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Feed and fishmeal use in the production of carp and tilapia in China

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ABSTRACT

China dominates the global aquaculture industry, most clearly with its massive production and consumption of low trophic-level carp species and its rapidly rising output and exports of tilapia. Although these fish do not require a high percentage of fishmeal in their diets, their large production volumes contribute to China's leading role in global fishmeal consumption. The magnitude of China's dependence on fishmeal supplies – and hence the pressure it places on wild forage fisheries – remains a contentious issue. In this study, we use primary survey data from three provinces in China to examine the current use of aquafeeds in the carp and tilapia sectors and to assess how future demand for fishmeal will likely be affected by the country's shifting patterns of seafood consumption and production. Our results indicate that virtually all carp and tilapia farmers in our survey regions use manufactured feeds containing fishmeal and that median feed conversion ratios (FCRs) are in the range of 1.4 to 1.9. Feeds are poorly targeted on many farms due to widespread polyculture practices, especially the integration of higher-value species into carp ponds to improve farm-level profitability. Our study also suggests that government statistics underestimate household demand for fish by 20–35% because they do not account for out-of-home consumption. As China's demand for fish continues to rise in the future with per capita incomes and urbanization, the co-culture of high-valued species and the use of aquaculture feeds containing fishmeal are also expected to expand.

1. Introduction

China plays a dominant role in the global fisheries sector: it is the largest aquaculture producer and exporter, and the biggest consumer of seafood, aquafeeds, and fishmeal worldwide (FAO, 2012). Seafood production and consumption are both predicted to increase as the country's middle class prospers and demands larger quantities of seafood (*ibid.*). The latest available statistics show that, in 2010, China produced 63% of global aquaculture output in volume and over 61% of global farmed finfish output (FAO, 2013). The volume of freshwater aquaculture (excluding mollusks) more than quadrupled in China between 1990 and 2010; the top six finfish species currently farmed, by volume, include grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), common carp (*Cyprinus carpio*), bighead carp (*Hypophthalmichthys nobilis*), crucian carp (*Carassius carassius*), and tilapia (*Oreochromis* spp.) (Fig. 1). In 2010, China produced over 15 million metric tons (mmt) of carps and around 1 mmt of tilapia, accounting for about 90% of global carp production and 40% of global tilapia production (FAO, 2013). A little over half of the tilapia produced are exported as processed products, amounting to about 250,000 metric tons (mts) of processed tilapia (Hanson et al., 2011). Meanwhile, nearly all carps are consumed domestically (UN Comtrade, 2013).

Although tilapia and most carps have relatively low protein requirements and can survive well on plant-based diets,[1] small amounts of fishmeal are routinely incorporated into manufactured feeds to enhance the growth of these species. China's typical inclusion rates (share of individual dietary components in feeds), as reported by Tacon and Metian (2008), are 2–5% fishmeal in tilapia feeds and 0–12% fishmeal in carp feeds. The International Fishmeal and Fish Oil Organization (IFFO) previously estimated 2–4% fishmeal inclusion in carp feeds (Tacon et al., 2006). However, because these fish are cultured in such large volumes, even low inclusion rates add up to a substantial portion of global fishmeal demand. Earlier estimates show that global carp production consumes about 15% of total fishmeal supplies, and tilapia production consumes about 3% of total fishmeal (Tacon et al., 2006). China's overall consumption of fishmeal has grown from an estimated 5% of global supply in 1990 to 45% in 2009, although this share varies from year to year (FAO, 2013).

Consumption patterns for fish within China are also changing as per capita incomes rise. The middle class already consists of more than 300 million people and is predicted to reach 600 to 800 million by 2025 (Wang, 2010). China consumed almost 60% of global aquaculture production in 2010, and the United Nations Food and Agriculture Organization (FAO) predicts that the country's average seafood

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[1] There is a difference among carps; for example, silver and bighead carp species are generally not fed (unless in polyculture where the feed is directed toward other species in the system) while crucian carp are typically given compound feeds.

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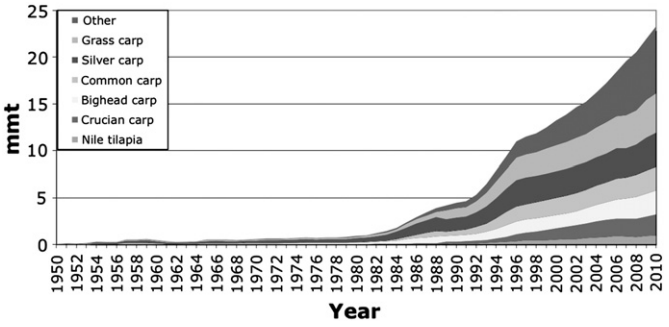

Fig. 1. Chinese freshwater aquaculture production (mmt), 1950–2010. Carp and tilapia species comprise the top six finfish species produced in China, totaling >16 mmt of production in 2010 (~70% of total Chinese freshwater aquaculture production, excluding mollusks). While the traditional carp species continue to make up the majority of aquaculture production, the culture of other freshwater finfish species is growing rapidly.
Source: FAO (2013).

consumption will jump by one-third from 26.7 kg/capita in 2007 to 35.9 kg/capita in 2020 (FAO, 2012, 2013).[2] In addition to eating more fish and shellfish per capita, the Chinese middle and upper classes are also eating more high-valued fish. Observers expect that China's growing demand for fish will be met largely by domestic production, and that its aquaculture exports will weaken (Sævarsson, 2007).

Despite China's dominant role in the global aquaculture sector, it remains a black box to many analysts in terms of production practices, feed inputs, and dependence on wild fish supplies for feed. In this paper, we attempt to crack open this box by revealing field-based evidence on China's carp and tilapia feed practices, fishmeal production, and sourcing of wild fish for feeds. Our data come from field surveys in three provinces of China where we interviewed rural fish farmers growing tilapia and/or carps, feed companies, fishmeal manufacturers, and rural and urban households (for their seafood consumption habits). Our focus on tilapia and carps allowed us to examine the consumption of fishmeal by lower-value, lower-trophic-level fish species, and to compare production practices for fish destined for export versus fish destined for domestic consumption.

Our farm surveys included four broad types of aquaculture systems: polyculture of mixed carp species in ponds, polyculture of carps with other higher-value species in ponds, floating cage systems containing carps and other finfish in lakes, and tilapia monoculture (with minimal polyculture for bio-control) in ponds. A primary goal of our study was to investigate feed practices in these culture systems, including the ingredients used, feed efficiencies, and sourcing of feeds and fishmeal. Interviews with domestic fishmeal manufacturers revealed information on species used for fishmeal production, feed yields, and the relationship between domestic and imported fishmeal. We also collected household data on fish consumption in rural and urban areas in order to measure seafood consumed both within and outside of the home. Through our analysis of primary field data, we could begin to tell a story about fish consumers, low-valued finfish producers, and fishmeal use in China.

2. A field-based approach

Our study draws on four separate surveys of fish production, rural fish consumption, urban consumption, and feed and fishmeal manufacturing. In all cases, survey teams organized by the Center for Chinese Agricultural Policy (CCAP) in Beijing conducted the interviews. The surveys on fish production, rural fish consumption, and feed and fishmeal manufacturing were conducted in the provinces of Hainan, Shandong, and Zhejiang (Jiashan and Qiandaohu[3]). These provinces were chosen because of their prevalent production of tilapia (in the case of Hainan) and carps (in the cases of Zhejiang and Shandong). Zhejiang is a highly developed area of China, whereas Shandong is more mixed; our survey region of Shandong was characterized by small-scale agriculture and aquaculture (predominantly mixed carp) production. A more detailed listing of the survey contents can be found in Appendix Table 1.

The fish production survey targeted a sample of small, household aquaculture operations and sought to gain a better understanding of feed use and production patterns of carps and tilapia. From August to November 2010, survey teams visited two to three regions in each province and interviewed a total of 351 fish farmers. The sample included farmers who grew mainly tilapia, mainly carps, or some combination of carps and other fish. Survey sites were selected to capture a diversity of aquaculture systems, from the temperate North to the tropical South, from pond systems to suspended cage systems. As is typical of research in China, where access to information tends to be difficult, survey respondents were identified through networks of contacts, and thus they may not represent unbiased cross-sections of the regions. In most cases, the survey team established a few key contacts in each location, who then introduced the team to other locals who provided further connections (i.e., snowball sampling).

In addition, the survey team collected consumption data from 410 households in rural Hainan, Zhejiang, and Shandong selected opportunistically (based on local contacts). Household members were asked to recall their fish consumption over the past year, including all aquatic products eaten both at home and away from home. Fish consumption fluctuates seasonally in China (with a large peak during the Chinese New Year), so a longer recall period better captures intra-annual variations. While in-home consumption was specific by fish type (e.g., tilapia, grass carp, oyster), out-of-home consumption data only specified the general class of aquatic product (e.g., fish, shrimp, crab, algae). When eating out, it is often impossible to know the exact type of fish being consumed; even in the U.S., 25–70% of seafood consumed in restaurants is mislabeled (Oceana, 2012).

At the time of our rural study, a separate consumption survey project was in progress at CCAP, and we were fortunate to gain access to their seafood consumption data for urban areas. Urban participants were given diaries in which to record all their food consumption for one week, both at home and away from home. The diaries gathered data from 769 urban households in Beijing (July 2007), Nanjing (September 2009), and Chengdu (September 2010) and asked about overall seafood consumption (not about consumption of different seafood types). The data collected on urban fish consumption reflect a conservative estimate because they did not cover consumption during the Chinese New Year. Both recall and record surveys are commonly used in social science research; however, each method has its strengths and weaknesses. In this case, the rural surveys yielded more detailed data (i.e., consumption of specific fish types) while the urban survey results were less specific but more accurate (i.e., consumption recorded as it occurred rather than estimated after the fact).

In addition to the production and consumption surveys, we interviewed fifteen feed and fishmeal manufacturers in Hainan, Zhejiang, and Shandong in October–December 2011. Our sample targeted large feed companies in each area; these companies were the ones used most frequently by the farmers in our producer survey. Fishmeal manufacturers, concentrated in the coastal areas of Shandong and Zhejiang, were selected opportunistically based on contacts at local fisheries bureaus. Although the sample size for these companies was

[2] The FAO data on per capita fish consumption are based on total fish and shellfish supplies available for consumption (accounting for trade), which depict live weight and not edible weight. As a result, the numbers are significantly higher than the official Chinese statistics, as discussed later in the paper.

[3] Jiashan and Qiandaohu townships in Zhejiang are treated as separate survey regions in this paper because the aquaculture production practices in these townships are quite distinct from each other, while the numerous townships surveyed in the other provinces were more homogeneous.

Table 1
Characterization of production methods and species by region.
The regions surveyed were selected for the prevalence of carp and tilapia aquaculture. They collectively encompass a diversity of fish species, production methods, and containment systems.

	Shandong	Jiashan	Qiandaohu	Hainan
Species grown	Mainly carps	Carp/turtle polyculture	Carps (0–88%) & other finfish	Tilapia
% focus species	96% carps	83% carps	27% carps	97% tilapia
Average # of species	4 (±1)	6 (±2)	4 (±2)	2 (±1)
Production method	Polyculture	Polyculture	Polyculture	Essentially monoculture
Containment system	Constructed ponds	Constructed ponds	Floating cages in lake	Constructed ponds, reservoirs

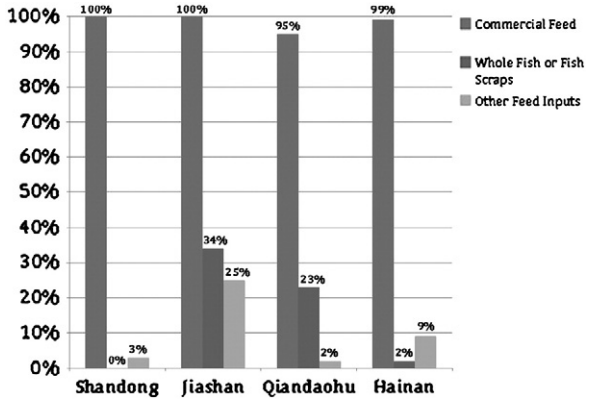

Fig. 2. Prevalence of feed inputs. The percentage of farmers in each region who reported using commercial feed, whole fish or fish scraps, and other feed inputs. The use of commercial feed was nearly universal in all systems surveyed, either solely or in conjunction with other feed inputs. About 20% of the "other" responses included the use of kitchen scraps.
Source: Aquaculture producer survey.

small, they collectively accounted for 12–13% of domestic fishmeal production and 2.5–3% of the country's total aquafeed production.[4]

The data gathered from these surveys were compiled and analyzed using Microsoft Excel, MathWave EasyFit, and "R". Treatment of missing variables and outliers is explained in Appendix Text 1.

3. Results and discussion

3.1. Characterization of study regions

Farms within each survey region tended to share similar production methods, but each region differed in system design (Table 1). Although our sample was oriented around carp and tilapia producers, a striking outcome of the survey was the large number of other species also raised in these systems—31 different species farmed in total (see Appendix Table 2). Farmers in Shandong mostly raised a mixture of carps in traditional pond polyculture systems. In addition to the traditional integrated system containing grass-, silver-, bighead-, and black carp, many farmers also raised crucian carp that typically depend on commercial feeds containing fishmeal. Polyculture was also prevalent in the other carp-based regions; however, these systems were not necessarily designed to optimize feed efficiency or minimize wastes).[5] Jiashan had the highest average number of species grown, with a variety of carps farmed alongside other higher-value species, such as soft-shelled turtles (*Pelodiscus sinensis*), whiteleg shrimp (*Litopenaeus vannamei*), Chinese mitten crab (*Eriocheir sinensis*), and rainbow trout (*Oncorhynchus mykiss*). Qiandaohu farmers also grew a rich assemblage of species that included carps as well as higher value finfish, such as yellow catfish (*Tachysurus fulvidraco*), longsnout catfish (*Leiocassis longirostris*), and Wuchang bream (*Megalobrama amblycephala*). Qiandaohu was also unique among the regions surveyed in its use of floating cages in lakes.[6] Farmers surveyed in Hainan produced predominantly tilapia. These farms cannot be considered strictly monocultures, however, as it was common to keep a few carps and other fish for bio-control purposes (e.g., to improve water quality and fish health).

3.2. Feed use and efficiency

The purchase and use of commercially manufactured feeds were evident in all four of the study regions, with >95% of the farmers using manufactured feeds (Fig. 2). In Jiashan and Qiandaohu, it was relatively common to use small, whole fish, either fresh or frozen, as well as fish scraps to supplement commercial feeds. These inputs were targeted at the more carnivorous species in the systems — turtles and higher-value finfish. The use of whole fish, often sourced from marine by-catch (or "trash fish"), raised the feed conversion ratios (FCR) of these systems. Floating feeds, which are more efficient and less polluting – but also more expensive – than traditional sinking pellets, were not common. Within our surveys, floating feeds comprised only 15% of all feeds used by farmers in the four regions, and only one of the feed manufacturers we interviewed (a tilapia feed company in Hainan) produced floating feeds.

Feed conversion ratios (total feed used to total fish biomass produced for market) varied within and between systems (Fig. 3). The median FCR for the farmers surveyed in the all-carp system (Shandong) was 1.5, and the median FCR for the farmers surveyed in the tilapia system (Hainan) was 1.4. One of the large feed companies in Hainan reported that the typical FCR for their tilapia feed was 1.45–1.60. By comparison, the median FCR for carp systems integrated with other species (including high-valued species) was 1.9 for both Jiashan and Qiandaohu. These numbers are similar to global average FCRs for carps and tilapia reported by Tacon and Metian (2008): 1.8 for carps and 1.7 for tilapia in 2006.[7]

Tacon and Metian's (2008) estimates, which are cited widely in the literature, were based on electronic survey information from feed manufacturers, farmers, researchers, and other fishery experts in 5 countries for carp and 14 countries for tilapia. It is interesting to

[4] The fishmeal and feed companies in our survey sample produced an estimated 152,000 mt of fishmeal and ~400,000 mt of aquafeeds. According to FishStat (FAO, 2013), China produced 1.2 mmt of fishmeal in 2009; this estimate includes wild fish and fish processing waste inputs, and the number varies from year to year. Some observers estimate domestic production of fishmeal to be closer to 400,000 mt, and aquafeed production in China to be 15.4 mmt in 2011 (Godfrey, 2012). The latter estimate of fishmeal production appears to be largely from wild fish inputs.

[5] There is a large literature on polyculture systems and their achievement of feed efficiency and waste circulation, including the largely experimental integrated multi-trophic aquaculture systems (IMTA). Some relevant papers for our discussion include: Li (1987), Milstein (1992), Kestemont (1995), Edwards (1998), Lazard and Dabbadie (2002), and Chopin et al. (2007).

[6] This lake system has been phased out since our survey due to a change in government policy protecting water quality and favoring tourism over aquaculture.

[7] The estimates for FCRs in our study and in the study by Tacon and Metian (2008) reflect economic FCRs, defined as the amount of feed supplied to a farm divided by the volume of fish produced for market. By contrast, biological FCRs account for the feed actually consumed by the fish (feed provided less the uneaten portion) divided by the total fish biomass produced for market including escapes and mortalities (Stickney and McVey, 2002). Jackson (2009) uses Tacon and Metian's (2008) estimates for total feeds used and total production to calculate "world FCRs" of 0.83 for carp and 1.38 for tilapia for 2006.

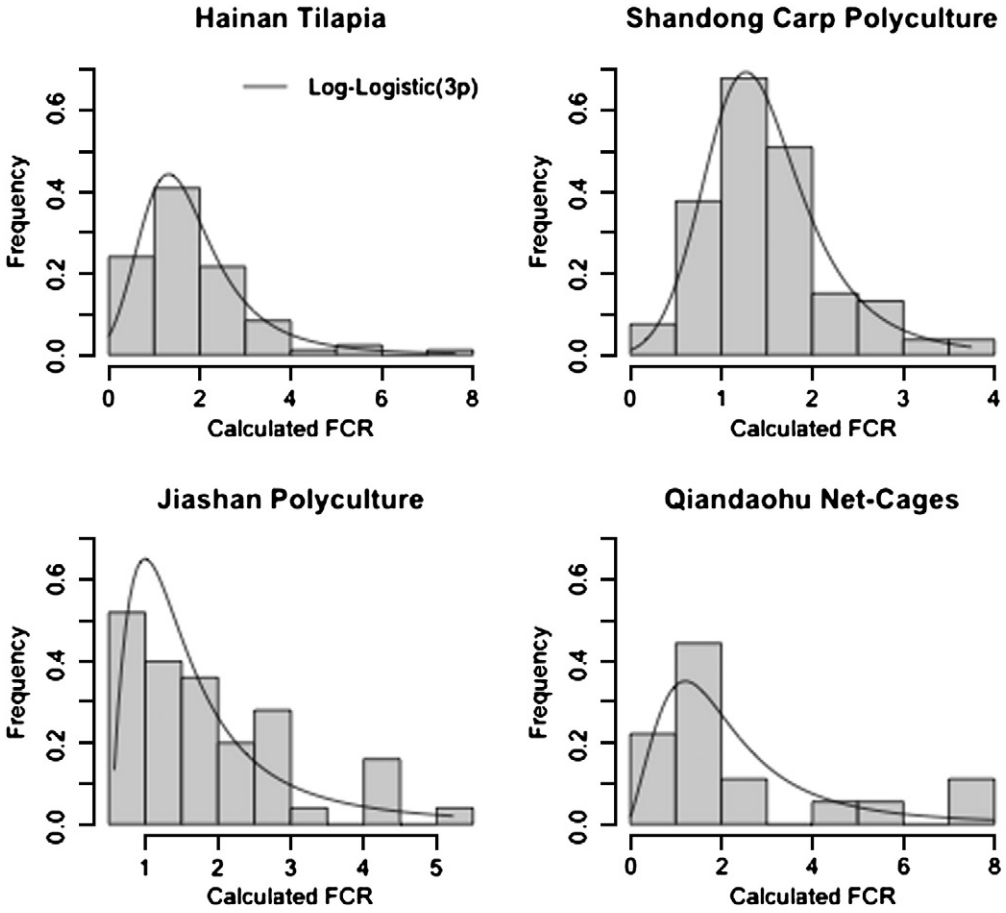

Fig. 3. Feed conversion ratios by region/production system. FCRs were calculated from survey responses using the total amount of feed used and the total amount of fish produced for market in each production system. Goodness-of-fit tests showed FCRs in each region to best fit a log-logistic distribution. The median FCRs for the farmers surveyed are as follows: 1.4 for Hainan (tilapia), 1.5 for Shandong (carps), 1.9 for Jiashan (carp/turtle polyculture), and 1.9 for Qiandaohu (carps and other finfish).
Source: Aquaculture producer survey.

note, however, that FCRs were not directly reported for China in the survey results of their paper. The absence of direct survey estimates for carp and tilapia FCRs in China – despite the large global role that China plays in the production of these fish – underscores the complex nature of feed management in the country's low-trophic level and polyculture systems. Leading textbooks on Chinese aquaculture (e.g., Wang, 2000) also suggest that it is infeasible to calculate specific FCRs for carp in the vast array of polyculture systems that exist throughout the country given their complexity. As in our study, the calculation of aggregate FCRs is recommended.

The relatively high FCR for carp polyculture systems in China reported in our results is likely due to inefficient feed practices and poor feed targeting, particularly given the prevalence of co-culture with higher-value species. In these systems, it is often difficult to maximize the nutritional efficiency of feeds due to the varied combinations of species farmed, particularly if the fish are at different stages of development (Lazard and Dabbadie, 2002; Milstein, 1992; Wang, 2000). Feed formulations for polyculture systems are also difficult. Farming higher-value species, which tend to be more carnivorous, requires higher-protein feed inputs, thereby raising the overall FCR of ponds in which carps are also present. The range of reported FCRs in Qiandaohu appeared to be especially high, reflecting the inefficiency of feed use in open cage systems and the use of whole fish and trash fish for feeds. Given the growing importance of non-carp species in these systems – and the generally poor reporting of output by species at the farmgate – it is worth asking: "What is really meant by a carp FCR in China?"

3.3. Fishmeal inclusion and sourcing

Although many farmers (e.g., up to 70% of farmers in Jiashan) reported knowing the contents of their feeds, further questioning revealed that farmers were only able to identify very general feed components, e.g., protein, crude fiber, amino acids (the printed contents on feed bags). Most farmers were unclear about the distinction between protein content and fishmeal content, which became apparent when they stated fishmeal inclusions in the 26–30% range — far too high for fishmeal content and more in line with total protein content. Thus, it was necessary to contact feed companies for a better understanding of fishmeal use. Interviews with feed companies revealed that lower trophic level fishes such as carps and tilapia are commonly fed diets including fishmeal. Fishmeal inclusion for carp feeds in our survey averaged 8.5% for all carp species and stages of development (juvenile to mature) (Table 2). This result compares with earlier estimates of 2–4% by IFFO for fishmeal inclusion in global carp feeds (Tacon et al., 2006), and 1.5% (grass carp), 5% (common carp), and 10% (crucian carp) for fishmeal inclusion in China by Tacon and Metian (2008). The widespread culture of crucian carp in our survey helps to explain the relatively high average fishmeal inclusion rate.

Most of the feed companies in our survey used domestically produced fishmeal in feeds for carps and other lower value fish species. For higher value finfish, tilapia, and whiteleg shrimp feeds, most companies preferred to use fishmeal from South America or a mix of imported and domestic fishmeal. The exact ratio of domestic

Table 2
Average fishmeal inclusion rates.
Fishmeal inclusions rates, as reported by feed companies. The values on the high end represent inclusion rates in feeds for fry/fingerlings feeds.

Feed	Avg. fishmeal inclusion	Range	N (# of companies)
Tilapia	2.5%	2–3%	2
Low value fish (carps)	8.5%	0–30%	7
White legged shrimp	27%	20–35%	6
High value fish	36.8%	24–60%	5

Table 3
Top five fish consumed.
Average per capita in-home consumption in 2010, by province and by species. Carps remain the most frequently consumed fish species, except in Hainan, where tilapia production and consumption are both prevalent.

Rank	Shandong	Zhejiang	Hainan
#1	Common carp (3.8 kg)	Crucian carp (3.5 kg)	Tilapia (7.3 kg)
#2	Grass carp (3.0 kg)	Silver carp (2.4 kg)	Common carp (1.0 kg)
#3	Crucian carp (1.9 kg)	Bighead carp (2.4 kg)	Bighead carp (0.9 kg)
#4	Silver carp (1.5 kg)	Common carp (1.9 kg)	Grass carp (0.9 kg)
#5	Bighead carp (0.8 kg)	Grass carp (1.7 kg)	Shrimp (0.3 kg)

versus imported fishmeal used by feed companies appeared to vary with price. Fishmeal used in turtle feeds was reported to come from countries such as the U.S., Russia, and New Zealand and included materials such as cod trimmings; however, the species composition probably varies according to price and availability.

Feed manufacturers claimed to adjust the formulation of their feeds based on price, while attempting to maintain the nutritional value of the product. Seasonal differences in crop harvests, fish physiology, and consumer preferences also reportedly affected feed formulations. In feeds for lower value fish, fishmeal was sometimes replaced partially with cottonseed meal and/or rapeseed meal. Some adjustment was also possible between fishmeal, soybean meal, and animal protein meals. One manager reported that his firm did not use any fishmeal in grass carp feeds five years ago, a practice that has since been reversed.

3.4. Domestic fishmeal production

In addition to being the largest importer of fishmeal, China also produces an estimated 1.2 mmt of fishmeal domestically, which accounts for almost one-half of China's total fishmeal consumption (FAO, 2013).[8] Based on information from our interviews, the province of Shandong produces about half of this fishmeal, while Zhejiang accounts for another 25%. These two regions are quite distinct in the fishing methods they employ, the fish species they utilize, and the quality of fishmeal produced. Fishmeal produced in Shandong is made predominantly from anchovies caught in the Yellow Sea using purse seines. The anchovies yield about 3% fish oil and about 20% fishmeal. Fishmeal produced in Shandong, with protein levels of 65% or higher, is considered to be of better quality than that produced in Zhejiang, and when processed properly, can be equal in quality to Peruvian fishmeal. However, the fishmeal industry in China consists of many small companies that source processed fish products and wild fish (including trash fish), and it is often difficult to discern the quality of the product purchased.

According to industry professionals, fishmeal production in Zhejiang relies on fish captured from the East China Sea, and these fisheries involve substantial bycatch. The companies interviewed in Zhejiang processed a combination of skinnycheek lanternfish (*Benthosema pterotum*), fish and shrimp processing byproducts, trash fish, anchovies, and other fish. Fish processed in Zhejiang factories yielded 0–2% fish oil, depending on the particular mix of fish being used, and around 20% fishmeal, with protein levels of around 60% in the final fishmeal product. Not all fish used by these companies have suitable quantities of oil; oil can be extracted from anchovies and processing byproducts, whereas lanternfish have no usable oil. In addition, fishmeal production facilities utilize fish from various sources to achieve targeted protein levels. For example, lanternfish, a small pelagic fish, contain ~65% protein, processing byproducts contain ~55% protein, and trash fish contain roughly 50% protein.

Domestic fishmeal production appeared to be less efficient than fishmeal produced in other countries. Typical global yields from 1 mt of reduction fish are 22–24% fishmeal and 5% fish oil (R. Hardy, Fig. 1 in Naylor et al., 2009), whereas the fishmeal producers interviewed in our study reported yields of only 20% fishmeal and 3% fish oil. Based on our interviews, it appeared that the prices of domestically produced fishmeal were linked to the prices of imported fishmeal, and not determined solely by domestic supply and demand. The advantage of domestically produced fishmeal is that it is fresher and less expensive. The disadvantage is that the quality is often inferior and less reliable in terms of labeled protein ingredients.[9]

3.5. Farmers' adaptations

Of the many challenges that aquaculture producers face in China, increased scarcity of land and water resources, and rising feed prices are at or near the top of the list. A key question in our study was how farmers were responding to these challenges. Based on our surveys, two common trends were evident: farmers were expanding the number of species raised, and they were raising species that were valued more highly in the market. In Jiashan, 57% of the farmers surveyed had added turtles to their aquaculture systems, while in Qiandaohu, farmers were producing higher-value finfish, such as yellowhead catfish, bream, black carp (*Mylopharyngodon piceus*), and bass. Jiashan and Qiandaohu respectively averaged 6 (± 2) species and 4 (± 2) species per farm (Table 1). Producers in Shandong mainly farmed multi-species carp ponds (4 ± 1 spp). In Hainan, farmers were more prone to increase their volume of tilapia production rather than to diversify; however, a few farmers reported shifting to striped catfish (*Pangasianodon hypophthalmus*) production.

Rising feed prices were the predominant production concern across all carp systems (identified by 49–62% of farmers depending on the region). However, when asked about their response to price changes, most farmers reported that they simply absorbed the increased cost. Only 3% of farmers surveyed had implemented active adaptations, such as changing to a different feed, using less feed, reducing wasted feed, or buying feeds strategically by stockpiling whenever prices fell slightly. Two-thirds of farmers surveyed had established relationships with a particular feed trader who controlled access to supplies, markets, and information. In Hainan, many of these middlemen offered comprehensive services including supplying feed, fingerlings, and other inputs, organizing labor for harvest, and loaning trucks for delivery to processing plants. The traders also served as a key source of information and many also provided credit to farmers, both for feeds and sometimes cash advances for other expenses. This centralized system simplified the supply chain for tilapia aquaculture but also limited farmers' individual ability to adapt to change. Feed trader relationships were particularly strong in Hainan, but similar structures were also observed in the other survey regions.

[8] See note 4 on estimates for domestic fishmeal production.

[9] Based on survey information, domestic fishmeal quality varies over time and by location depending on fish inputs from trash fish, bycatch and processing wastes.

3.6. Fish consumption patterns

Our survey of fish consumption confirmed that carp species remain the mainstay of rural Chinese diets, particularly in regions where carp is grown. Common carp, grass carp, crucian carp, silver carp, and bighead carp are the top five fish species consumed in Shandong and Zhejiang, accounting for 83% and 69%, respectively, of total in-home consumption of aquatic products (Table 3). In contrast, tilapia is the primary fish consumed in Hainan, with carps and other species playing much smaller roles. Based on our rural household sample, nearly all the carps and tilapia consumed were purchased as live fish. Farmers' markets were the predominant source for procuring fish across all regions, accounting for 58%–82% of fish consumed, depending on the species.

Local consumption thus appears to be driven by local supply. Because the urban surveys did not catalog consumption by species, we were unable to analyze patterns of carp and tilapia consumption in urban areas. However, during our study period, tilapia was available for sale in urban wet markets in major cities such as Beijing, Shanghai, and Hangzhou. One barrier to acceptance appeared to be the strong preference for live fish – mostly purchased at local markets – over the frozen filets that supply export markets and domestic supermarkets. On the other hand, increasing wealth, urbanization, and desire for convenience products in urban areas are reportedly leading to higher consumption of processed tilapia. If domestic demand for tilapia increases in the future, it is likely to be at the expense of exports. Based on our analysis, consumption of aquatic products is more generally correlated with wealth, both at home and outside of home (Fig. 4).

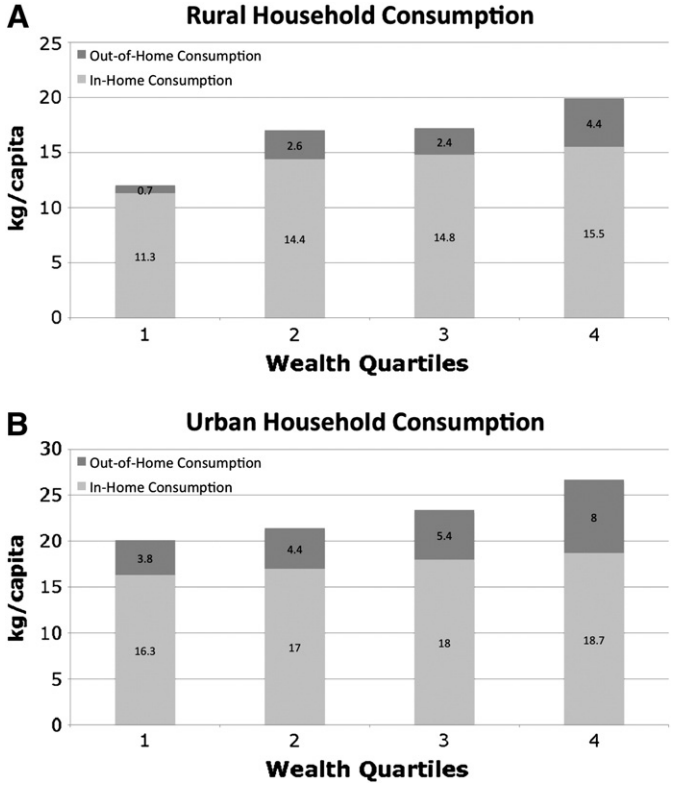

Fig. 4. A) Rural fish consumption by wealth quintiles and B) urban fish consumption by income quintiles. Per capita fish consumption including both in-home and out-of-home consumption. Wealth thresholds were chosen that divided the sample population into four equal parts (in terms of households). For the rural population, wealth thresholds were based on the cumulative estimated value of all reported assets. For the urban population, wealth thresholds were based on reported income. Results show fish consumption rising with increasing wealth in both rural and urban areas.
Source: Consumer surveys.

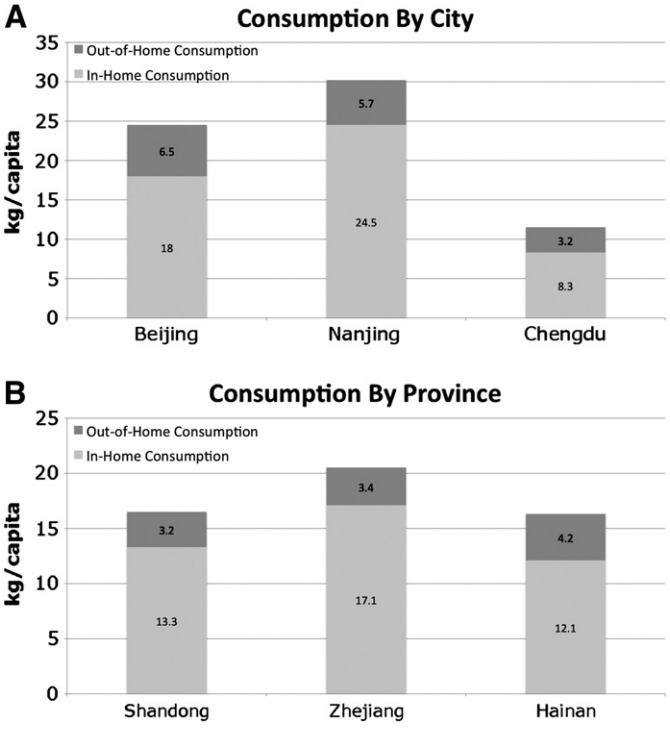

Fig. 5. A) Rural fish consumption and B) urban fish consumption by region. Per capita fish consumption including both in-home and out-of-home consumption. Results show consumption to be roughly 20–35% higher than stated in official estimates.
Source: Consumer surveys.

Estimates of per capita seafood consumption in China vary widely by source. The 2012 China Statistical Yearbook reports average annual fish consumption by province as follows: Shandong 4.73 kg/capita, Zhejiang 16.00 kg/capita, and Hainan 16.85 kg/capita (NBSC, 2012). One shortcoming of the official Chinese statistics is that they do not account for food consumed outside the home, which our survey does capture. The in-home consumption results from our survey match up reasonably well to the Yearbook statistics, except for in Shandong.[10] In addition, the official statistics for fish consumption in Hainan are higher than our survey findings. When out-of-home consumption is added, our study suggests that the official fish consumption statistics are underestimated by 20–35% for both rural and urban populations (Fig. 5). If this out-of-home margin were added to estimates for fish consumption for China as a whole, the country's overall demand for seafood would be much larger than previously thought. The China Statistical Yearbook reports that average fish consumption for the nation was 10.1 kg/capita in 2011 (NBSC, 2012).[11] Adding the out-of-home margin would increase overall consumption by 2–3.5 kg/capita, or by 2.7 mmt to 4.7 mmt for the country as a whole.

[10] The discrepancy in Shandong is likely due to consumption surveys being conducted at the same time as aquaculture production surveys, and thus, for logistical reasons, may have been conducted in areas with greater access to fish than is typical across the entire province. In the other regions, the producer and consumer surveys were conducted at different times and locations.

[11] The estimates distinguish between rural and urban consumption and are weighted by the respective populations. The Chinese population as a whole was 1.35 billion in 2011, with a greater share of the population in urban areas for the first time on record. The FAO data on per capita seafood consumption in China are substantially higher than the numbers reported in the China Statistical Yearbook (26.7 kg/cap); see note 2.

4. Conclusions

Aquaculture in China can be characterized as comprising numerous diverse systems with many moving pieces. Information on these systems is difficult to obtain, particularly with regard to the volume of fish harvested by species at the farmgate, and the quantity and composition of feed and fishmeal inputs. Without good data in these categories, it is difficult to gauge the magnitude of China's aquaculture demand for wild fish inputs. This study provides a snapshot from a few representative regions of carp and tilapia culture, but it cannot be considered representative of the entire country. What is evident from the results, however, is that a wide variety of finfish species are integrated into carp polyculture systems, obscuring estimates of FCRs and fishmeal inclusion in feeds. Even with such ambiguity, the study suggests that there is ample room for improvement in efficiencies of feed and fishmeal production and use, both in manufacturing facilities as well as in field production systems.

More on-the-ground research and evaluation are needed to understand better why these inefficiencies are perpetuated and how these systems could be improved. One area of opportunity might be to leverage feed trader networks in order to educate farmers on the advantages of floating feeds and improved feeding practices (Li et al., 2011). Another opportunity pertains to the use of seafood processing byproducts in domestic fishmeal production (the use of waste products to create fishmeal). Investments to improve quality and ensure food safety would be valuable in this area. The use of processing wastes in fishmeal production is currently expanding throughout China and other parts of Asia (FAO, 2013; Newton et al., in press). This trend is somewhat limited, however, by the strong preference for whole fish by many Chinese consumers. Identification of the full range of fish species being used in domestic fishmeal production would give a clearer picture of the magnitude of China's impact on forage fisheries.

The demand for aquaculture feeds and fishmeal in China will likely increase in the future with the continued expansion of higher-trophic level species, farmed in response to rising urban and rural consumption (Fabinyi, 2011; Wang, 2010). More field level data are needed to calculate accurate FCRs for these polyculture systems and to define what a carp FCR actually means in the current China context. As more evidence emerges from the field, farmers' management of feeds – and avenues for improvements in the aquafeed sector more generally – will also become more apparent. Improved data on seafood consumption in China, accounting for both in-home and out-of-home consumption, will help clarify projected patterns of production, trade, and input use. If China can significantly raise the efficiency of its aquaculture feed production and use, it will be in a better position to supply its growing seafood demand while reducing stress on wild fisheries.

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Apendix A

Appendix Table 1
Survey contents[a].

Survey	# of responses	Topics covered
Fish production	351 aquaculture households (Hainan 113, Zhejiang 118, Shandong 120)	Fish production, feed knowledge and use, size, costs, species raised, water quality concerns, sales and marketing, reactions to price fluctuations, challenges faced, outlook on future of industry, labor inputs and experience, family demographics
Rural fish consumption	410 households	Consumption amount and frequency, expenditure, product form, product sourcing, recognition of various species of aquatic products, consumption location, consumption preferences, household demographics
Urban fish consumption	769 households	Consumption amount, expenditure for aquatic products in general, household demographics
Feed and fishmeal manufacturing	11 feed companies, 4 fishmeal companies	Feeds produced, production quantities, feed ingredients/species used, yields, production season, price trends, substitutions

[a] The survey instruments, written in Mandarin, are available upon request.

Appendix Table 2
Species farmed within the producer survey sample.

Common name	Scientific name	Chinese name	Region farmed
Grass carp	*Ctenopharyngodon idella*	草鱼	Shandong, Jiashan, Qiandaohu, Hainan
Silver carp	*Hypophthalmichthys molitrix*	鲢鱼/白鲢	Shandong, Jiashan, Qiandaohu, Hainan
Bighead carp	*Hypophthalmichthys nobilis*	鳙鱼/花鲢鱼/胖头鱼/大头鱼	Shandong, Jiashan, Qiandaohu, Hainan
Common carp	*Cyprinus carpio*	鲤鱼	Shandong, Jiashan, Qiandaohu, Hainan
Crucian carp	*Carassius carassius*	鲫鱼	Shandong, Jiashan, Qiandaohu, Hainan
Black carp	*Mylopharyngodon piceus*	青鱼	Shandong, Jiashan, Qiandaohu
Tilapia	*Oreochromis* spp.	罗非鱼	Jiashan, Hainan
Striped catfish	*Pangasianodon hypophthalmus*	巴沙鱼	Hainan
Amur catfish	*Silurus asotus*	鲶鱼	Shandong, Qiandaohu, Hainan
Longsnout catfish	*Leiocassis longirostris*	长吻鮠/长江鮰鱼	Qiandaohu
Yellow catfish	*Tachysurus fulvidraco*	黄颡鱼/黄刺鱼/黄牛头	Shandong, Jiashan, Qiandaohu
White Amur bream	*Parabramis pekinensis*	鳊鱼	Shandong, Jiashan, Qiandaohu, Hainan
Wuchang bream	*Megalobrama amblycephala*	武昌鱼 (团头鲂)	Shandong

(continued on next page)

Appendix Table 2 (*continued*)

Common name	Scientific name	Chinese name	Region farmed
Mongolian redfin	*Chanodichthys mongolicus*	红珠 (蒙古红鲌)	Qiandaohu
Channel catfish	*Ictalurus punctatus*	红鮰鱼 (美国红鮰鱼, 无鳞红鮰鱼)	Qiandaohu
Topmouth culter	*Culter alburnus*	白花 (翘嘴鲌)	Qiandaohu
Sharpbelly, Wild carp	*Hemiculter leucisculus*	白条 (白鳞)	Qiandaohu
Spotted steed	*Hemibarbus maculatus*	花(鱼骨)鱼	Qiandaohu
Parma Pingova* (*Czech name; no common name exists in English)	*Percocypris pingi*	花鱼 (鲈鲤)	Hainan
Rainbow trout	*Oncorhynchus mykiss*	鲑鱼/鳟鱼	Jiashan
Largemouth bass	*Micropterus salmoides*	鲈鱼	Qiandaohu
Sunfish	*Lepomis*	太阳鱼	Qiandaohu
Roughskin sculpin	*Trachidermus fasciatus*	花鼓鱼/松江鲈鱼	Qiandaohu
Snakehead	*Channa*	黑鱼/乌鱼	Hainan
Red-bellied pacu	*Piaractus brachypomus*	白鲳鱼	Hainan
Chinese fat minnow	*Sarcocheilichthys Sinensis*	石斑鱼	Qiandaohu
Eel	*Anguilla japonica*	鳗鱼	Jiashan, Hainan
Oriental river prawn	*Macrobrachium nipponense*	青虾 (日本沼虾)	Jiashan, Hainan
Whiteleg shrimp	*Litopenaeus vannamei*	白对虾	Jiashan
Chinese mitten crab	*Eriocheir sinensis*	蟹	Jiashan
Soft-shelled turtle	*Pelodiscus sinensis*	鳖/甲鱼	Jiashan

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