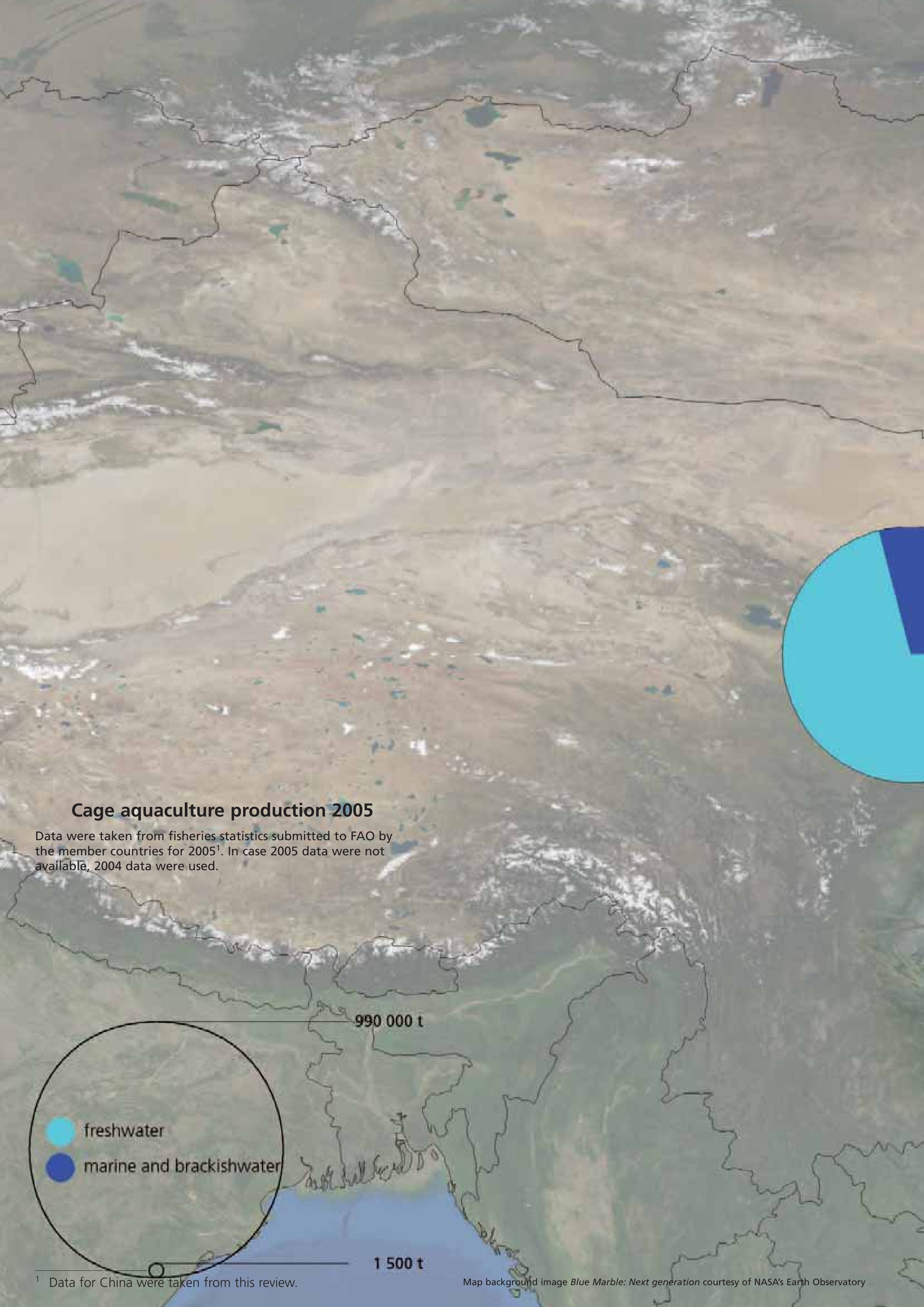
Cage aquaculture production 2005

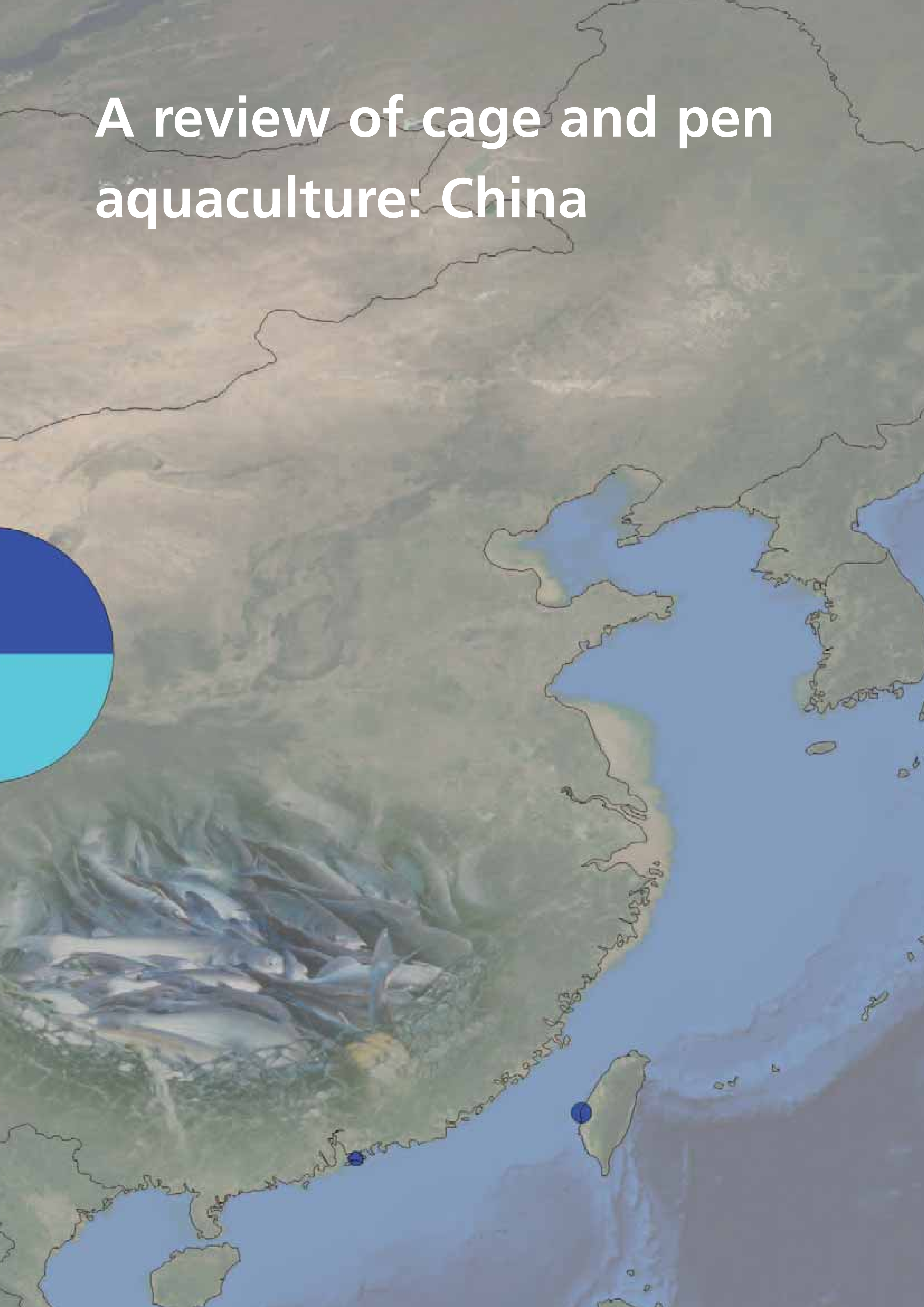
Data were taken from fisheries statistics submitted to FAO by the member countries for 2005[1]. In case 2005 data were not available, 2004 data were used.



[1] Data for China were taken from this review.

Map background image *Blue Marble: Next generation* courtesy of NASA's Earth Observatory

A review of cage and pen aquaculture: China



A review of cage and pen aquaculture: China

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ABSTRACT

Cage and pen[6] culture has a long history in China, but the development of modern intensive cage culture for food production and ornamental purposes dates from the 1970s. Cage/pen culture was first adopted in freshwater environments and more recently, in brackish and marine systems. Due to advantages like land and energy savings, high yields, etc., cage/pen culture has quickly expanded countrywide since the 1970s. In 2005, inland cages and pens occupied areas of 7 805 and 287 735 ha, respectively. The number of freshwater species cultured now exceeds 30 and includes fish such as carps, tilapias, breams, catfishes, trout, bass and perch, as well as crustaceans, turtles and frogs. Cages and pens in freshwater lakes and rivers yielded 704 254 tonnes and 473 138 tonnes of fish and other aquatic animals, respectively, in 2005.

The number of traditional marine fish cages distributed in coastal provinces, cities and zones is estimated at one million units. Since the 1990s, offshore cage culture has been considered a priority as a means to culture suitable marine fish in the twenty-first century. At present more than 40 marine fish species are being farmed, of which 27 species are reared in hatcheries. Six models of offshore cages have been developed, and around 3 000 units are currently under production. The volume of traditional cages and offshore cages reached 17 million and 5.1 million cubic metres, respectively, in 2005; and the yield harvested from all coastal cages was 287 301 tonnes in the same year.

In some aquaculture sites, especially those in lakes, reservoirs and inner bays, the ecological balance has been affected due to an overload of cages or pens, with consequent disease problems. Direct losses caused by disease amount to US$10 million or more annually, accounting for about one percent of the total losses in aquaculture.

The fishery policies of the Chinese Government require local authorities to limit the number of cage and pen culture operations to a reasonable level in order to maintain an ecological balance and a harmonious environment.

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[6] **Pen**: Fenced, netted structure fixed to the bottom substrate and allowing free water exchange; the bottom of the structure, however, is always formed by the natural bottom of the waterbody where it is built. A pen generally encloses a relatively large volume of water. **Cage**: Floating rearing facility enclosed on the bottom as well as on the sides by wooden, mesh or net screens. It allows natural water exchange through the lateral sides and in most cases below the cage.

BACKGROUND

This study was commissioned by the Food and Agriculture Organization of the United Nations (FAO) as one of a series of reports on the global status of cage aquaculture and was presented at the Second International Symposium on Cage Aquaculture in Asia, held in Hangzhou, China, 3–8 July 2006.

This paper reviews the history and status of cage and pen aquaculture in China, discusses the issues affecting their development and proposes a way forward for their sustainable development within the Chinese context. Data on cage and pen culture in China are rarely disaggregated and hence, are also reported in aggregated form here. However, to the extent possible, the paper attempts to differentiate between the two production systems.

HISTORY AND ORIGIN OF CAGE AND PEN CULTURE IN CHINA

Modern cage and pen culture in China has a history of over 30 years, dating from the early 1970s (Hu, 1991; Wang, 1991). During this period, cage culture became an indispensable part of Chinese fisheries. In 2005, the production from cage/pen culture attained 1.46 million tonnes, accounting for 4.4 percent of the total aquaculture production by value and 2.9 percent of the total by volume in that year (Fisheries Bureau, 2005). Although these percentages represent only a small fraction of the country's total aquaculture output, the advantages of these production methods have been recognized as important factors stimulating the growth of fish culture. As a result of the experience gained from cage and pen culture, Chinese farmers have made significant advances in cage and pen design and in management methods. At the same time, cage/pen culture has promoted the development of secondary industries such as net production and has created new employment opportunities for rural labourers. However, farmers have also faced many constraints, including: (i) environmental problems caused by overloading of aquaculture sites with cages and pens; (ii) financial problems for small-scale farmers and investors due to excessive investment in offshore cages; and (iii) a shortage of operational techniques for offshore cages and associated facilities. Cage farmers, policy-makers and investors have thus had to face the problem of how to deal with these constraints in order to achieve the sustainable development of cage and pen culture.

Inland fish cage culture

China has a long history of inland cage culture of freshwater fishes. Some 800 years ago, Chinese fish farmers began using densely meshed cages to culture fry collected from rivers, holding them temporarily in the cages for 15 to 30 days before their sale (Zhou, 1243).

These methods of natural fry collection and small-scale pond fish culture are still practised today (modern large-scale cage culture started only in 1973) (Hu, 1991; Xu and Yan, 2006). Cages were established to culture fingerlings of silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) using primary production (phytoplankton) from a reservoir. The use of large-size fingerlings (>13 cm) improved survival rates when they were stocked back into the reservoir. This method is still being used today. Later, the method was further developed to culture two-year-old silver and bighead carp fingerlings in cages. Since 1977, techniques have been developed for the cage culture of table-sized silver and bighead carps without the application of supplementary feeds. At the same time, the cage culture of grass carp (*Ctenopharyngodon idella*), Wuchang bream (*Megalobrama amblycephala*) and common carp (*Cyprinus carpio carpio*) with the application of feeds was also launched.

Aiming to find more efficient ways to utilize China's water resources, cage culture entered a period of great expansion in the 1980s. During this period, the main characteristics of Chinese cage culture were: (i) the culture of silver and bighead carp fingerlings for stocking into reservoirs using natural plankton productivity; (ii) the culture of silver and bighead carps from fingerlings to grow-out without applying feeds; and (iii) the cage polyculture of two or more species of fish. At this stage cage culture yielded some production, but the per-unit-area output and economic returns were not considered satisfactory. Since the late 1980s, experiments on various kinds of cage-culture techniques have all aimed at increasing fish yields or economic returns. During this period the technological basis for models for (i) the cage monoculture of common carp at high stocking density with complete culture from fingerling to grow-out using an all-nutrient feed application and (ii) the cage culture of grass carp with the application of aquatic plants were fully developed and extended rapidly.

In the 1990s, China experienced some great breakthroughs in the development of cage-culture techniques. Many new species were cultured, and the use of formulated feeds was applied. The species farmed in cages expanded to include Crucian carp (*Carassius carassius*) and Wuchang bream, which are normally cultured in ponds, as well as rainbow trout (*Oncorhynchus mykiss*), tilapias (*Oreochromis* spp.) and channel catfish (*Ictalurus nebulosus*), exotic species introduced from other countries, as well as carnivorous fishes like bracoo grunter (*Scortum barcoo*), Chinese perch (*Siniperca chuatsi*) and white Amur bream (*Parabramis pekinensis*).

With the extension of small-scale cage culture and the increase in the number of species cultured, individual fish farmers with little capital have increasingly taken up cage culture. The integration of the excellent environmental conditions associated with open waters with high-yielding cage-culture techniques has lead to the production of high-quality aquaculture products, higher production efficiency, and excellent market competitiveness, which has enabled China's cage culture sector to continue to develop.

History of pen culture

For more than 50 years, Chinese fish farmers have practised aquaculture by enclosing large areas in lakes and rivers with dykes on two or three sides. However, this method, which results in limited water exchange, and the extensive culture methods used, resulted in low yields and economic returns. In the 1970s, the overstocking of grass carp in "aquatic plant-type" lakes (i.e. lakes whose aquatic flora is characterized by aquatic plants such as *Chara*, *Isoetes*, *Ceratopteris*, *Alternanthera*, etc. that can be used as feed by herbivorous fishes and crabs) turned these lakes into "aquatic algae-type" lakes. In order to utilize the aquatic plant resources in a sustainable way, pen culture experiments were carried out in the main areas of the aquatic weed-type lakes. In the late 1980s, pen culture expanded rapidly and became widely applied for aquaculture production. China's pen culture is based mainly on the principle of culturing herbivorous fishes that feed primarily on submerged plants. Research and monitoring studies indicated that: (i) the submerged plants had high biological productivity; (ii) adoption of techniques to increase aquatic plant production would not only lead to quite high fish yields and economic returns from pen culture, but would also delay lake eutrophication (i.e. the deterioration of lakes into marshes); and (iii) pen culture can be an ecologically sound method of fish farming that is suitable for sustainable development. Since the 1990s, pen culture has become a preferred culture method, mainly for culturing Chinese mitten crab (*Eriocheir sinensis*).

History of marine cage culture

In the late 1970s, Huiyang County and Zhuhai City, Guangdong Province tried to farm marine fishes, including groupers and seabream, in cages. These successful experiments were the first trials of marine cage farming in China (Chen and Xu, 2006; Xu and Yan, 2006). By 1981 experimental marine cage farming had been expanded to a commercial scale. Almost all marine cage production was exported to markets in Hong Kong Special Administrative Region (SAR) and Macao Special Administrative Region, providing significant economic benefits. Beginning in 1984 other counties and provinces (e.g. Fujian and Zhejiang provinces) also began to farm marine fish in cages. According to survey data, the number of marine fish cages in the three provinces of Guangdong, Fujian and Zhejiang had exceeded 57 000, and more than 40 species of marine fish were farmed. In its early stages of development, cage farming was conducted at an artisanal level. Research leading to the development of modern cage systems has only taken place since the 1990s, primarily in line with the development of techniques for the culture of such marine fishes as red seabream (*Pagus major*), Japanese seaperch (*Lateolabrax japonicus*), cobia (*Rachycentron canadum*) and croceine croaker (*Larimichthys crocea*). The rapid development of marine cage culture in China has continued since the beginning of the twenty-first century. Currently the total number of marine cages has reached an estimated one million units, which are distributed in China's coastal provinces and zones: Liaoning, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan provinces and Guangxi Zhuangzu Autonomous Region. Among them, some 3 000 offshore cages have been installed.

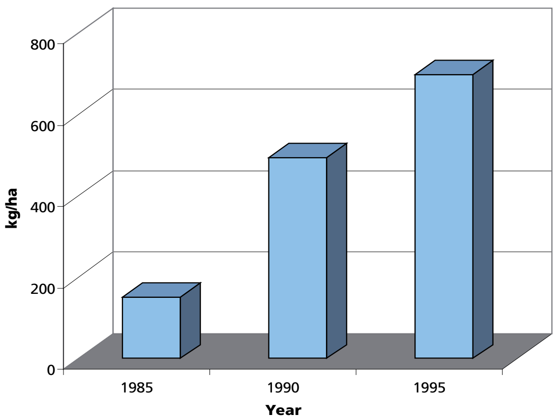
THE CURRENT SITUATION

Advantages of cage and pen culture

In China, great importance is attached to the development of cage and pen culture because these aquaculture farming systems:

- directly and efficiently utilize natural water resources;
- save national land resources because there is no need to dig ponds; (For example, cage/pen culture yielded a production of 69 111 tonnes in Jiangsu Province in 1995, equal to the yield

FIGURE 1
Increase in fish yield in Gehu Lake resulting from the introduction of pen-culture technology



obtained from 9 213 ha of ponds with an average output of 7 500 kg/ha.)
- provide energy savings, as there is no need for facilities for irrigation or aeration;
- are high-yielding intensive culture methods; (Compared with artificial leasing, they are strongly controllable with regard to both inputs and outputs. Moreover, they can fully utilize the advantages of open waterbodies, which include good water quality, efficient water exchange, the presence of relatively few diseases and the ability to produce high yields.)
- create employment opportunities for rural labourers and contribute to poverty alleviation in some inland areas;
- conserve natural fish resources and increase the total fishery output of a given lake area. (For example, in 1985 fish production in Gehu Lake, which mainly resulted from a capture fishery, was 150 kg/ha. In 1990 when pen culture was initiated, the production rose to 495 kg/ha, an increase of 3.3 times and by 1994 it reached 698.52 kg/ha or a total increase of 460 percent in ten years [Figure 1].)

TABLE 1
Fish yields from natural waterbodies in China

System	Acreage (A) (ha)	Yield (Y) (tonnes)
Open waters		
Lakes	939 700	1 147 000
Reservoirs	1 689 600	2 051 000
Rivers	377 400	773 000
Subtotal	3 006 700	3 971 000
Open water production (Y/A)	1.32 tonnes/ha	
Cages	5 310	592 300
Cage production (Y/A)	111.54 tonnes/ha	
Pens	301 900	487 700
Pen production (Y/A)	1.61 tonnes/ha	

Source: Fisheries Bureau, 2004; Xu and Yan, 2006

Present status of inland cage and pen culture

Prior to initiating cage or pen culture in the lakes, reservoirs or rivers of China, the waterbody must first be checked to assure that its conditions are suitable. Cage culture is suitable for the monoculture of fish at high stocking density, mainly with the application of feeds. Oligotrophic waterbodies with quite deep water or showing a wide fluctuation of water levels are suitable. Pen culture is suitable for multispecies, high-density polyculture, either with the use of natural feeds or the supplementary application of commercial feeds. Waterbodies having water level fluctuations of less than 1 m, a water depth less than 3 m and an abundant supply of aquatic plants are suitable. They are also suitable for the application of the high-yielding techniques used in China's pond integrated fish farming as applied to open waters.

In 2004, China's inland natural waterbodies comprised 939 700 ha of lakes, 1 689 600 ha of reservoirs and 377 400 ha of rivers, fisheries-based activities yielding 1 147 000 tonnes, 2 051 000 tonnes and 773 000 tonnes of production, respectively (Table 1). Within these waterbodies 5 310 ha were allocated for cage culture, yielding 592 333 tonnes, and 301 900 ha were allocated for pen culture, yielding 487 751 tonnes. It is noteworthy that the yield per hectare from cage culture is much higher than that from either natural waters or pen culture. Thus, following their initial extension, cage-culture techniques for farming fish in open waters have developed rapidly and maintained a trend of continuous development.

The technology used in the introduction of the two aquaculture methods is briefly summarized below:

Species cultured in freshwater

The principal species cultured in freshwater are given in Annex 1. Feed-fed fishes mainly cultured in cages include common carp, grass carp, Crucian carp, rainbow trout, tilapia, channel catfish, other catfishes, Chinese perch and white Amur bream. Nonfeed-fed fishes cultured in cages include silver and bighead carps, both adults and fingerlings.

Herbivorous fishes are mainly cultured in pens. About 85–90 percent of the fishes raised are grass carp and Wuchang bream, the rest being silver, bighead, common and Crucian carps.

Size and type

The cages used in cage culture are mainly traditional cages measuring 4×4×2.5 m or 5×5×2.5 m and small-sized cages measuring 2×2×1.5 m or 3×3×1.5 m. All cages used in the reservoirs are floating, while in shallow-water lakes, fixed cages are also used. In northern China, some of the lakes and reservoirs may be frozen in winter; hence submersible cages that can be lowered to a depth of 2 m below the ice are widely adopted. Boat-shaped cages are available for use in flowing rivers. In flowing irrigation channels small metal cages measuring 2x2x1 m are effective for farming feeding fishes. The mesh size of the nets used in the cages varies with the size of the stocked fish, starting at 1.0 cm mesh for fish averaging 3.9 cm in length and gradually increasing to 3.0 cm mesh for fish averaging 11.6 cm and thus being equal to about 25 percent of the body length.

The pens used to culture freshwater fish are mostly of about 0.6–1 ha in area and are fixed in shallow lakes having little fluctuation of water level. Pens for farming crabs are also mostly fixed and of about 2–4 ha in area. High-dike, low-barrage pens are also designed according to local conditions, taking into account the annual changes in water levels.

Stocking densities

The stocking density varies with the type of cage, the species farmed and the local conditions. Four examples are given below:

1) **Filter-feeding fish:** Silver carp and bighead carp for nursing from fry to large juveniles.
   The small juveniles should be farmed in eutrophic water (the biomass of phytoplankton should be > 2 million cells/litre; zooplankton biomass > 2 000/litre). The cage stocking densities are 200–300 summer fry of bighead carp with 20–30 percent of silver carp (stocking ratio of 9:1), or vice versa. Additionally, 20–30 common carp or tilapia are stocked in each cage to control fouling weeds that attach to the nets.
2) **Carnivorous fish:** Chinese perch or mandarin fish (*Siniperca* spp.).
   Chinese perch is a typical carnivorous fish farmed in China. Normally fry and juveniles of silver carp, bighead carp and mud carp (*Cirrhinus molitorella*) are used as feed fish. The size of the feed fish is correlated with the mouth gape of the Chinese perch, ranging from 1.5–4.0 cm in length for feeding perch of 3–7 cm body length to 10–18 cm in length for perch 21–26 cm in length. The stocking density in the cage is about 10–15 individuals per square metre; the size of the juveniles used for stocking is about 50–100 g.
3) **Fish fed pellet diet:** largemouth bass (*Micropterus salmoides*).
   The largemouth bass is an exotic fish introduced from the United States. The stocking density in the cages depends on their size, being 500, 300, 200–250 and 120 fish/m^2 for bass of 5–6, 50, 50–150 and 150 g, respectively.
4) **Omnivorous fish:** common carp.
   The stocking density of common carp farmed in cages is similar to that for largemouth bass being fed formulated pellets. As the size of juveniles is 50–150 g per fish, the stocking density is about 100 fish per square metre. When ambient conditions are quite suitable, the density can be increased to 200 fish or more.

Pen culture is based on the polyculture of multiple species, and the stocking densities are closely related to the size of the main cultured fishes stocked, their individual growth rates and the expected recapture rate. When pens are used for the farming of mitten crab, the stocking density of young crabs (about 10 g each) is around 15 000 individuals per ha.

Culture period and yield per unit area of waterbody

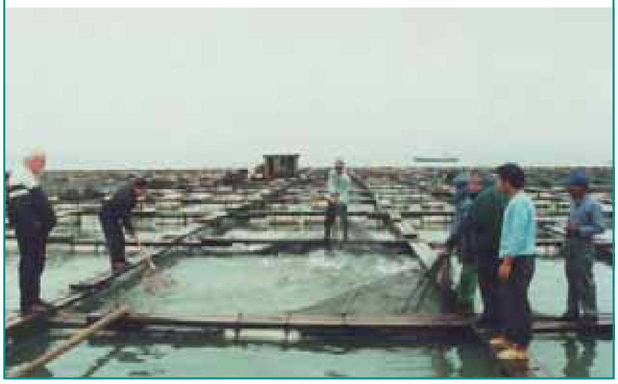
Normally the culture period is between 240 and 270 days. The yield per unit area of waterbody is determined by the size of the cage or pen, the type of culture technique applied and the objectives of the culture operation, and thus there can be wide variation: yields can be as high as 200 kg/m^3 (with feed application) and as low as 2–3 kg/m^3 (without feed application). Based on 2004 national data, the production from cage monoculture averaged 11.15 kg/m^2, while that from pen monoculture averaged 0.16 kg/m^2. This indicates that the total level of production is very low (Xu and Yan 2006).

Marketable size and price

China has a very large domestic market for aquatic products. Local market demand is related to local customs. In general, Chinese prefer to cook round fish, not fillets or other processed fish products.

FIGURE 2
Traditional cages, simple and rough

FIGURE 3
Inshore cages crowded into inshore waters



Thus, a fish weighing 500–600 g can be marketable. The marketable size of grass carp and black carp (*Mylopharyngodon piceus*) is above 3 000 g in the region of the low reaches of the Changjiang River.

The market price varies depending on the fish species. Normally the price of fish originating from traditional aquaculture is 6–30 Yuan/kg. Some famous rare fishes may be priced at 50–100 Yuan/kg or more. A characteristic of pricing is that wild fishes are typically higher priced than aquacultured fishes, fish cultured in cages are higher priced than those from pond culture, and rare species are higher priced than traditional fish species.

Among freshwater fishery products, the prices of oriental river prawn (*Macrobrachium nipponense*), Chinese white prawn (*Exopalaemon modestus*) and Chinese mitten crab are generally higher than that of fish.

TABLE 2
Numbers and distribution of traditional marine fish cages in China

Year	Location	Number of cages
1993	Guangdong, Fujian, Zhejiang provinces	57 000
1998	All coastal provinces	200 000
2000	All coastal provinces	> 700 000 (450 000 in Fujian Province)
2004	All Provinces and Zones	1 million
Specifically:	Fujian	540 000
	Guangdong	150 000
	Zhejiang	100 000
	Shandong	70 000
	Hainan	50 000
	Other provinces & zones	100 000

Source: Guan and Wang (2005); Chen and Xu (2006)

Present status of marine cage-fish culture

Traditional cages still account for the majority of marine cages in use today. The total number of cages that are distributed in China's coastal provinces and zones is about one million. These

TABLE 3
Numbers and distribution of offshore cages in China

Model	Zhejiang[c]	Shandong	Fujian	Guangdong	Other Provinces	Total
HDPE circle	640	495	488	60	100	1 800
Floating rope	1 083	–	–	150	–	1 300
Dish-formed submersible	13	–	–	–	–	13
Other	51	110	–	–	100	180
Total	1 787	605	488	210	200	3 293

Source: Guan and Wang (2005) and Chen and Xu (2006)[a,b]
[a]Cage volume: >500 m^3.
[b]Offshore cages are cages located in sites distant from the coastal line, where swift currents and high waves are normally encountered.
[c]Data for Zhejiang Province were collected in the first half of 2004; other data were collected in 2005.

cages are operated at an artisanal level; they are small (normally 3 x 3 m to 5 x 5 m in size, with nets of 4–5 m in depth), simple (square in form) and roughly fashioned (Figure 2).

The materials used for these cages are collected from local markets and include bamboo, wooden boards, steel pipes and PVC or nylon nets. The operating principles of their owners are low investment cost and ease of manipulation; thus, most inshore cages are made by the farmers themselves. Due to the fact that these cages cannot withstand the waves generated by typhoons or swift sea-currents, they must be installed in inshore waters and sheltered sites. In some locations, the cages are connected to form a large floating raft that fills small inner bays (Figure 3).

Most of the marine cages (80 percent of the total number in China) are located in Fujian, Guangdong and Zhejiang provinces (Tables 2 and 3). There are more than 40 species of fish farmed in these cages (see Annex 2), almost all of which can be bred in hatcheries, the exception being some rare species.

Size and type of cages used for marine fish culture

Traditional cages used for farming marine fish are simple and small, in general being 5 x 5 x 5 m, and are mostly constructed from wooden boards, bamboo, steel pipe or other local materials.

Traditional cages are usually made by the farmers themselves and therefore, their cost is much lower than that of an offshore cage. According to the results of a survey conducted by the authors, their construction cost is about US$250 per cage (for the size previously mentioned), including nylon nets. The life span of these traditional cages is on the order of 8 to 10 years.

The stocking density used during the grow-out stage is 500–600 fish per cage. Trash fish are typically used for feed, as the farmers believe the cost is lower than that of pelleted feed. The cost of feeding with trash fish is approximately US$1.5 for each kilogram of fish produced. Wholesale (farmgate) prices of farmed fish in Fujian Province in 2005 were US$2.0–2.5/kg for croceine croaker, US$3.0–3.5/kg for red seabream, US$1.6–2.0/kg for red drum (*Sciaenops ocellatus*), US$3.0–4.0/kg for Japanese seaperch and US$30–40/kg for grouper.

Since the 1990s offshore cages have been imported from other countries, including Norway, Japan, the United States and Denmark as part of offshore cage-culture projects that have received priority from local governments and other relevant authorities. At present about six models of offshore cages are manufactured by local companies and research institutes. More than 3 000 sets of offshore cages are installed along the coastal provinces (Table 3). All of these offshore cages have been briefly discussed in the papers of Xu (2004), Guo and Tao (2004), Guan and Wang (2005) and Chen and Xu (2006). Their characteristics are summarized in Table 4.

TABLE 4
Summary of the main characteristics of different types of marine cages used in China

Cage Type1	FRC	HDPE	MFC	DFC	PDW	SLW
Anti-wind (grade)	12	12	12	12	12	12
Anti-wave (m)	7	5	5	7	6	7
Anti-current (m/s)	≤0.5/0.5	≤1/0.5	≤1/0.8	≤1.5/1.7	≤1.0/1.2	≤1.5/1.7
Cubage rate (%)	50	70	70	90	80	90
Frame material2	PPPE	HDPE	steel	steel	steel	steel
Site installed	semi-open	semi-open	inshore	offshore	semi-open	offshore
Installation	easy	easy	easy	laborious	easy	laborious
Maintainence	laborious	easy	easy	laborious	easy	laborious
Harvesting	easy	easy	easy	laborious	easy	laborious
Fishes raised	pelagic	pelagic	pelagic	pelagic	benthic	pelagic
Relative cost	low	medium	medium	high	medium	high

EMERGING ISSUES IN INLAND CAGE AND PEN CULTURE

Technical problems

China has an abundant supply of fish seed for use in cage and pen culture. However, long-distance transportation and vehicle transfer may cause the death or injury of fingerlings or lead to disease. The use of too many species in cage culture might result in inadequate production of special feeds. Lack of immunization, nutritional deficiencies caused by the random use of feed, and other causes may lead to disease occurrences.

Socio-economic problems

In order to develop production, enterprises engaged in cage and pen culture should always first consider the potential market likely to be encountered, and then consider the possible production problems. However, individual fishermen often consider production costs first. They may lack adequate knowledge and capability for marketing and thus have to depend on middlemen or brokerage institutions and individuals. The separation of production from marketing activities is likely to lead to over-production.

Environmental problems

Catastrophic pollution of waterbodies is the most severe disaster affecting the fish-farming industry. While cages can be moved, pens cannot and will thus suffer destruction.

Other catastrophes that can affect cage and pen culture operations include unpredictable gales and floods, which can completely destroy fish farms. In some waterbodies, wild terrestrial or aquatic animals may also cause problems to cage and pen culture. For instance, turtles and water rats can bite through the nets to eat dead fish, and in doing so, release the cultured stock, causing aquaculture losses.

Legal constraints

In China different levels of government have adopted various policies to encourage fish farming, including waiving of rents for the use of open waters, providing interest-free or low-interest loans and dispatching experts to extend aquaculture techniques and experimental demonstration.

When the techniques of cage and pen culture are extended and become popular, phenomena such as the unplanned distribution of cages and pens in open waters, the use of inappropriate feeds and inconsistent feed application may occur.

These problems are difficult to prevent due to the faultiness of the legal system. In recent years culture certificates have been issued to control aquaculture development, but China still lacks appropriate legal mechanisms and the legal basis needed to support sustainable aquaculture development.

Other problems

Various stakeholders attach great importance to cage and pen culture because of the impacts they may have on open waterbodies.

When culture techniques are comparatively mature, a considerable amount of scientific data is required in order to manage cage and pen culture under the conditions of aquatic conservation, i.e. so that aquaculture is developed within the ability of each open waterbody to sustain it. This is difficult multidisciplinary work that requires significant capital input.

CONSTRAINTS TO MARINE CAGE CULTURE

Due to the fact that traditional cages cannot withstand the waves caused by typhoons or swiftly flowing currents, they have to be installed in inshore waters or in sheltered sites.

The clustering of too many cages in inshore waters may cause a series of problems (FAO, 2001, 2003; Qian and Xu, 2003; Huang, Guan and Lin, 2004). These include:

- Water pollution caused by cage culture;
  The primary problem is pollution caused by the metabolites excreted by fishes and by unconsumed feeds. Cages linked in series may block inner bays during periods of low current and water exchange, such that metabolites and residual feed may start to accumulate on the sea bed. According to Xu (2004), the accumulated waste in some severely affected locations is as high as one metre or more in depth. In such situations the ability of the local aquatic environment for self-depuration may be exceeded.
- Diseases caused by polluted seawater;
  Eutrophication, epidemic disease outbreaks and lowered quality of farmed fish may occur when poor seawater quality occurs due to pollution that causes red tides or otherwise negatively influences the aquatic ecology. This may jeopardize other farmed animals such as oysters and scallops; the loss to aquaculture caused by diseases and red tide is estimated to be as high as US$one billion annually (Yang, 2000; FAO, 2001, 2003), of which about 1 percent is in cage culture.

- Natural disasters;
  The inability to protect cage and pen culture operations against the devastating impacts of typhoons causes severe economic losses. For example, in 2001 the direct financial losses caused by typhoon "Chebi" attacking Fujian Province reached US$150 million.

THE WAY FORWARD

In order to meet market demands and improve people's health, increase the income and well-being of farmers and protect aquatic environments, China needs the sustainable development of cage and pen culture. This section briefly outlines the directions that should be taken and the objectives that need to be obtained.

Sustainable development of cage and pen culture

At an early stage, farmers and policy-makers saw the advantages of cage and pen culture, but they neglected the potential issues that might arise during the sector's development. Thus there was neither planning of areas to be used for cage or pen culture nor estimates of the potential yields that could be derived. All the provinces and metropolises need to work out individual plans and objectives for cage and pen culture development to their local conditions. In order to protect and improve China's freshwater environments, a decision on whether to permit or prohibit cage culture or pen culture in a specific waterbody is made based on the state-issued standards for lake and reservoir water quality (the Surface Water Environment Quality Standard) and on the primary function of the waterbody (e.g. drinking water, irrigation or floodwater storage). If permitted, cage culture will be monitored all year round; if the water quality of lakes and reservoirs used for cage or pen culture does not meet the minimum standards, it must be terminated or reduced. For example, cage culture is prohibited in Yuqiao Reservoir of Tianjin Metropolis. In 2004 all cage and pen culture facilities were removed from Changshou Lake of Chongqing Metropolis. In Taihu Lake, Jiangsu Province, the area of the lake that can be used for cage and pen culture is limited to the eastern aquatic-weed type part of the lake. In Qiandao Lake, Zhejiang Province (area of 573 ha), 73 ha of non-feed-applying cages and 33 ha of feed-applying cages are certified for cage culture in order to protect water quality (Xu and Yan, 2006). This indicates the care that China is taking in the development of cage and pen culture.

Establishing production chains for cage and pen culture

In China, most cage and pen culture models employ a family-operated system. Even when the model is of the enterprise-type, most of the employees are still members of the same family. In recent years many fish-farming households have started to organize various types of "fish-culture associations" and to establish production chains that involve seed culture, feed supply, fish culture, marketing and processing. Obviously this newer model of association benefits Chinese aquaculture by decreasing the level of risk faced by the family-operated farms.

The relationship between the environment, aquaculture and formulating regulations and standards for cage/pen culture

The present situation in China is one of too large a population and too little land. This has led to great importance being attached to the production of grain and livestock, and also to aquaculture, and involves the rational utilization of water resources such as lakes, reservoirs and the seas. This policy will promote national food security and heighten the capability of China's regions to supply their own needs. In order to guarantee the sustainable development of fishery production, it is necessary to regulate the acreage under culture, the use of chemicals and choice of species.

Protecting aquatic plants is a priority for pen culture

Successful pen culture depends on an abundant supply of aquatic plants. Therefore, the conservation of aquatic plants is of primary importance. China's experience with pen culture during the past 20 years indicates the aquatic plants within a pen culture area will be consumed after one month of fish farming. However, if the pen culture facilities are removed, the aquatic plants will resume growth in the second year. Therefore China has implemented the policy, "Pen Culture of Fishes in Moveable Underwater Meadow", which is detailed as follows:

- Administration of control and monitoring;
  There are fishery administration institutions for each open-water region, and all of them work out fishery administration regulations. Through the issuance of culture certificates, the area under culture is controlled and reasonably organized, so that deterioration of water quality due to overly high density of cages is prevented. The facilities to monitor the water quality are

also used to monitor changes in species and the amount of aquatic plants, in order to provide a basis for the layout of pens.

- Regulation of techniques;
  The Fisheries Bureau has recently drafted the Technical Regulation of Cage and Pen Culture in Aquatic Weed Type Lake (under examination and verification). The Regulation includes standardized cage and pen culture techniques with estimates of fish yield and is designed to protect aquatic plant resources which, in turn, leads to protection of water quality. This serves not only aquaculture development but also other fishery interests. Thus, the abundant aquatic plant resources that occur in aquatic-weed-type lakes are rationally used to provide fishes with a large amount of inexpensive feed. The Regulation includes basic operating procedures for maintaining the environmental conditions of waterbodies, the design and construction of cages and pens, the stocking densities for fish fingerlings and crab seed, feed quality and application techniques, the requirement for feed application management and techniques for harvesting and temporary culture.

Cage culture management

Technical regulations for the cage culture of certain species have been formulated since the end of the last century, but they are focussed purely on culture techniques, with no consideration of the negative effects that cage culture may have on waterbodies. In the new century, China will continue to implement these technical regulations for aquaculture; however, waterbody administrations need to supervise cage layouts and control the production and release of wastes based on scientific planning and the issuance of culture certificates. Fish farmers will decide on the species of fish to be cultured and the type of feed and will manage both the feeding regimes and health of their stocks. However, the quality and safety of feed and the use of fish medicines and chemicals must be supervised by fishery supervision stations that will integrate aquatic product security examination, environmental monitoring and fish disease prophylactic systems at different levels.

Technical measures to prevent pollution

Unscientific cage culture can have negative impacts on waterbodies due to feed residues caused by the over application of feeds, wastes excreted by the fish being cultured and the inappropriate use of fish medicines. Therefore, administrators and fish farmers need to be better trained, and some additional measures need to be adopted to ensure healthy aquaculture. These include:

- controlling the total amount of fish farming in a given area based on the area's capacity to sustain fish culture;
- ensuring that the general layout of cages is appropriate to the type of waterbody and the nature of its bottom substrate. In order to prevent the transmission of diseases and pests, cages should be linked in a lineal style, the distance between lines of cages being at least 10 metres; they should not to have a chessboard-style layout;
- selecting the species to be cultured based on their feeding behavior. Whether or not feeding will be required often depends on the species to be raised (if silver carp are stocked, for example, no supplementary feeding is needed because this fish can use natural plankton as its food).
- improving feeding techniques by adopting scientific methods for feed application and controlling the feed coefficiency;
- improving feed formulations by promoting the use of high-quality, low-waste, floating feed, which will reduce feed residues;
- stocking appropriate aquatic animals in open waters to improve water quality; for instance, silver and bighead carps can be stocked to reduce eutrophication; and common carp, Crucian carp and other feed-fed fishes can be used to reduce the feed residues from cage culture, preventing accumulation of residues on the bottom; and
- protecting or transplanting large aquatic plants to clean water.

The importance of developing offshore cage culture

Cage culture plays an important role in inland fish culture; additionally, it makes a significant contribution to marine aquaculture. The developing offshore cage-culture industry has recently become a significant component of the marine fish farming sector. The reasons for this are as follows:

- China has a population of more than 1.3 billion, and its land resources are lower on a per capita basis than the world's average. Official data show that China has a land area of 9.6 million km^2, making it the third largest country in the world. However, the land area per capita is only 0.008 km^2, much lower than the world's

TABLE 5
Proportion of total output from marine fisheries derived from mariculture and marine capture fisheries

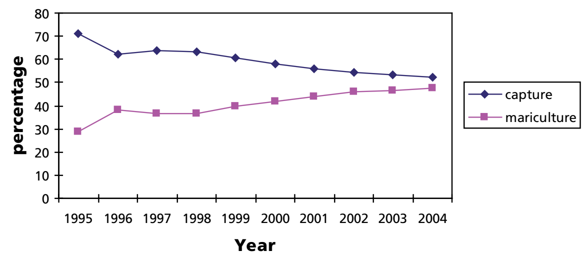
Year	Total output of marine fisheries (tonnes)	*Marine capture fisheries*		*Mariculture*	
		Output (tonnes)	% Total	Output (tonnes)	% Total
1995	14 391 297	10 268 373	71.3	4 122 924	28.7
1996	20 128 785	12 489 772	62.0	7 639 013	38.0
1997	21 764 233	13 853 804	63.6	7 910 429	36.4
1998	23 567 168	14 966 765	63.5	8 600 403	36.5
1999	24 719 200	14 976 200	60.5	9 743 000	39.5
2000	25 387 389	14 774 524	58.2	10 612 865	41.8
2001	25 721 467	14 406 144	56.0	11 315 323	44.0
2002	26 463 371	14 334 934	54.2	12 128 437	45.8
2003	26 856 182	14 323 121	53.3	12 533 061	46.7
2004	27 677 900	14 510 900	52.4	13 167 000	47.6

Source: Anon., 1998; Fisheries Bureau, 2000, 2003, 2004.[a]
[a] Editors' note: The figures presented here differ from the ones reported in FAO (2006), however, the discrepancy can be accounted for by the conversion of the Chinese reported figures on dry weight to wet weight for aquatic plants. So, for example, aquatic production excluding aquatic plants in 2004 was 10 778 640 tonnes, aquatic production with aquatic plants (dry weight) was 13 167 000 tonnes, and aquatic production with aquatic plants (converted to weight) was 21 980 595 tonnes.

average of 0.3 km^2 per capita. The agricultural land area per capita in China is only 7 percent of the world's total (Anon., 1998; National Development and Reform Commission, 2003). It is estimated that the demand for grain and other food products will reach 160 million tonnes by 2030. As a major developing country with a long coastline, China, in facing up to these serious facts, must make the exploitation and protection of the ocean a long-term strategic task in order to achieve the sustainable development of its national economy.

- In developing an oceanic fishing industry, China adheres to the principle of "speeding up the development of aquaculture, purposefully conserving and rationally utilizing offshore resources, and actively expanding deep-sea fishing" (Anon., 1998; Yang, 2000). Since the mid-1980s, China's mariculture has been rapidly developed, with a large increase in the number of species raised and in the breeding areas utilized. In accordance with the current state of its marine fisheries resources, China has actively readjusted the structure of this sector and made efforts to conserve and rationally exploit off-shore space, constantly adapting its mariculture industry to changes in marine fisheries production. Since the 1990s, the Government of China has been carrying out a series of comprehensive reforms and new policies in the fishery sector:

FIGURE 4
Proportion change between marine capture and mariculture



– Since 1995, China has practised a new "mid-summer moratorium system".[1] Every year, for two to three and a half months during summer, fishing is banned in China's Bohai, Yellow, East China and South China seas

[1] The "midsummer moratorium system" is a regulation for protecting natural resources, especially commercially important fish and crustaceans. The regulation was initiated in 1995 in the Yellow, East China and South China seas. According to the regulation, in midsummer (the exact period depends on the seas), fishing vessels must anchor in harbors and stop all fishing activities. For example, in 2002 the moratorium was in effect for the Yellow Sea beginning at 12:00 on 1 July and ending at 12:00 on 16 September; in 2005 the period was extended to three months, starting on 1 June and ending on 1 September. The regulation is supported by the provincial governments and welcomed by fishermen, as the fishery resources are seen to be gradually recovering.

(Yang, 2000). During this period, there are about 100 000 fishing vessels with one million fishermen that lay anchored in harbors;
- In 1999 a policy of "zero gain" in marine capture fisheries was implemented, and in the following year, a policy of "minus gain" was put into practice;
- Between 2003 and 2010, some 30 000 fishing vessels of various types will be removed from the industry, and more than 300 000 fishermen will have to find employment in other sectors, including mariculture.

The goal in implementing these new policies is to establish sustainable fisheries by protecting marine resources and promoting mariculture and sea ranching. To date substantial progress has been achieved: for example, the total marine production was 14.39 million tonnes in 1995, of which mariculture accounted for only 28.7 percent (4.1 million tonnes). Since then mariculture's contribution has continuously increased, the landed volume reaching 47.6 percent (13.1 million tonnes) in 2004 (Table 5 and Figure 4). It is expected that mariculture will contribute the majority of China's total marine output in the near future. Thus any gains in production from the marine fishery will shift from the marine capture fishery to mariculture. Developing offshore cage culture has thus become a priority for the Government of China, as well as for investors. Experts have estimated that the output of farmed marine fish will increase to one million tonnes (Wang, 2000), and coastal cage culture will, no doubt, contribute greatly to this increase.

Besides favorable policies supporting the development of offshore cages, both farmers and research institutes have obtained financial support from the relevant authorities. Developing offshore cage culture requires high investment and entails high risk. Because individual farmers are unable to finance offshore cage development or assume the associated risk, China's central government and provincial authorities are strongly supporting this project. Investments in the project from various sources are estimated to have reached more than US$10 million.

For example, 20 projects dealing with offshore cages had been granted and have obtained as much as 20 million Yuan (Renminbi) in financial support during the last five years. In addition, since 2001 Zhejiang, Fujian, Guangdong and Shandong provinces have arranged special funds (more than 50 million Yuan) for developing offshore cages. The funds are partially for research and development (R&D) and directly support the purchase of offshore cages by fishermen. These financial incentives and favorable policies promote the development and extension of offshore cage culture. According to survey data, about 3 300 offshore cages of different models have been installed in coastal provinces, of which there are 1 800 plastic hose (high density polyethylene or HDPE), circular cages (both floating and submersible) distributed in Zhejiang, Shandong, Fujian and Guangdong provinces. Another 1 300 floating rope cages have been installed in Zhejiang, Guangdong and Hainan provinces.

According to the most recent fisheries data (Fisheries Bureau 2003, 2004, 2005), marine fish production currently accounts for less than 5 percent of China's total yield from mariculture, the bulk of production being from the culture of seaweeds, molluscs and crustaceans.

In order to meet the demand for high-quality marine fish, offshore cage-fish culture is recognized as an indispensable measure. The reason for this is that (i) the capacity for inner bays and sheltered sites to accommodate traditional cages has already been met, and thus there is no space available for further expansion of this sector, and (ii) coastal lands are so valuable that it is impossible to use them for the construction of ponds for mariculture. Given these factors, offshore fish cage culture is considered a first option for increasing the output of marine fish. Although most mariculture is done on a family scale, offshore cage culture, being beyond the capacity of most of Chinese fish farmers, is suitable for large-scale operation.

Thus we believe that offshore fish cage culture is an indispensable means to increase the yield of quality finfish, however, the realization of its full potential is still at least five or ten years or more in the future.

CONCLUSIONS AND RECOMMENDATIONS

China has addressed the issue of rational utilization and protection of resources of both marine and freshwater environments in the overall, cross-century plans for national economic and social development, and has adopted incorporation of sustainable development within its environmental programmes as a basic strategy. With the continuing growth of the forces of social production, the further build-up of comprehensive national strength and the gradual awakening of the people's awareness of the importance of environmental protection, China's cage and pen culture programmes will definitely enjoy still greater development. Together with other countries and with international organizations, China will, as always, play its part in bringing mankind's work for aquaculture development and environmental protection onto the road towards sustainable development.

Developing cage and pen farming is a long-term aquaculture strategy, and thus the increased attention given to its development will continue for many years to come. Its social effects and environmental impacts will be far-reaching.

Beyond all doubt, it is essential to improve its current status, using rational planning and science-based decision making to ensure sustainable aquaculture in China as well as in the world's fisheries.

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Annex 1:

Freshwater fish and other aquatic animals farmed in cages and pens in China

Chinese name	English Name[a]	Scientific Name	Origin
青鱼	Black carp	*Mylopharyngodon piceus*	Native
草鱼	Grass carp	*Ctenopharyngodon idella*	Native
鲢	Silver carp	*Hypophthalmichthys molitrix*	Native
鳙	Bighead carp	*Aristichthys nobilis*	Native
鲤	Common carp	*Cyprinus carpio carpio*	Native
锦鲤	Koi	*Cyprinus carpio carpio*	Exotic
鲫	Goldfish	*Carassius auratus auratus*	Native
鳊	White Amur bream	*Parabramis pekinensis*	Native
三角鲂	Black Amur bream	*Megalobrama terminalis*	Native
翘嘴红鲌	Predatory carp	*Culter erythropterus*	Native
鳜	Chinese perch	*Siniperca chuatsi*	Native
虹鳟	Rainbow trout	*Oncorhynchus mykiss*	Exotic
香鱼	Ayu	*Plecoglossus altivelis altivelis*	Native
罗非鱼	Nile tilapia, blue tilapia	*Oreochromis niloticus, O. aurea*, and their hybrid	Exotic
澳洲宝石鲈	Barcoo grunter	*Scortum barcoo*	Exotic
加州鲈	Largemouth bass	*Micropterus salmoides*	Exotic
长吻鮠	Long-nose catfish	*Leiocassis longirostris*	Native
黄颡鱼	Yellow catfish	*Pelteobagrus fulvidraco*	Native
乌鳢	Snakehead	*Channa argus argus*	Native
大口鲶	Largemouth catfish	*Silurus meridionalis*	Native
斑点叉尾鮰	Channel catfish	*Ictalurus punctatus*	Exotic
革胡子鲶	North African catfish	*Clarias gariepinus*	Exotic
短盖巨脂鲤	Pirapitinga	*Piaractus brachypomus*	Exotic
黄鳝	Swamp eel	*Monopterus albus*	Native
泥鳅	Orientalweatherfish	*Misgurnus anguillicaudatus*	Native
鲟	Sturgeon	*Acipenser* spp.	Native
匙吻鲟	Mississippi paddlefish	*Polyodon spathula*	Exotic
中华绒螯蟹	Chinese mitten crab	*Eriocheir sinensis*	Native
青虾	Freshwater prawn	*Macrobrachium nipponense*	Native
罗氏沼虾	Giant river prawn	*Macrobrachium rosenbergii*	Exotic
龟	Freshwater turtle	*Chinemys* spp. (and others)	Native

[a] Scientific and English language common names (where available) are taken from Froese and Pauly (2006).

Annex 2:

Economically important fishes bred in hatcheries of China and farmed in cages

Chinese Name	English Name[b]	Scientific Name	Origin
鲻	Flathead mullet	*Mugil cephalus*	Native
梭鱼[a]	So-iuy mullet	*Mugil soiuy*	Native
鲈鱼[a]	Japanese seaperch	*Lateolabrax japonicus*	Native
遮目鱼/虱目鱼	Milkfish	*Chanos chanos*	Native
军曹鱼，海鲡	Cobia	*Rachycentron canadum*	Native
尖吻鲈	Barramundi	*Lates calcarifer*	Native
赤点石斑鱼[a]	Hongkong grouper	*Epinephelus akaara*	Native
青石斑鱼[a]	Yellow grouper	*Epinephelus awoara*	Native
锐首拟石斑鱼（驼背鲈/老鼠斑）	Humpback grouper	*Cromileptes altivelis*	Native
大黄鱼[a]	Croceine croaker	*Larimichthys crocea*	Native
鮸状黄姑鱼	Amoy croaker	*Argyosomus amoyensis*	Native
眼斑拟石首鱼[a]（美国红鱼）	Red drum	*Sciaenops ocellatus*	Exotic
真鲷[a]	Red seabream	*Pagus major*	Native
黑鲷	Black porgy	*Acanthopagrus schlegelii schlegelii*	Native
平鲷	Goldlined bream	*Rhabdosargus sarba*	Native
笛鲷	Snappers	*Lutjanus* spp.	Native
胡椒鲷	Sweetlips	*Plectorhinchus* spp.	Native
大泷六线鱼	Fat greenling	*Hexagrammos otakii*	Native
黑平鲉	Black rock-fish	*Sebastes pachycephalus nigricans*	Native
牙鲆[a]	Bastard flounder	*Paralichthys olivaceus*	Native
漠斑牙鲆（南方鲆）	Southern flounder	*Paralichthys lethostigma*	Exotic
夏鲆	Summer flounder	*Paralichthys dentatus*	Exotic
石鲽	Stone flounder	*Kareius bicoloratus*	Native
黄盖鲽	Marbled flounder	*Pseudopleuronectes yokohamae*	Native
大菱鲆[a]	Turbot	*Psetta maxima*	Exotic
半滑舌鳎	Tongue sole	*Cynoglossus semilaevis*	Native
红鳍东方鲀	Torafugu	*Takifugu rubripes*	Native

[a] Main species cultured on a large commercial scale.
[b] Scientific and English language common names (where available) are taken from Froese and Pauly (2006).