cirrhinus mrigala* (Hamilton 1822) (Jhingran 1991). In general, the energy transfer and ecological aspects of polyculture systems are well understood (Li 1987; Milstein 1992). It is evident from Table 2 that there are differences, as expected, in the productivity of polyculture systems using different species combinations. However, importantly, all carp polyculture systems tended to be very productive often averaging over 10 t ha^{-1}, exceeding the unit production of many primary production systems.

In the past and more often than not, carp polyculture systems were often integrated with poultry, pig and/or duck farming (Li 1987; Cheng *et al.* 1995), and was common rural activity. This trend is fast disappearing in Chinese aquaculture (Edwards 2008) in view of the possible impacts and concerns of such farming systems on human health and hygiene.

Overall, in pond culture, it is difficult to pinpoint major advances *per se*; however, the farming communities are better informed of markets and as such tend to shift the emphasis to meet market demands and thereby remain economically viable, which perhaps is the main driving force. It is in this context that there has been a gradual shift to include economically more valuable species in polyculture systems and indeed test out new species. For example, the culture of exotic Nile tilapia and channel catfish is relatively

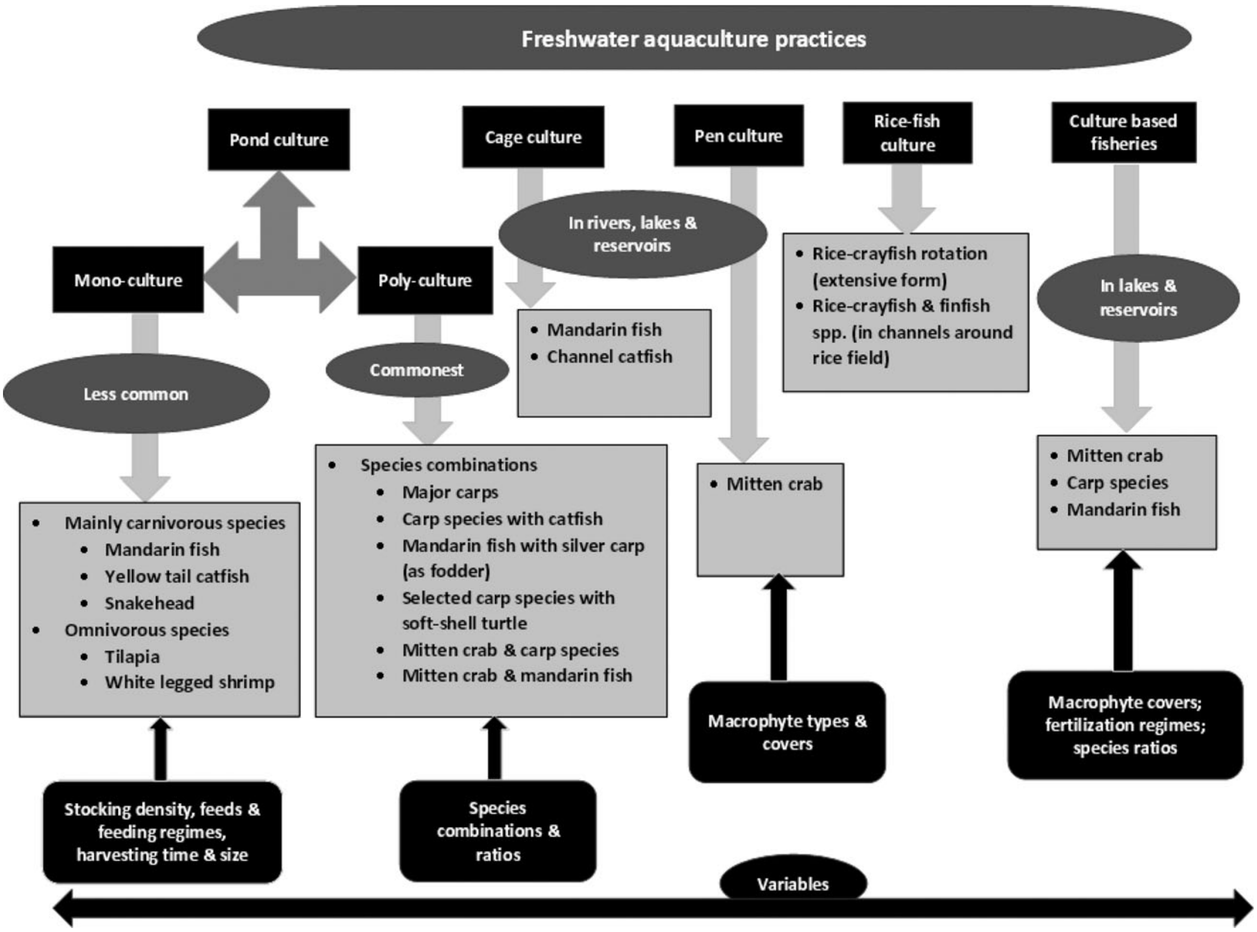

Figure 8 A schematic of the forms of freshwater aquaculture in China. Please note that the species/species groups cited in each instance are, i.e., only and does not cover the whole range(s) cultured.

new in China and so is the wide-scale culture of the yellow catfish as well as that of soft-shelled turtle in polyculture systems. To make complete use of food resources and space available, Chinese farming communities embarked on polyculture with valuable species based on the principle that each species stocked has its own feeding niche that does not completely overlap with those of other species. As the case in most of mitten crab farming area in the Yangtze River basin, it is very common to stock mandarin fish in mitten crab culture ponds where the former is expected to forage on naturally recruited wild fish. In a typical polyculture pond, 750–900 individuals ha^{-1} of average weight of 1.2–1.5 g of mandarin fish are stocked and 150 kg ha^{-1} (60 RMB kg^{-1}) could be harvested at the end of each culture cycle. This is a profitable practice as no extra cost is incurred for feed. As for soft-shelled turtle farming, to reduce the increasing risk associated with large price fluctuations, most of turtle farming stakeholders adopt to coculture yellow catfish in polyculture systems.

Cage culture

In terms of history of freshwater aquaculture in China, cage culture can be considered as a relatively recent development. Perhaps one aspect that may have triggered this development is the very extensive dam building that was initiated with the liberation of the nation in 1949. It is estimated that there are over 85 000 reservoirs in the country, covering approximately 2.32 $\times$ 10^6 ha (Bureau of Statistics 2007) and a total storage capacity of 562 $\times$ 10^9 m^3 (Ministry of Agriculture 2006). Impoundment of reservoirs leads to displacement of rural, agricultural communities, and encouraging such communities to take to cage culture was and still seen as a plausible livelihood alternative and also adopted elsewhere (Abery *et al.* 2005).

Presently, a number of species are cultured in net cages (Table 1), and there are reasons to expect that the species range will continue to expand. In general, cage-cultured species tend to be relatively higher value (e.g. mandarin fish

Table 2 Randomly selected examples of overall production of different species/species groups in different culture systems in China

Culture type/species	Production	Province (Source)
Pond: polyculture		
Black carp, crucian carp, bream, yellowtail catfish, channel catfish, mandarin fish, silver carp, big-head carp	12805 kg ha^{-1}	Hubei (Chen 2006)
Grass carp, black carp, crucian carp, common carp, yellowtail catfish, mandarin fish, silver carp, big-head carp	10221 kg ha^{-1}	Hubei (Chen 2006)
Grass carp, black carp, crucian carp, common carp, silver carp, big-head carp	10416 kg ha^{-1}	Hubei (Chen 2006)
Yellow catfish		
Pond culture	5109 kg ha^{-1}	Hubei (He *et al.* 2004)
Mandarin fish		
Pond culture	6000 kg ha^{-1}	Guangdong (Liang 1994)
	6093 kg ha^{-1}	Hubei (Gao *et al.* 2006)
Cage culture	15.4 kg m^{-2}	Hubei (Qi *et al.* 1999)
	31.75 kg m^{-2}	Jiangsu (Zhao 2003)
Culture-based fishery	18.2 kg ha^{-1}	Hubei (Cui & Li 2005)
Nile tilapia		
Cage culture	95.2 kg m^{-2}	Hubei (Wang *et al.* 1990)
Pond culture (semi-closed)	14487 kg ha^{-1}	Hainan (Zhou 2010)
Pond culture (closed)	13444 kg ha^{-1}	
Channel catfish		
Cage culture	148.1 kg m^{-2}	Guangdong (Tang *et al.* 1994)
	89.5 kg m^{-2}	Hubei (He & Pei 2007)
	56.3 kg m^{-2}	Jiangsu (Zhang & Huang 2005)
Mitten crab		
Pond culture	931.6 kg ha^{-1}	Hubei (Zhou 2009)
	751.9 kg ha^{-1}	Jiangsu (Zhou *et al.* 2013)
Pen culture	400.4 kg ha^{-1}	Jiangsu (Cui & Li 2005)
Culture-based fishery	24 kg ha^{-1}	Hubei (Cui & Li 2005)
Crayfish		
Pond culture	5843 kg ha^{-1}	Jiangsu (Yin 2010)
Paddy culture	3518 kg ha^{-1}	Jiangsu (Yin 2010)

and channel catfish) and/or directed towards export (Nile tilapia). The production level from cage culture is species dependent and also varies in a narrow range between provinces (Table 2). It is evident from Table 2 that the production of mandarin fish from cage culture is much less than, for example, Nile tilapia. This difference is a result of the use of significantly lower stocking densities of mandarin fish in cage culture to avoid cannibalism. Of course, the lower production of mandarin fish is easily compensated for by the higher farm gate price it commands. The differences in production in different provinces could result from differences in management, including feed management and water quality.

Multilayered cage farming, for example as done in Indonesia and referred to as 'apis dua' (Abery *et al.* 2005), is gaining popularity in China, with many design variations being adopted. Multilayered cage farming improves feed utilization efficiency and reduces environmental impacts of cage culture, when one or more species are expected to forage on feed waste. As such in cage farming practices in China, it is very common to stock omnivorous fish (e.g. yellow catfish and crucian carp) to use uneaten feed and/or to stock silver carp and big-head carp to maintain water quality. In recent years, two- or three- layered cages are adopted to separate the major cultured species and the co-cultured species into different spaces which facilitate cage farming management (Zhu *et al.* 2011).

As the case in two-layered cage culture, four relatively smaller and shallower inner net cages are installed in a larger and deeper outer net cage and a cross-sidewalk made of steel is installed in the centre of the outer cage. Around the edge of the outer cage, the cement sidewalks are paved on cement floats replacing the traditional floating equipment (e.g. oil drums or floating). The floats are connected using seamless welding steel, and there is a 50-cm gap between adjacent floats to permit water flow. Workshops and feeding platform are also built for cage farming operations. The net cages are made of polyethylene. As for the feeding, only the major cultured species in the inner net cages are fed, while the cocultured species in the outer net cages are not.

Compared with the traditional single-layered cage culture system, the two- or three-layered cage culture systems can enhance resistance to wind and waves, reduce the risk of escape of cultured species, improve the efficiency of feed utilization and reduce the adverse impacts of cage farming associated with uneaten feed and faeces. These systems are significantly longer lasting. All these features could compensate for the initial higher capital investment needed.

Rice-fish culture

Rice-fish culture is one of the oldest forms of aquaculture practices, particularly in rural China (Li 1988, 1992; Miao 2010). Miao (2010) summarized the changes that have taken place in these farming systems, when the trend was to replace the traditional low-valued aquatic species cultured with relatively higher valued species. One transformation that has taken place has coincided with the adoption of the culture of the exotic crayfish (*P. clarkii)* where two basic models are evident. These are as follows:

- The extensive rice-crayfish rotation, and
- Continued, more intensive rice-crayfish culture.

In the former system, once the rice crop is harvested (around September/October), a few centimetres of water is retained and this area is stocked with crayfish, which feed on zooplankton, benthic and epiphytic organisms that grow on the rice stubble (Fig. 9a). As opposed to this system is where the channel around the rice growing area is stocked with crayfish, together with other desirable species such as mandarin fish (Fig. 9b), and the latter continually harvested after about 2 months. Furthermore, in some instances small quantities of artificial/supplementary feed may be provided. Once the rice is cropped and until the next growing season, the whole area is utilized for crayfish and culture of other species. In general, crayfish farming is considered to be relatively lucrative, in view of the high market price and the demand both locally and for export.

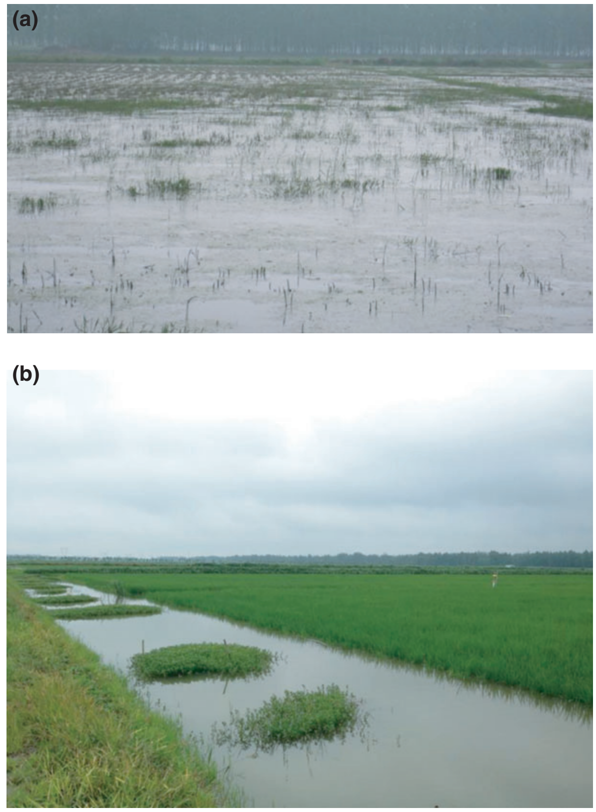

Figure 9 (a) An example of extensive culture of crayfish after the rice harvest; (b) Rice-cum-crayfish culture, stocked in the channel, and after the rice harvest, the area will also be stocked with crayfish.

Pen culture

Pen culture is a common semi-intensive farming system in lakes, rivers and reservoirs. Similar to net cage culture systems, pen culture also experienced a shift from low-valued species cultured (e.g. grass carp and bream) in the 1980s to relatively higher valued species like Chinese mitten crab from the 1990s. There are more than 4000 lakes in the middle and lower reaches of the Yangtze River basin, covering an area of about 20 000 km^2 (Guo & Li 2003). Most of these are shallow macrophytic lakes which were considered suitable for the culture of Chinese mitten crab in pen culture systems in the last decades. But in practice, pen culture of mitten crab achieved a relatively higher production only in the first few years and the production and economic returns declined significantly later. Many reasons have been attributed to this decline, and among which are a reduction in macrophytes and other natural resources, eutrophication, changes in physical and chemical properties of sediment and so on (Cui & Li 2005). Also, the feed conversion rates of mitten crab cultured in pen systems were relatively poorer than when cultured in ponds which could be due to competition for feed with wild fish or other crustaceans. In the recent decade, Chinese government has paid much attention to the protection of lakes and more stringent regulations are gradually being introduced to control pen culture in many lakes.

For example, in 2009, the government of Jiangsu Province released administrative notification to clear all pen culture installations by 2020 in Taihu Lake to reduce nutrient loading associated with pen culture. Now the scale of pen culture in East Taihu Lake has been cut down from 11 267 ha to 3000 ha. In 2012, the government of Hubei Province passed a law on lake protection which clearly pointed out to ban pen culture in lakes and all the net pens will have to be removed in due course.

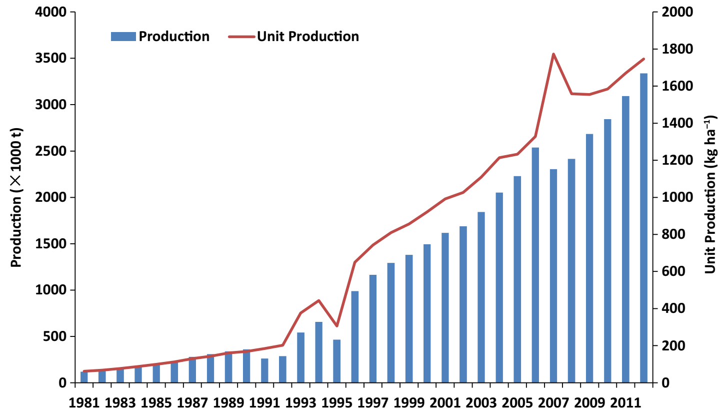

Figure 10 Trends in change in Culture-based fishery (CBF) production and the corresponding production per unit area in reservoirs. (▬) Production, (—) Unit Production.

Culture-based fishery

Culture-based fishery (CBF) is considered as an extensive to semi-intensive aquaculture practice that is capable of contributing significantly to inland fish production in most developing countries (De Silva 2003), with beneficial impacts on rural communities (Nguyen *et al.* 2005; Wijenayake *et al.* 2005; Pushpalatha & Chandrasoma 2010). Aspects of CBF in Chinese lakes and reservoirs have been dealt with previously (Li & Xu 1995; Liu & Huang 1998; Song 1999).

Culture-based fishery (CBF) is practised in most reservoirs and lakes in China, often utilizing the natural productivity and macrophyte presence that favours species such as grass carp, and indirectly through favouring benthos production on cultured species such as mitten crab. Overall, CBF production from reservoirs has shown a regular increase through the years 118 705 t (1981) to 3 337 690 t (2012) corresponding to unit productions of 62 and 1746 kg ha^{-1}, a very significant increase that has been achieved through the years, averaging 53 kg ha^{-1} year^{-1} (Fig. 10). Importantly, the major spike in unit production commenced in 1996 as was in many other forms of aquaculture production in China. In China, unlike in other countries that practice CBF, even high-valued species such as mandarin fish and mitten crab could be stocked, with yields up to 18 kg ha^{-1} and 24 kg ha^{-1} obtained, respectively (Table 2).

Overall, the increase in CBF production over the years has come about as a result of better management of the fishery resources, such as division of the individual water bodies into manageable sections, and the use of improved combinations of stocked species, as well as proper management of the ecosystem(s). However, there are increasing restrictions being imposed by the Government of China on some of the management measures that are in operation in CBF, which will be addressed later.

Marketing

In general, global food fish consumption has been increasing readily (FAO 2011), as a result of increasing population and also in view of the perception that fish consumption offers many health benefits (see for e.g. Conor 2000; Ruston *et al.* 2005). As stated earlier, nearly 50% of the food fish consumed globally originates from aquaculture (Subasinghe *et al.* 2009). China is no exception in this regard, and for example, the freshwater fish consumption increased from 4.40 in 1990 to 13.3 kg capita^{-1} year^{-1} in 2009 (FAO 2011). Although data pertaining to the source of this freshwater fish is not readily available, it is likely that a very high proportion of it is from aquaculture.

In China, there is a considerable extent of movement and marketing of aquaculture produce across provincial borders, often kept alive, and transported by road, as often preferred in Chinese cuisine. Overall, the market price of freshwater aquaculture produce has increased from 8000 RMB t^{-1} in 2003 to 15 000 RMB t^{-1} in 2012, almost doubling in a decade (Fig. 11). This overall increase in commodity price could be at least partially impacted by the gradual increase in the proportionate contribution of high-valued commodities such as mandarin fish, crayfish, mitten crab and the like to freshwater aquaculture production.

It is also important that as much as aquaculture production and consumption of cultured commodities have increased in China over the years, it has also become a major exporter of aquaculture produce in the world. This aspect is best exemplified in respect of the Nile tilapia exports to the USA (Fig. 12a,b). China dominates the aquaculture of exotic tilapia globally and accounts for nearly 70% and 66% of the total exports to the USA in volume and in value, respectively. Also importantly, the export volume and the revenue have been increasing steadily over the years. In a similar vein, the exports of exotics crayfish, white-legged shrimp, channel catfish and indigenous species such as mitten crab and mandarin fish are also

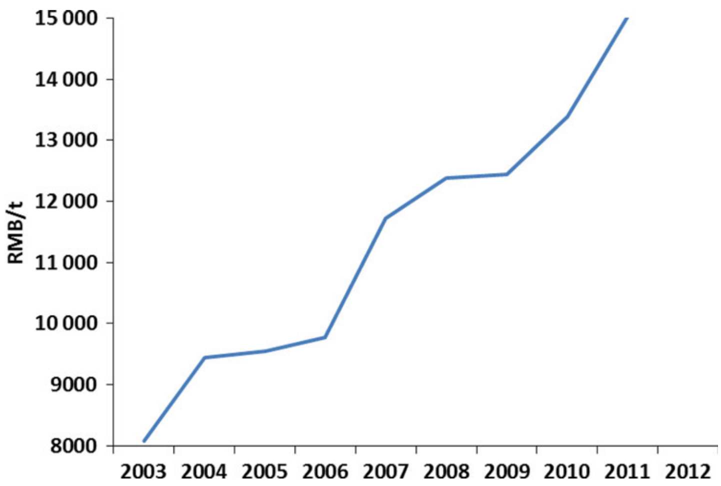

Figure 11 Trends in changes in mean value in RMB per ton of freshwater aquaculture produce 2003–2012 (6.25 RMB = 1 US$).

important and significant commodities that are exported, the former to the west and the latter primarily to countries in Asia with sizeable ethnic Chinese communities.

Emerging species

As pointed out previously, it is estimated that there are 336 species belonging to 115 families cultured globally, and these numbers are increasing significantly over the years (Bartley *et al.* 2009). Comparisons are beginning to be made with other animal protein (meat)-producing sectors in respect of the number of species involved, and questions are being raised with regard to the long-term sustainability of the aquaculture sector if it were to nurture the culture of such a wide range of species (Teletchea & Fontaine 2014). These authors pointed out that only a small number of species used in aquaculture are domesticated and this exacerbates issues associated with sustainability in the long term.

In China, the global leader in freshwater aquaculture production, however, the number of species contributing to it is limited (Table 1), even though many more are cultured on a small scale, often of regional importance only. The most significant upsurge in global as well as Chinese aquaculture occurred in the last two decades (Aquaculture Service 2011; FAO (Food & Agriculture Organization of the United Nations) 2011; Subasinghe *et al.* 2012), and coincidentally, it was in this period when there was a significant increase in the introduction of alien species for aquaculture purposes in China (Lin *et al.* 2013). The consequence of these introductions was the upsurge in the production of some of the alien species, in particular Nile tilapia and channel catfish (Liu & Li 2010; Lin *et al.* 2013). An equally significant development was witnessed in the shift to and the subsequent dominance of white-legged shrimp culture, both in brackish and fresh waters in China, more uniquely the latter.

Some of the other major developments in freshwater aquaculture in China are perhaps also related to the improvements in living standards and the consequent clamour for high-priced cultured commodities. Foremost among such species are the culture of mandarin fish (Fig. 6) and mitten crab (Fig. 7); the farm gate price of a kilogram of both these species are minimally five to six times that of a major carp species. Also note that for both these species production has doubled over the last decade, and the trend indicates that production would continue to increase.

General considerations

Undoubtedly, freshwater aquaculture sector in China has remained a cornerstone of global aquaculture and continues to contribute to food fish availability and food security. Chinese freshwater aquaculture has evolved around millennia of old traditions with gradual injection of scientific and technological advancements pertaining to improving production and long-term sustenance of practices. In this regard, perhaps the development of the polyculture systems incorporating the Chinese major carps and common carps and the gradual improvements brought about in the species combinations and other related aspects is one of the major contributions of Chinese aquaculture to global aquaculture development. These systems triggered off a comparable development using Indian major carps in the Indian subcontinent and elsewhere resulting in a significant boost in global aquaculture. Many other Chinese freshwater aquaculture developments over the years have impacted comparable developments elsewhere, and such impacts and successes not only on Chinese aquaculture but globally, are too exhaustive to be enumerated in this review.

In China, except freshwater eel culture, seed requirements for all cultured species are met with from artificial

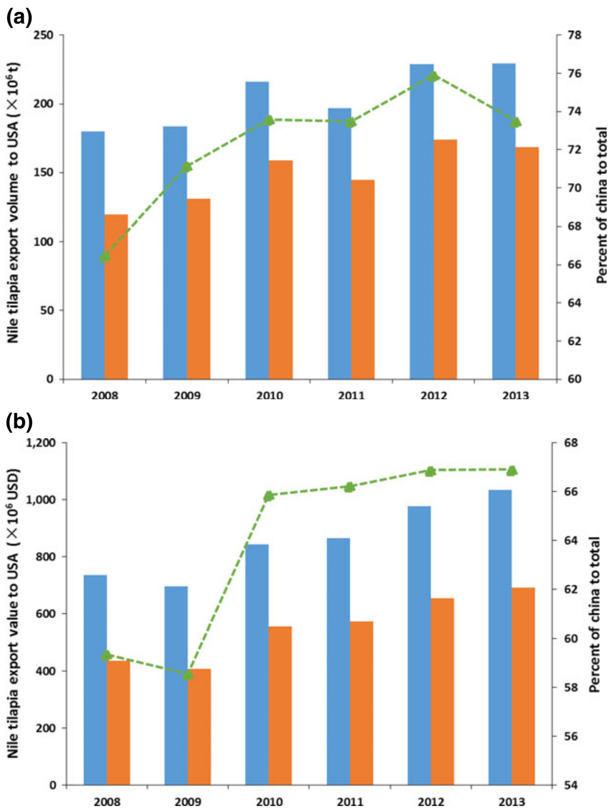

Figure 12 (a) The total volume exports of Nile tilapia to the USA and that from China and the per cent contribution of the latter to the total; (b) The corresponding values in US Dollars (based on data from USDA 2014). (▬) Total, (▬) China, (-▲-) %China;

propagation. The artificial propagation of most of the economically important species is routine and even rural enterprises are well versed with the required techniques and protocols. On the other hand, there had been careful adoption of practices in accordance with the life-cycle traits of particular species. In this regard, the best example is that of the culture of mitten crab; The mitten crab hatcheries are located in coastal provinces and/or in areas where saline ground water is available but almost all grow out operations occur in inland (Table 1).

In general, modern techniques used for inducing ovulation and spawning in fish use a combination in which one of the drugs blocks the inhibiting action of dopamine of the neurohormonal systems and is referred to as the 'Linpe method'. The contributions of Chinese scientists' work in the development of these techniques have been significant (see for e.g. Lin *et al.* 1986; Peter *et al.* 1988; Lin & Peter 1991). The Linpe method, with many variations that are practised commonly, is known to be more effective in many ways; it ensures,

- a high rate of ovulation,
- consistency between broods,
- complete ovulation and
- the time lag between injection and ovulation is short and predictable.

One of the commonly directed criticisms on aquaculture is the use of alien species, which is purported to impact on biodiversity (e.g. Moyle & Leidy 1992; Naylor *et al.* 2001). On the other hand, it has been argued that alien species have played a major role in assuring food security through aquaculture in the developing world (De Silva *et al.* 2006, 2009) and that more often than not explicit evidence of alien species of aquaculture importance impacting on biodiversity is often lacking. Admittedly, a large number of alien species have been a result of aquaculture developments that have taken place deliberately or accidentally over the years (Welcomme 1988; DIAS 2004). It has been recently reported that a total of 179 species, of which 111 and 27 of finfish and molluscs, respectively, were introduced into China for aquaculture-related purposes since the 1920s and mostly in the 1990s (Lin *et al.* 2013). Lin *et al.* (2013) evaluated the status, risks and management solutions associated with introduced species in Chinese aquaculture.

China stands out in regard to the role of alien species in freshwater aquaculture and indeed even in relation to the culture of shrimp in brackish waters (Lin *et al.* 2013). If one were to leave aside white-legged shrimp, which is also cultured very extensively in some Asian countries such as Thailand, Indonesia and Vietnam, it dominates global production of alien species such as crayfish, Nile tilapia and channel catfish (Liu & Li 2010). All these species constitute very significant export commodities. Such a scenario in respect of freshwater aquaculture is not encountered elsewhere. Importantly, there is no explicit evidence that has forth come to this date that any of the above exotic species has impacted adversely on biodiversity.

China is beginning to address issues related to primary production and environmental impacts in a concerted manner. Some of these changes have been triggered off by environmental calamities that were experienced in the recent past that were thought to result from aquaculture and associated primary production systems among others (e.g. Li & Lee 1997; Qin *et al.* 2007; Cai *et al.* 2013; Herbeck *et al.* 2013).

The steps that are being taken, as directed by the government are likely to impact on freshwater aquaculture production, but adoption of these measures will likely to make the practices sustainable in the long term. Among the measures that are being gradually implemented are as follows:

- Strict regulation of the scale of cage culture, pen culture and culture-based fisheries operations in selected lakes, reservoirs and rivers.

- Encourage ecologically favourable aquaculture practices, for example transplanting macrophyte in mitten crab culture systems to maintain water quality.
- Reduce the volumes and frequencies of water exchange.
- Encourage integrated aquaculture and agriculture farming systems which can make comprehensive use of resources and reduce effluent discharge; for example, the lotus-fish (mitten crab or crayfish) farming systems, the other aquatic vegetable-fish (soft-shelled turtle) farming systems and
- Advocate effective treatment of aquafarm effluent and encourage recycling of effluent.
- Improved feeds and feed management that effectively reduces waste output without compromising growth and production.

Conclusions

Over the last four to five decades, major shifts have occurred in the fisheries sector, when the dominance of capture fisheries and overall fish consumption changed from a developed country dominance to a developing country dominance (Delgado *et al.* 2003; De Silva 2012). Modern aquaculture, however, was always dominated by developing countries, and the Asia-Pacific region in particular. These trends have resulted in contributions to the GDP of certain countries from aquaculture exceeding that from capture fisheries, including China (De Silva & Soto 2009). While the Asia-Pacific region produces the great bulk of world's aquatic products, because of its population, it also consumed nearly 70% of the world production in 2007, an increase from 50% in 1980 (Aquaculture Service, Network of Aquaculture Centres in Asia-Pacific 2011). For example, large increases in per caput consumption of food fish was evident in some of the countries in the Asia-Pacific region, such as in China when it increased from 6 to 35 kg from 1980 to 2003 (Aquaculture Service, Network of Aquaculture Centres in Asia-Pacific 2011). The love for fish in Chinese culture and the multitude of variations in the culinary preparation of all types of fish enable a stable market demand to be maintained and perhaps are responsible to a larger extent driving the aquaculture sector in the country.

In the above context, it is likely that China will continue to dominate freshwater aquaculture production well into the future. With increasing living standards and a growing middle class in the developing world and in China (Li 2010) that generally has an appetite for new food varieties, one could expect a change in the species profile of cultured species; perhaps significant increase in carnivorous species, which often are purported to have a better taste and rarities like puffer fish. In spite of such changes, the backbone of Chinese freshwater aquaculture is likely to be the polyculture of carp.

The major changes that are likely to occur in freshwater aquaculture in China in all probability will be associated with minimizing environmental perturbations arising from aquaculture practices. These will necessarily include use of better feeds; feeds that will result in improved utilization efficiencies, result in reduced discharge of nitrogen and phosphorous into the environment, coupled with better feeding management practices such as avoiding over feeding. Freshwater aquaculture in China also utilizes many models incorporating principles of polyculture; not only as a means of increasing productivity but improving the utilization of feed resources, allochthonous and autochthonous, which in turn reduces nutrient content in the effluent. Such practices will tend to increase and be further intensified to maximize returns in volume and in monetary terms.

In regard to the trends of freshwater aquaculture in China, two aspects can be expected. Firstly, it is the stricter use of natural freshwaters including lakes, reservoirs and rivers for aquaculture. As China, overall, is a nation of serious water shortage, and water pollution is accelerating this situation. Semi-intensive and intensive aquaculture like cage culture and pen culture especially with use of feed or fertilizers will be curtailed in the near future. In fact, two largest reservoirs in China, the Three Gorges Reservoir and the Danjiangkou Reservoir, cage culture is being gradually phased out. For natural freshwater bodies, eco-fisheries will be adopted as done in many lakes such as Liangzi Lake and Wuhu Lake, Hubei Province, which is balanced and made efficient through stock enhancement and fisheries management, which encourages the use of natural food resources and also ensures biodiversity protection and ecosystem health. It can be foreseen that aquaculture production from these waters will decrease. However, the product quality will be improved and the monetary gains could be maintained if not higher as the case of Xin'An'Jiang Reservoir (Qiandao Lake) in Zhejiang Province (Shao *et al.* 2005). Secondly, in compensation for aquaculture production losses from natural water bodies, more attention will be paid to controlled water bodies. Advanced techniques will be used for pond aquaculture to increase production with pollution control including efficient feed use, introduction of better aeration machinery, use of genetically improved species and/or strains, deeper ponds etc. High-intensive aquaculture systems may be used like recirculating farming systems in areas of water shortage such as in northern China and industrialized areas like in Shanghai and Beijing. Xie *et al.* (2013) attempted to demonstrate the growing importance of organic aquaculture in China, which has increased 1700% from 2003 to 2012 and suggested that the increasing environmental concerns and food safety issues will further strengthen this sector well into the foreseeable future.

Future developments, in particular intensification and shift to carnivorous species are likely to be constrained by resource limitations and corresponding price increases, such as fish meal and fish oil for feed manufacture. Use of fish meal and fish oil in aquaculture has been a 'bone of contention' over the last two decades, and no attempt is made in this review to dwell into this controversial issue, except to state that the aquaculture sector is the major user of fish meal and fish oil (see for e.g. Tacon & Metian 2008; Tacon *et al.* 2009; Rana *et al.* 2009; Tacon *et al.* 2011). Tacon *et al.* (2011) observed that more than 46% of global aquaculture production in 2008 was dependent upon the supply of external feed input. These authors suggested that if the sector was to maintain its current average growth rate of 8–10% per year to 2025, the supply of nutrients and feed inputs will have to grow at a similar rate; challenge the sector will face in the ensuing years is that it becomes an increasing competitor for feed resources. The above observations are very relevant to Chinese aquaculture, including freshwater aquaculture as demonstrated by the analysis of carp and Nile tilapia production in China (Chiu *et al.* 2013). As such future developments in freshwater aquaculture in China, as elsewhere, will have to make concerted attempts to adopt effective feed management practices as well as be innovative in the use of nutrient resources (potential feed ingredients) in feed manufacture.

All strategies that will come into being in respect of freshwater aquaculture development in the foreseeable future in China, will have to take into account climatic changes and impacts thereof on aquaculture. Climate-change impacts on fisheries and aquaculture in general and specifically on aquaculture were dealt with by Cochrane *et al.* (2009) and De Silva *et al.* (2009), respectively. There is a paucity of studies on climate-change impacts on freshwater aquaculture *per se* in China. Piao *et al.* (2010) alerted the negative impacts of climate change on water resources and agriculture production, indicating that major centres of production – the river deltas – which are also the main centres of aquaculture production – are likely to be effected. These authors raised the question that whether the country will be able to continue to feed the large population in the wake of major climatic change impacts. It was suggested that the climatic change impacts or increased temperature (=global warming) would be likely to have minimal impacts on aquaculture (De Silva *et al.* 2009). On the other hand, freshwater farming systems near to the coasts are likely to be impacted by sea level rise and concurrent seawater intrusion coupled with water scarcity, such as the pangasius (*Pangasianodon hypophtalmus*) farming systems in the Mekong Delta, Vietnam (Nguyen *et al.* 2014). As such there is a need to encourage work on climate-change impacts on freshwater farming systems in China, and consequently to develop mitigating and adaptive strategies.

Finally, it is difficult to assess and/or to predict the path that freshwater aquaculture would take in the ensuing decades. The policy changes that are gradually being introduced, mostly revolving around environmental issues, as discussed before together with possible resource limitations, particularly related to feed ingredient availability and price are likely to have an impact on aquaculture developments in China; these are issues that are not exclusive to Chinese aquaculture development either. In spite of the above, it will be very difficult to perceive a decline in relation to its global dominance in freshwater aquaculture in China.

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