Monterey Bay Aquarium Seafood Watch®

Tilapia

(*Oreochromis* spp.)

(© Diane Rome Peebles)

China

Ponds

Aquaculture Standard Version A3.2

November 14, 2018

Seafood Watch Consulting Researchers

Final Seafood Recommendation

Criterion	Score	Rank	Critical?
C1 Data	3.64	YELLOW	
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	2.93	RED	NO
C4 Chemicals	0.00	CRITICAL	YES
C5 Feed	8.16	GREEN	NO
C6 Escapes	0.00	CRITICAL	YES
C7 Disease	3.00	RED	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-3.00	GREEN	NO
C10X Secondary species escape	-6.00	YELLOW	
Total	**13.73**		
Final score (0-10)	**1.96**		

OVERALL RANKING

Final Score	1.96
Rank	RED
Red criteria	3
Interim rank	RED
Critical Criteria?	YES

FINAL RANK

RED

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

The final numerical score for tilapia produced in pond production systems in China is 1.96 out of 10 which is in the Red range. There are two non-Critical Red criteria and two Critical criteria. The final recommendation is an "Avoid."

Executive Summary

This Seafood Watch assessment involves various criteria covering impacts associated with: effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), disease, the source stock, and general data availability.

China continues to be one of the largest contributors to global aquaculture, at >60% of global production, and production has grown compared to the global average. Total Chinese tilapia production was estimated to be 1.7 million metric tons (MT) in 2017. Approximately 26% of Chinese tilapia was exported in 2014, and China is a major exporter of tilapia to North America. Exports to the US approached 134,000 MT in 2017, accounting for roughly 73% of total US tilapia imports, and are largely in the form of frozen fillets. Cost analysis has shown that the volume of competition in Chinese tilapia production makes it cheaper than the largest competitors.

There are a variety of cultivation methods for tilapia in China, including intensive monoculture, semi-intensive polyculture, intensive culture in brackish ponds, integrated fish/duck culture, cage culture, and integrated tilapia/rice culture. Despite this large variation, pond monoculture and polyculture are the most popular methods as either intensive or semi-intensive systems. Intensive monoculture techniques are mainly practiced in southern coastal provinces, which produce approximately 95% of Chinese tilapia: Guangdong, Hainan, Guangxi, Yunnan, and Fujian. There is great variation in the species/strains that are cultured within China; however, current cultivated species are largely Genetically Improved Farmed Tilapia (GIFT) strains and hybrids.

Data

The China Aquatic Products Processing and Marketing Association (CAPPMA) compiles statistics and other information on the industry. This information is available in English and should be available to the public; however, due to website technical difficulties and despite multiple requests to several members within the organization, this information is not currently accessible. Information provided by government bodies is fragmented, disparate, and often unavailable. The majority of information used in this assessment is compiled from peer-reviewed scientific literature and grey literature, where smaller specific studies are often used to describe the average situation in Chinese tilapia cultivation, and these are often outdated. The majority of regulatory information is in Chinese, making it difficult for consumers and businesses importing tilapia products from China to the Unites States to understand environmental implications of production. The final score for Criterion 1 – Data Quality and Availability is 3.6 out of 10.

Effluent

With minimal data on the ecological impact of effluent that is released specifically by tilapia pond-based farms in China, the Risk-Based Assessment is used to estimate the discharge of nitrogen into receiving ecosystems and the regulations and management that govern it. Average values are calculated using limited data on the use of feeds (28.5% protein and eFCR of 1.4) and water management methods (discharge only at harvest), which result in an estimated 14.09 kg of nitrogen per ton of tilapia production leaving production sites as effluent waste. This is based on intensive pond culture methods using only feed inputs, as this is the primary production method for tilapia in China. The legal framework addressing effluent management of aquaculture in China is regionally fragmented and lacking in set standard limits. Despite recent changes to the primary environmental laws, the content and enforcement of regulations lacks evidenced repercussions and monitoring data, resulting in difficulty assessing efficacy of the system. Ultimately, farms discharge a low amount of nitrogen waste per ton of production, but there is weak regulatory legislation and implementation. The combined scores for Factors 2.1 (8 out of 10) and 2.2. (0.8 out of 10) result in a final score of 5 out of 10 for Criterion 2 – Effluent.

Habitat

A large proportion of farms have been converted from agricultural land to aquaculture ponds. While many of these ponds initially became shrimp ponds until the early 1990s, they were abandoned due to problems with disease and eutrophication of the receiving waters and later became repurposed for tilapia culture. Most information suggests that, due to development of various types, there has been historic loss (>15 years ago) of high-value habitat (i.e., freshwater and wetlands) in China. Although some conversion has been secondary (i.e., from virgin habitat to agriculture to aquaculture), and some specifically for aquaculture have been, anecdotally, for species other than tilapia (e.g., primarily carp or shrimp), there is ultimately a lack of information regarding the tilapia industry's contribution to overall habitat conversion or degradation. As such, given tilapia's prominence among China's fish aquaculture production, it is a reasonable, precautionary conclusion that tilapia farming has resulted in some loss of ecosystem services in China. The score for Factor 3.1 is 4 out of 10. Current siting regulations and permitting requirements are spread among many levels of government, are vague, and not often specific to aquaculture. Environmental impact assessments and habitat connectivity are incorporated into the regulations, though consideration for habitat connectivity is only applicable to new construction after 2017. Enforcement is divided among many government departments and lacks clear punitive measures or documented action against farms that do not comply, resulting in an overall score of 1 out of 10 for Factor 3.2. Since there is evidence of wetland habitat functionality loss in the last 15 years, and enforcement measures are unclear and likely minimal, Factors 3.1 and 3.2 combine to give a final Criterion 3 – Habitat score of 2.93 out of 10.

Chemical Use

There is poor availability of data regarding on-farm use of chemicals in Chinese tilapia production. Furthermore, the regulations that govern chemical use in aquaculture in China appear to be aimed at food safety rather than primary application of chemicals or the potential ecological impacts of their use. There is, however, recent evidence that the banned chemical malachite green is still being used in tilapia production in China, and was the cause for detention of frozen tilapia fillets entering the US in 2016. Also, nine import rejections since

2015 have been imposed on Chinese tilapia due to detection of antibiotics in fish fillets, including several antimicrobials listed as “Highly Important for Human Medicine” by the World Health Organization (WHO): sulfadiazine, trimethoprim, and sulfamethoxazole. The Chinese government has recently begun to implement plans to address overuse of antibiotics, but there is not yet evidence of improvements in management practices. There is also evidence of antimicrobial resistance in strains of *Aeromonas* and *Streptococcus* bacteria in direct connection with tilapia farms and farming regions. Due to the use of illegal chemicals as defined by the country of production and use of chemicals that are classified by WHO as “Highly Important for Human Medicine,” as well as evidence of resistance in bacterial pathogens affecting the tilapia industry, this results in a Critical final score for Criterion 4 – Chemical Use.

Feed

The inclusion levels of fishmeal (FM) (1.5%) and fish oil (FO) (0.5%) in feeds used in tilapia production in China are relatively low in comparison to other fed finfish species. The combination of a low eFCR (1.4) and low FM and FO inclusion gives a low Feed Fish Efficiency Ratio (FFER) of 0.18, and an overall score for Factor 5.1a of 9.56 out of 10. Regarding the use of wild fish, China is a significant importer of feed from South America, in particular Peru. However, a significant amount of feeds are produced domestically using unknown “trash fish,” or fisheries that are fully exploited, overexploited, or depleted. Since the FishSource score for the most widely reported source of imported feeds, the Peruvian Anchovy, are all >6, but there are still significant concerns over the use of marine ingredients in domestic feeds and the score for Factor 5.1b is –7 out of –10, the result is a final Factor 5.1 score of 9.32 out of 10. Protein in feeds used for tilapia in China is sourced from approximately 70% from edible sources, and approximately 30% from sources not suitable for human consumption. There is an overall net edible protein loss of –44.87%, leading to a Factor 5.2 score of 5 out of 10. When combined, the total area of land and ocean appropriated to produce one ton of tilapia in China is 1.25 ha. These values equate to a final score of 9 out of 10 for Factor 5.3. When combined, factors 5.1, 5.2 and 5.3 give a final Criterion 5 – Feed a numerical score of 8.16 out of 10.

Escapes

Tilapia are considered highly invasive outside their native range and this includes the most commonly cultivated species in China (blue tilapia and Nile tilapia), which are named on the IUCN Global Invasive Species Database. Reports on tilapia escapes at the farm level in China are unavailable; therefore, the risk of escapes from a pond system is measured by both the openness of the system and the vulnerability of the ponds to flooding events. Although ponds are generally only drained externally at harvest, recent literature provides evidence that tilapia cultivation occurs in regions where ponds are vulnerable to river flooding events and that escapes do indeed occur. There are large areas where tilapia is cultivated and are now known to have well-established (>10 years) populations (e.g., Hainan and Guangdong provinces). However, there are still some regions in China where tilapia have not yet become established but are showing signs of developing establishment. There are also documented examples of tilapia populations vastly outcompeting local fish species for resources in Chinese waterways. Given the risk of extending the range of establishment and the invasiveness of the species, as evidenced by their competition with native species in China, the final score for Criterion 6 – Escapes is a Critical score of 0 out of 10.

Disease, Pathogen and Parasite Interactions

Because there is a lack of information about the impact of on-farm disease in Chinese tilapia production on wild fish, the Risk-Based Assessment is utilized. The intensification of tilapia cultivation in China has increased the risk and incidence of diseases through higher stocking densities and higher feeding rates, leading to decreased water quality and increased stress on the cultivated fish. Additionally, the GIFT strain selective breeding did not include characteristics related to disease resistance. The main diseases of tilapia in Asia include bacterial diseases caused by *Streptococcus* and *Aeromonas* species, of which *S. agalactiae* is reported as the most prevalent cause of mortalities, including in China. Other diseases are also known to be present in the industry. Currently very few vaccines are approved for aquatic use in China, few of which are relevant to the more prevalent known disease problems in the tilapia industry. The regulations for the control of disease in Chinese aquaculture are largely aimed at protecting farmed stocks from epidemics, and although these regulations may protect wild fish by reducing the prevalence of disease at the farm level, little detail is available on the enforcement measures for these regulations. In addition, there is evidence of a lack of enforcement on reporting requirements, which makes understanding current industry-wide disease incidence difficult. Pond systems are typically drained once at harvest, which reduces the risk of transmission to wild fish populations. However, there is growing evidence for disease outbreaks and resistance to treatments on farms, unknown implementation of biosecurity protocols, and little research regarding the impact this is having on wild fish populations. The final numerical score is 3 out of 10 for Criterion 7 – Disease.

Source of Stock

Seed production of tilapia in China can occur by collecting seedlings from grow-out ponds, however the predominant method is via large-scale hatchery production. The development of Genetically Improved Farmed Tilapia (GIFT) seed has helped overcome inconsistencies in traditional seed collection from grow-out ponds, increased growth rates, and increased cold and salinity tolerance. There are >200 hatcheries/nurseries nationwide, which includes five national seed hatcheries and >10 tilapia seed brands. Recent literature confirms that (domestic) hatchery production is more than 100 billion fingerlings annually and is sufficient to meet industry demand. Because this is a closed, domesticated life cycle and 0% of the farmed tilapia stock is dependent on wild broodstock or wild fisheries, the final numerical score for Criterion 8X - Source of Stock is 0 out of –10.

Predator and Wildlife Mortalities

Pond cultivation of tilapia is considered to attract a variety of predators and other wildlife: reptiles, birds, and small mammals. However, data on mortalities that occur as a result of this interaction in China are not available. Water birds in Chinese tilapia-growing regions have been shown to be closely associated with aquaculture ponds. Despite this documented interaction, there is no information regarding whether control methods are taken by farmers against migratory birds. There is also a lack of research on wildlife interactions with tilapia ponds in

China, and current literature suggests there is potential for migratory water birds to utilize ponds for foraging and resting. Chinese law does contain protections for rare and endangered species; however, the level of implementation for these regulations, as well as the specificity for aquaculture activities is unclear. Due to unknown interactions, evidence of the presence of wildlife on the farms, the presence of legal protections, yet unclear implementation, and the possibility of migrating birds utilizing ponds for foraging and resting, the score for Criterion 9X – Predator and Wildlife Mortalities is –3 out of –10.

Escape of Secondary Species

Trans-waterbody movement between ecologically distinct environments risks introducing non-native pathogens, parasites, and non-target species, and the risk is driven by the reliance of production on such movements. In China, international imports of tilapia species for aquaculture breeding programs have occurred historically; however, there is currently a national program for seed production. In this program, seed is produced nationally and distributed locally to farmers of all production scales, which is likely to include trans-waterbody movements, resulting in a factor 10Xa score of 0 out of 10. The biosecurity of the source (hatchery) is presumed to be higher than that at the destination (farm), due to the developed industrial hatchery system and the inherent risks of culture for young life stages, resulting in a moderate score of 4 out of 10 for factor 10Xb. Although Chinese tilapia is self-sufficient in domestic seed production, the dissemination of tilapia broodstock and seed is reliant on trans-waterbody movements. Combining the scores for factors 10Xa and 10Xb results in the final numerical score for Criterion 10X – Escape of Secondary Species is –6 out of –10.

The final numerical score for tilapia produced in pond production systems in China is 1.96 out of 10 which is in the Red range. There are two non-Critical Red criteria (Habitat and Disease) and two Critical criteria (Chemical Use, Escapes). The final recommendation is “Avoid.”

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Scope of the analysis and ensuing recommendation

Species
Nile Tilapia (including GIFT strains) and Ao-Ni Tilapia (Nile-Blue Hybrids)
(*Oreochromis niloticus, O. niloticus x O. aureus, Oreochromis* spp.)
*Some minor production of Mozambique tilapia (*Oreochromis mossambicus*)

Geographic Coverage
Mainland China

Production Method(s)
Ponds

Species Overview

Brief overview of the species
Tilapia is a prolific fast-growing tropical species, native to Africa and the Middle East, but introduced elsewhere as a valuable food fish. Tilapia is a common name applied to three genera: *Oreochromis* (maternal mouthbrooders), *Sarotherodon* (paternal mouthbrooders), and *Tilapia* (substrate spawners). The species that are most important for aquaculture are in the genus *Oreochromis*, including *O. niloticus* (Nile tilapia), *O. mossambicus* (Mozambique tilapia), *O. aureus* (blue tilapia), and *O. u. hornorum* (Wami tilapia). Most species are unable to survive at temperatures below 50 °F (10 °C); their optimum temperature range is approximately 82 to 89 °F (28 to 32 °C). Tilapia can live in either fresh or salt water; Boyd (2004) reports the capability of culturing them in waters up to 25 parts per thousand (ppt). They are omnivores feeding mainly on algae, aquatic macrophytes, detritus, and associated bacterial films (Fitzsimmons and Watanabe 2010). Therefore, tilapia can be grown on feeds with relatively lower protein and higher carbohydrate levels than carnivorous species (El-Sayed 2006).

This report focuses on pond-raised Nile tilapia (*Oreochromis niloticus*) from Mainland China. Although there are many different strains of tilapia farmed in China, the predominant species listed in statistics and literature are Nile tilapia, Genetically Improved Farmed Tilapia (GIFT) strains, and Nile tilapia hybrids. The adoption of GIFT tilapia technology has become the most popular method of seed production and produces seed with traits that have been favorable to the growth of Chinese tilapia production, such as growth rate, age at maturation, and temperature tolerance (Qiuming and Yi 2004) (Thodesen et al. 2011, 2013) (Kumar and Engle 2016). Exported species that are cultivated in China are reported by the Food and Agriculture Organization (FAO) to be Nile tilapia GIFT strains and Ao-ni tilapia (*O. niloticus x O. aureus*), at 75% and 25% of total production respectively (FAO 2016). However, there is also some minor production of a hybrid Nile-Mozambique tilapia, called red tilapia (FAO 2018).

Production system

Tilapia species are largely omnivorous and during cultivation they can be fed formulated compound feeds or algae, macrophytes, detritus, and bacteria through pond fertilization (Fitzsimmons and Watanabe 2010). Techniques for seed production are largely dependent on the scale of the farm, where small-scale farmers collect seed from grow-out ponds and larger farms obtain juveniles produced from broodstock in dedicated hatchery facilities (Lai and Yang 2004) (pers. comm., K. Fitzsimmons 2017) (pers. comm., F. Chen 2018). These hatchery facilities can produce seed with a high male percentage, which are either dosed with methyl testosterone (MT) or bred to produce Genetically Male Tilapia (GMT) (Mair et al. 1997) (Lai and Yang 2004) (Kumar and Engle 2016).

There are a variety of cultivation methods for tilapia in China, including intensive monoculture, semi-intensive polyculture, intensive culture in brackish ponds, integrated fish/duck culture, cage culture, and integrated tilapia/rice culture (Beveridge and McAndrew 2000) (Dey 2000) (Gupta and Acosta 2004) (Lai and Yang 2004) (Lucas and Southgate 2012). Despite this large variation in cultivation methods, pond monoculture and polyculture are the most popular methods as either intensive or semi-intensive systems (Hanson et al. 2011).

Intensive monoculture of tilapia in ponds requires addition of manufactured feed to the pond (El-Sayed 2006). Intensive monoculture techniques are mainly practiced in southern coastal provinces (Guangxi, Guangdong, Hainan, Yunnan and Fujian), which produce approximately 95% of Chinese tilapia (Zhang et al. 2015). The size of ponds can range from 0.2 to 0.5 hectares (ha) and stocking density can be between 30,000 and 37,000 fish/ha (Lai and Yang 2004). Fish are given an artificial feed of 28 to 35% crude protein 2 to 3 times daily (Lai and Yang 2004), though more recently the protein content is typically around 28.5% (Weimin and Mengqing 2007) (Chiu et al. 2013). Fingerlings take approximately 6 months to reach commercial size, and yields can be between 12 and 20 metric tons (MT)/ha (Lai and Yang 2004) (Zhang et al. 2015).

Adoption of the polyculture model has been increasing due to rising costs and disease outbreaks associated with monoculture (Zhang and Pang 2017). For example, there is evidence that combinations of tilapia and shrimp (*Litopenaeus vannamei*) are complimentary for environmental disease management, and floating plants have also shown promise in water quality improvement techniques and provide additional income for farmers (Zhang et al. 2015). Polyculture techniques are either extensive or semi-intensive, where the pond is fertilized to produce secondary food such as microalgae (El-Sayed 2006). For polyculture, ponds are typically fertilized with fermented manure, and are dosed in small amounts on a regular basis to maintain healthy microalgae concentrations. Species that are typically co-cultivated with tilapia in ponds include shrimp, common carp, bighead carp, grass carp, and silver carp (Hanson et al. 2011) (Zhang et al. 2015). Semi-intensive polyculture is the dominant method across the remaining provinces in China, which produce the remaining 5% of Chinese tilapia (Liping and Fitzsimmons 2011).

Production Statistics
China continues to be the largest contributor to global aquaculture, accounting for >60% of global production (FAO 2014) (Zhao and Shen 2016). Roughly 30 to 40% of the world's tilapia production originates in China (Figure 1), which grew at an average annual rate of 20% between 1979 and 2010, compared to the global average of 12% per annum (Tveterås et al. 2017) (Zhang et al. 2015).

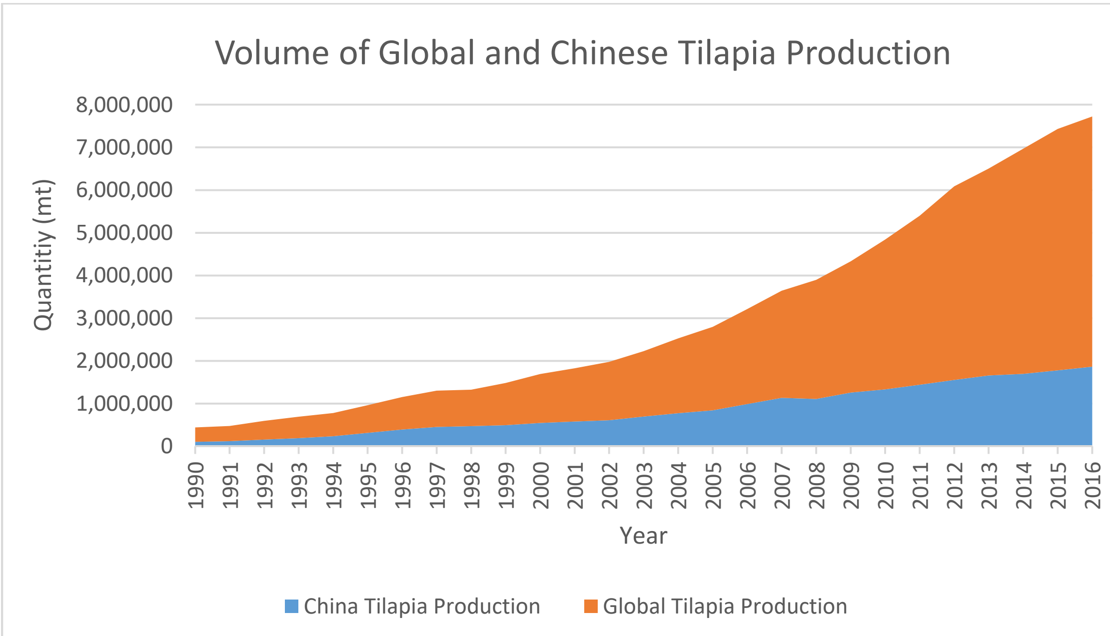


Figure 1. Production quantity of tilapia in China and globally from 1990 to 2016 (FAO 2018).

Although total tilapia production has continued to increase, growth rates have fallen due to a reduction in cost margins (Hanson et al. 2011), disease, and unstable climate conditions (Thodesen et al. 2011). The largest growth in production was recorded between 1985 and 1995 as new strains were introduced, and this increased male tilapia seed production and improved hatchery and grow-out techniques (Zhang et al. 2015). Between 2000 and 2010, tilapia production in China increased from 600,000 MT to 1.3 million MT (SFP 2012), and total Chinese production in 2014 was recorded to be approximately 1.6 million MT (FAO 2018). In 2017, tilapia production in China was estimated to be roughly 1.8 million MT (FAO 2018) and is expected to remain roughly constant for the next several years (Tveterås et al. 2017).

Growth in tilapia production in China was originally driven by a domestic market, but has become increasingly international (Zhang et al. 2015). Although China has dominated global tilapia production since 2006, its overall market share decreased from 42% in 2010 to 38% in 2012 (SFP 2012) (Kumar and Engle 2016). As a result of this reduced growth, China is predicted to drop from the world's leader to the second-largest producer of tilapia by 2030, second only to Southeast Asia, but still the largest producing country (World Bank 2013). The largest proportion of tilapia is produced in Guangdong province in the south, which accounts for 48% of total production in China, followed by Hainan, Guangxi, Yunnan and Fujian provinces (SFP

2012) (Zhang et al. 2015) As aforementioned, these five provinces account for approximately 95% of Chinese tilapia due to their favorable warm climate (Hanson et al. 2011).

Tilapia was first introduced to mainland China from Vietnam in 1957 as Mozambique tilapia (*O. mossambicus*) (Lai and Yang 2004), and several species, including Nile tilapia (*O. niloticus)* and blue tilapia (*O. aureus*), have since been introduced from different places. However, seed production of these species required the use of sex reversal hormones to produce larger proportions of faster growing males, which led to environmental concerns and unpredictable results (Macintosh 2008). A selective breeding program was developed to cross Genetically Male Tilapia (GMT) with females to produce all-male offspring for which growth is faster and more stable (Mair et al. 1997). The Genetically Improved Farmed Tilapia (GIFT) program was subsequently developed by the World Fish Centre, and in the 1990s, a selectively bred synthetic base population with high genetic variability was made available to farmers across Asia (Kumar and Engle 2016). This adoption of technology led to the rapid growth of tilapia production in China (Dey 2000), of which many production fish are now GIFTs of the original Nile species and hybrid crosses with Mozambique and blue species. Although there are a large variety of tilapia species used in Chinese cultivation (see Table 1), the predominant species are recorded by the FAO as Nile tilapia (including a variety of strains) and Ao-ni (*O. aureus*♂ x *O. niloticus*♀) (FAO 2018). Over the past 30 years, both the production and value of both these species has increased and trends are shown in Figures 2 and 3.

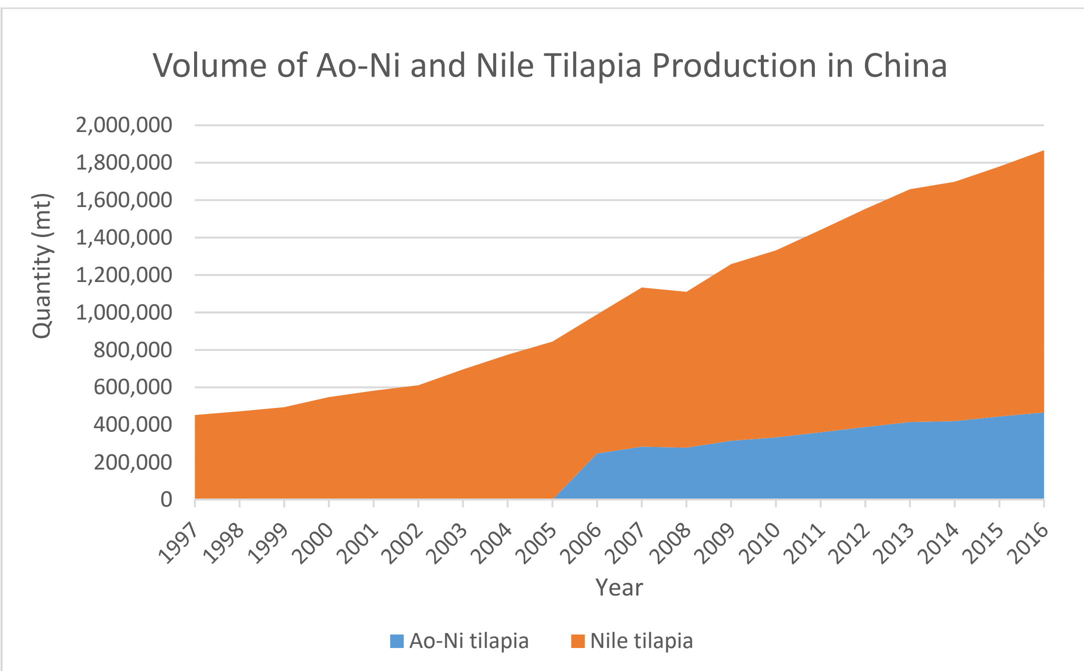


Figure 2. Production quantity of Nile and Ao-ni tilapia in China from 1997 to 2016 (FAO 2018).

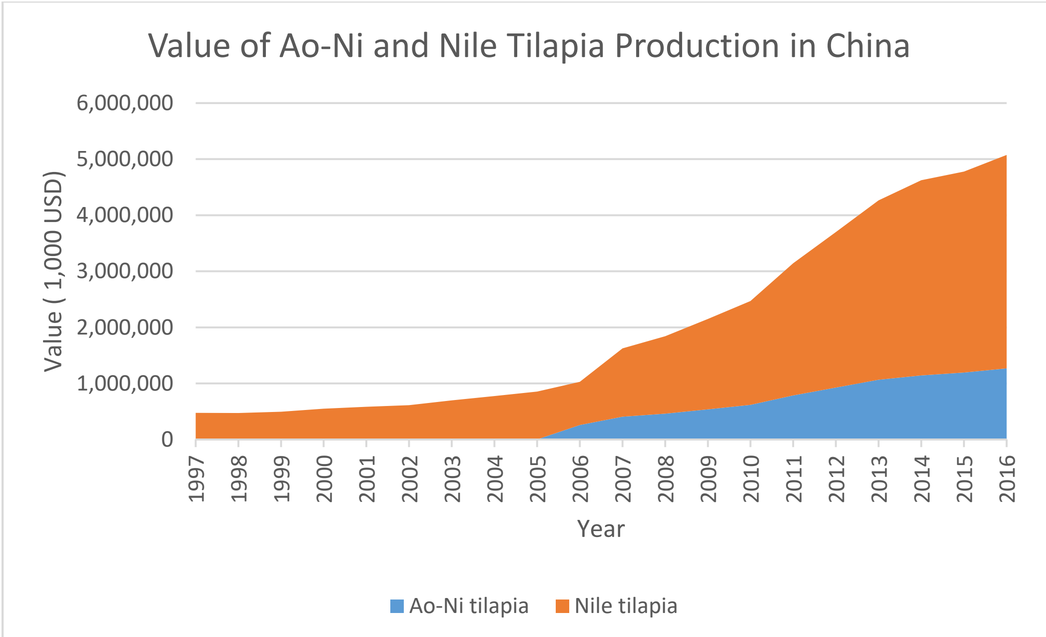


Figure 3. Production value of Nile and Ao-ni tilapia in China from 1997 to 2015 (FAO 2018).

Table 1. The major strains and species of tilapia cultured in China (Zhao 2011a).

Common name	Species/strain/variety
GIFT	Selected from a mixed population of 4 native and 4 domesticated of *O. niloticus*
NEW GIFT	Selected from GIFT strain of *O. niloticus*
Genomar GIFT	*O. niloticus*
Baolu GIFT	*O. niloticus*
Ao-ni	*O. niloticus* × *O. aureus*
GILI	*O. niloticus* × *S. melanotheron* F2
Red tilapia	*O. niloticus* × *O. mossambicus* variety
Mohe	*O. mossambicus* × *O. u. hornorum*

Popularity for GIFT Nile tilapia species is driven by their characteristic high growth rate (Thodesen et al. 2011); blue tilapia hybrids have been favored for their ability to produce a high percentage of male seedlings, and red tilapia for their tolerance of higher salinity (Zhao 2011a). Red strains of Nile tilapia were first produced in Taiwan and demand for this hybrid grew due to its desirable color and high salinity tolerance (Thodesen et al. 2011) (Zhao 2011a) (Zhang et al. 2015).

Import and Export Sources and Statistics

China has dominated global tilapia production since 2006 and is a major exporter to North America and the European Union (EU). Based on the most recent export data from China, approximately 26% (411,022 MT) of the 2014 tilapia production (1.55 million MT) was exported in that same year (China Customs in SFP 2014). Tilapia made up 8.2% of total exported Chinese aquaculture products in 2008 (NBSO 2010). The largest proportion of Chinese tilapia exported is destined for US markets (Zhang et al. 2015). Cost analysis has shown that the volume of national competition in tilapia production in China makes Chinese tilapia cheaper than its largest competitors (Zhang et al. 2015).

Total tilapia imports into the US were 182,000 MT in 2017, with China supplying roughly 73% (133,728 MT) of this; primarily as frozen fillets (NOAA 2018). Per capita consumption (edible weight) of tilapia in the US was 1.436 lb (0.65 kg) in 2014 (SFP 2012) and is the fourth-most popular fish to be consumed in the US (Liping and Fitzsimmons 2011). Though China is a major source for tilapia in the US, since 2015, there has been a drop in both imported tilapia volume and value from China by 33% and 54% respectively (Figure 4). As yet, there are no data to explain such a drop in imports or value, but statistical predictions have forecasted a stagnation in Chinese tilapia production (World Bank 2013); Hanson et. al. (2011) had suggested that Chinese tilapia production was unlikely to grow further as a result of low economic returns which limit incentive for further expansion of farming and processing. Based on the import information through 2017, this trend appears to be continuing (Fig. 4 and 5).

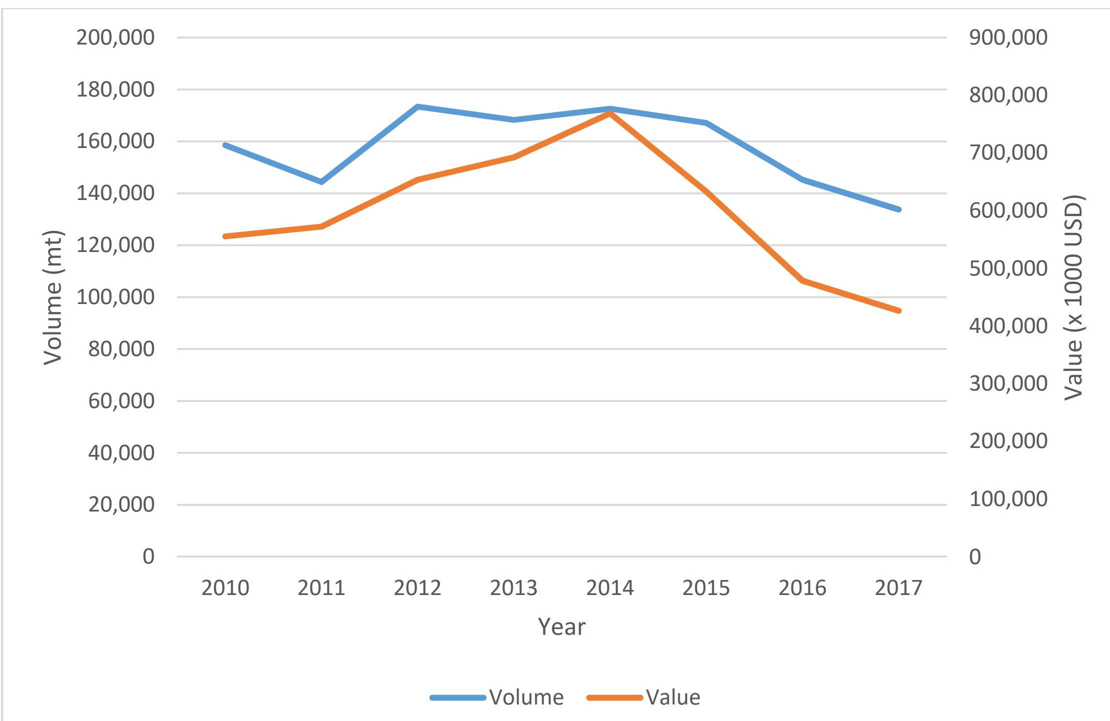


Figure 4. Volume and value of tilapia imported from China to the US (NOAA 2018).

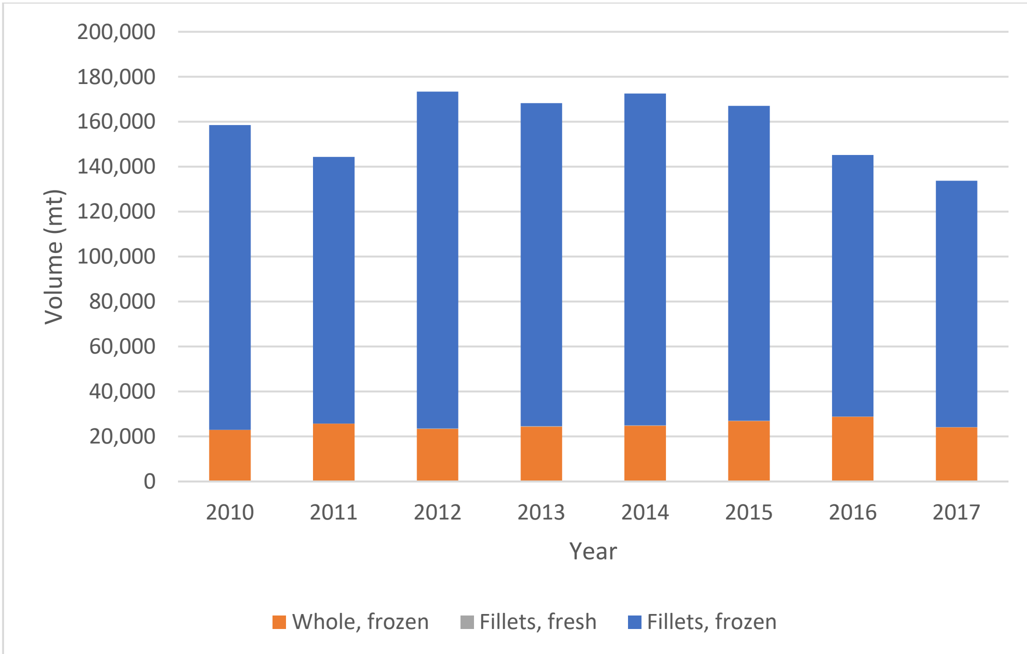


Figure 5. Tilapia products imported to US from China (USDA 2018).

Common and Market Names

Scientific Name	*Oreochromis spp.*
Common Name	Tilapia
United States Market Name	Tilapia
Chinese Traditional	罗非鱼
Chinese Simplified (Mandarin Pinyin)	Luó fēi yú

Product forms

Frozen whole or fillets, but exports are dominated by frozen fillets (See Figure 5).

Analysis

Scoring guide

- With the exception of the exceptional criteria (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rating. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the three exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Standard that the following scores relate to are available on the Seafood Watch website. http://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/mba_seafoodwatch_aquaculture%20criteria_finaldraft_tomsg.pdf?la=en

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.
- Sustainability unit: the ability to make a robust sustainability assessment
- Principle: having robust and up-to-date information on production practices and their impacts publically available.

Criterion 1 Summary

Data Category	Data Quality	Score (0-10)
Industry or production statistics	2.5	2.5
Management	2.5	2.5
Effluent	2.5	2.5
Habitat	2.5	2.5
Chemical use	2.5	2.5
Feed	5	5
Escapes	2.5	2.5
Disease	2.5	2.5
Source of stock	10	10
Predators and wildlife	2.5	2.5
Introduced species	5	5
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		**40**

C1 Data Final Score (0-10)	**3.6**	**YELLOW**

Brief Summary

The China Aquatic Products Processing and Marketing Association (CAPPMA) compiles statistics and other information on the industry. This information is available in English and should be available to the public; however, due to website technical difficulties and despite multiple requests to several members within the organization, this information is not currently accessible. Information provided by government bodies is fragmented, disparate, and often unavailable. The majority of information used in this assessment is compiled from peer-reviewed scientific literature and grey literature, where smaller specific studies are often used to describe the average situation in Chinese tilapia cultivation, and they are often outdated. The majority of regulatory information is in Chinese, making it difficult for consumers and businesses importing tilapia products from China to the Unites States to understand environmental implications of production. The final score for Criterion 1 – Data Quality and Availability is 3.6 out of 10.

Justification of Rating

Production. National production statistics are available in FAO documents and statistics, which includes production volume and value of two main tilapia species. However, literature reports much more diversity in species produced. The China Aquatic Products Processing and Marketing Association (CAPPMA) compiles statistics and other information on the industry. This information is available in English and should be available to the public, yet due to consistent website technical difficulties and despite multiple requests to several members within the organization, this information is not currently accessible. Some scientific reports include statistics on the main producing regions and the percentages of each province in contributing to national production, but there is little specific information on the types of farms in provinces, their methods of production, or specific locations. As specific information regarding the production methods and cultivated species are outdated and often inconsistent with each other, the quality and confidence of production data were regarded as low to moderate and scored 2.5 out of 10.

Management. English translations of larger national regulations are available, such as The Fisheries Law (2004), which includes regulation of aquaculture and the use of the aquatic and terrestrial environment. However, details of such legislation often only include the general objectives of the regulation and not specific limits. Specific limits are set by provincial and sometimes regional government bodies, and there is no centralized location for finding specific limits, enforcement measures, or repercussions for farms that are not in compliance with regulations. For example, it is clear that effluent management is regulated by local environmental authorities, but because monitoring is often absent, or data is withheld from the public domain, there are little or no data to demonstrate efficacy or implementation of regulations aimed at reducing discharge. In addition, there is a lack of area-based or cumulative impact measure included in aquaculture regulations. Often the overall aim of regulations is to facilitate the economic growth of aquaculture and not to limit the environmental impact. Although one provincial government (Zhejiang) has created its own local standard, setting their own regulations and standards, reports from this example are fragmented regarding enforcement measures (e.g., farm closures and effluent bans). Due to the lack of information from provincial governments regarding regional regulation and enforcement of the environmental aspects considered in the Seafood Watch assessment, the quality and confidence of management data is low. Therefore, the data score for this category is 2.5 out of 10.

Effluent. Little or no data or information is available to understand the effluent-related impacts of Chinese tilapia production on the waterbodies in which the industry is sited. As such, the Risk-Based Assessment method was used. To estimate the nitrogenous waste discharge, feed-related data could be averaged from values presented in the literature, but reported pond exchange rates are vague and inconsistent. Although literature, government websites, and personal communications allowed limited understanding of the structure and content of effluent management, no monitoring records are available for effluent discharge from tilapia production nationally or regionally. Due to the incomplete and inconsistent information available, the data are considered low to moderate, and scored 2.5 out of 10.

Habitat. Updates in national regulations have included improved licensing figures for farm sites. However, literature still reports that a proportion of farms remain unlicensed. Information on the conversion of land to freshwater pond cultivation, and subsequent impact largely occurs in the literature and refers to "fish ponds" of all species and methods collectively. A small number of studies have assessed the impact of wetland conversion to agriculture and aquaculture on water birds, though these studies are area specific and do not focus specifically on tilapia aquaculture. Despite an EIA requirement for construction of new and expansion sites in various laws, the content and implementation of the recently updated laws governing EIAs is not always clear. No information indicates that there is a process for comprehensive risk assessment of a site before it is licensed. Enforcement of these regulations is divided up among many government departments, and as a result, there is fragmented information on punitive measures or any documented actions against farms that do not comply. Thus, there is a gap in data regarding enforcement and compliance for habitat-related environmental laws. The combination of gaps in data and scientific literature, and unverifiable information on the efficacy of enforcement of habitat protection regulations results in low to moderate data quality and confidence, and a score of 2.5 out of 10.

Chemical Use. Although several regulations are aimed at preventing chemical residues from exceeding food safety standards in China, regulatory oversight of actual on-farm chemical use appears weak. Evidence demonstrates the use of a wide variety of chemicals in Asian aquaculture generally, but data on the amount of antibiotics and other chemicals used in Chinese tilapia production were not available. US FDA import refusals provide evidence that banned chemicals and antimicrobials considered "Highly Important for Human Medicine" by the World Health Organization (WHO) are being used. Several recent publications outline China's recognition of the overuse of antimicrobials and the central government has publicized a plan that is only starting to be implemented. Evidence for antibiotic resistance in the surrounding environment is provided by several recent journal articles investigating the more common bacterial strains affecting tilapia and their prevalence in the primary tilapia farming regions. As information on specific chemical use or its ecological impacts is unavailable from the Chinese tilapia industry, the information regarding chemical use is regarded as low to moderate. The data score is 2.5 out of 10.

Feed. Due to the significant consumption of feed in Chinese aquaculture, a number of large literature reviews include the average eFCR and inclusion rates of fishmeal and fish oil, including, in some cases, the percentage of that which is domestically produced from by-products. However, information describing the inclusion of crop ingredients and land animal products is limited and percentages vary greatly. The sustainability of marine ingredients is included in a detailed scientific study, largely in the supplementary information where the stock statuses of individual fisheries contributing to Chinese fishmeal production are assessed. As a result, data on the feed content for Chinese tilapia provide useful information to make the calculations required for the Seafood Watch Assessment, but may not fully represent the Chinese tilapia industry where there are still some gaps (i.e., crop and land animal ingredient content of feeds). Data quality and content is considered moderate and scores 5 out of 10.

Escapes. There are no national or regional datasets available for the numbers, size, or survival of escaped farmed tilapia from pond systems in China. However, as tilapia have become well-established in the wild, the impacts of their establishment have been reported in scientific literature. Tilapia are considered to be established in much of the tilapia cultivating regions of China, and the impact this has on local fish populations is examined in scientific literature in production areas. Without data on the number of escapes or evidence of best management practices for escape mitigation, the data quality and content are considered low to moderate, and scored 2.5 out of 10.

Disease. Data availability on diseases is largely found in the form of published, peer-reviewed studies. There are reported mass mortality events in Chinese tilapia pond cultivation systems, which are only reported in scientific literature. Despite this, there is little information on the enforcement of disease control regulations. Regulations on the control of disease in Chinese aquaculture are available, as are some details from enforcement reports. Regulations and enforcement reports are written in Chinese and it is difficult to assess the specifics of enforcement, especially as they relate to notifiable diseases. A 2017 study investigating the potential for the spread of Tilapia Lake Virus (TiLV) from a Thai hatchery identified China as a recipient of at-risk juveniles or eggs; however, there are no accessible data from within the Chinese tilapia industry to indicate that there was any import of eggs or juveniles from Thailand. Data quality and content for this criteria are considered low to moderate due to discrepancies in reports and the absence of current on-farm disease incidence information or research investigating the impact of on-farm disease on the ecosystems in which farms are sited. The data score is 2.5 out of 10.

Source of Stock. Recent literature has estimated that there are >200 hatcheries/nurseries nationwide. Since the development of GIFT strains, the source of seed is largely reported in scientific literature to be from domestic seed banks. A broad overview of the national breeding program was outlined in a 2018 publication and, though not accessible for this assessment, it appears that data on the number of tilapia seed produced is available in the annual China Fishery Statistical Yearbook (available for sale). There is enough information to determine that production is not reliant on the capture of wild fish. As such, confidence in the hatchery origin of farm stock is high, and the data score for Source of Stock is 10 out of 10.

Predator and Wildlife Mortalities. Pond cultivation of tilapia is considered to attract a variety of predators including reptiles, birds, and small mammals. However, data on mortalities that occur as a result of this interaction in China are not available. There is a lack of research on wildlife interactions with tilapia ponds in China, and current literature suggests the potential for migratory water birds to interact with ponds and utilize them for foraging and resting during a migration route. Several Chinese regulations do include environmental protection laws that contain information on protections for rare and endangered animals; however, these laws do not specifically apply to aquaculture. There is also an associated list of species considered rare and endangered by the Chinese government. As Criterion 9X – Predator and Wildlife Mortalities was assessed on limited information, none of which is specific to aquaculture, the data quality and content is considered low to moderate and scored 2.5 out of 10.

Escape of Secondary Species. Scientific literature reports that there have been international and trans-waterbody movements for seed production in the past, primarily from hatcheries in Vietnam and Taiwan. However, information is not sufficient to determine the current percentage of trans-waterbody or international movements for the average tilapia farm in China, although there is evidence of well-developed industrialized domestic seed production systems providing regional support for the Chinese tilapia industry. Even within the domestic seed production, however, information is limited on biosecurity at both the typical hatchery and growout locations. The biosecurity of each is estimated based on information outlining the typical production systems (tanks for hatcheries and ponds for growout) and their typical exchange rates. Due to these uncertainties, the data quality and content for Criterion 10X – Escape of Secondary Species is considered moderate, and scores 5 out of 10.

Conclusions and Final Score

Data availability is generally very low in China, with little comprehensive information on the environmental considerations in this Seafood Watch Assessment. Information is largely pooled from a growing source of peer-reviewed literature as a result of China's growing significance in the growth of global aquaculture. However, this information is often very specific to the farms that were included in the scientific study and therefore much of the information is used as a proxy for national production in China. Understanding regulations and their enforcement is made particularly difficult by the fragmented and inconsistent framework for provincial governments and governing bodies. This, in conjunction with a lack of evidence for enforcement, limits the ability to perform a robust assessment. Therefore, the final numerical score for Criterion 1 – Data is 3.6 out of 10.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.
- Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Effluent Risk-Based Assessment

Effluent parameters	Value	Score
F2.1a Waste (nitrogen) production per of fish (kg N ton-1)	41.44	
F2.1b Waste discharged from farm (%)	34	
F2.1 Waste discharge score (0-10)		8
F2.2a Content of regulations (0-5)	2	
F2.2b Enforcement of regulations (0-5)	1	
F2.2 Regulatory or management effectiveness score (0-10)		0.8
C2 Effluent Final Score (0-10)		5.00
Critical?	NO	**YELLOW**

Brief Summary

With minimal data on the ecological impact of effluent that is released specifically by tilapia pond-based farms in China, the Risk-Based Assessment is used to estimate the discharge of nitrogen into receiving ecosystems and the regulations and management that govern it. Average values are calculated using limited data on the use of feeds (28.5% protein and eFCR of 1.4) and water management methods (discharge only at harvest), which result in an estimated 14.09 kg of nitrogen per ton of tilapia production leaving production sites as effluent waste. This is based on intensive pond culture methods using only feed inputs, as this is the primary production method for tilapia in China. The legal framework addressing effluent management of aquaculture in China is regionally fragmented and lacking in set standard limits. Despite recent changes to the primary environmental laws, the content and enforcement of regulations lacks evidenced repercussions and monitoring data, resulting in difficulty assessing efficacy of the system. Ultimately, farms discharge a low amount of nitrogen waste per ton of production, but there is weak regulatory legislation and implementation. The combined scores for Factors 2.1 (8 out of 10) and 2.2. (0.8 out of 10) result in a final score of 5 out of 10 for Criterion 2 – Effluent.

Justification of Rating

As effluent data quality and availability is low (Criterion 1 score of 2.5 out of 10 for the Effluent category), the Seafood Watch Risk-Based Assessment was utilized. This method involves assessing the amount of waste produced by the fish and then the amount of that waste that is discharged from the farm. The effectiveness of the regulatory system in managing wastes from multiple farms is used to assess the potential cumulative impacts from the industry as a whole.

Factor 2.1 Waste discharged per ton of fish production

Factor 2.1a – Biological waste production per ton of fish

The protein content of feeds is low in comparison to other fed finfish species and is estimated to be 28.5% (Weimin and Mengqing 2007) (Chiu et al. 2013). A review by Chiu et al. (2013) of feeds and FCRs from intensive tilapia farms in Hainan (a region producing a large proportion of tilapia in China) found an average FCR was between 1.4 and 1.6. Additionally, Cao et al. (2015a) found an average economic FCR (eFCR) of 1.6 for intensive monoculture throughout China (Cao et al. 2015a). In 2018, a detailed review of the current status of numerous aspects of Chinese tilapia aquaculture indicated the range of typical eFCR to be between 1.2 and 1.5 (Xu and Ming 2018). Given the range of possible values, and the most recent range being 1.2 to 1.5, a value of 1.4 is used for all calculations in this report.

Descriptions of regimes for application of fertilizers in ponds in China is greatly varied and lacking in actual reported values. However, there are indications that the use of fertilizers in intensive monoculture for tilapia in China is likely minimal and restricted to early life stages (pers. comm., K. Fitzsimmons 2017). Therefore, nitrogen from fertilizers is not included in the calculation of nitrogen waste discharged from the farm for this report.

The protein content of whole harvested tilapia is, on average, 14% (Boyd et al. 2007) (Koch et al. 2016), and the nitrogen content of protein is 16% (using the Kjeldahl (1883) nitrogen conversion factor). Together with an eFCR of 1.4, these figures are used to calculate the removal of nitrogen (N) (incorporated in fish biomass) from the pond during harvest. Overall, this equates to an estimated total of 41.44 kg N t^{-1} of nitrogenous waste produced per ton of fish.

Factor 2.1b – Production system discharge

Pond systems in China fully drain the ponds at the end of the cycle for harvesting tilapia, (El-Sayed 2006) (FAO 2006). The water from drained ponds could potentially be redistributed to other ponds (Lin and Yi 2003); however it is unclear if this has become a widespread common practice in China. In the various pond-draining experiments, Lin and Yi indicated that liming and slowly draining (especially when draining to other not-yet-harvested ponds) was the most effective method in reducing effluent impacts for ponds. These experiments were performed in Thailand but were intended to apply across Asia. Liu et al. (2018) offer an overview on production practices for several major species cultured in China, including tilapia, and indicate that the ponds are typically emptied for harvest between November and December. The practice of draining ponds only once per cycle, if at all, is also confirmed specifically in Guangxi province (Kaiser et al. 2013) and in general via personal communication with an industry expert (pers. comm., K. Fitzsimmons 2017).

Since it is considered that tilapia ponds are drained once per cycle, at harvest, the resultant score for factor 2.1b – Production system discharge is 0.34 out of 1.0, meaning that 34% of the waste produced by the fish is discharged from the farm.

The final score for Factor 2.1 uses the combined values from Factors 2.1a and 2.1b, which equate to an estimated 14.09 kg N per ton of produced tilapia released in effluent. This results in a Factor 2.1 score of 8 out of 10.

Factor 2.2 Management of farm-level and cumulative impacts

<u>Factor 2.2a: Content of effluent management measures</u>
Various national laws address effluent and water quality management in aquaculture in China; these are listed in Table 2. Regulations are set on a national scale and enforced regionally through a central environmental inspectorate system (*China Fishery News* 2017), since water resources are considered federal property (Zhu and Dong 2013) (Xia 2014). The most basic of these regulations includes The Fisheries Law (2004) (Ministry of Agriculture 2013, 2014), which addresses the legal framework for both wild capture fisheries and aquaculture. Additionally, The Water Law (2002) is administered by the Ministry of Ecology and Environment and regulates the development, utilization, allocation, and management of water resources (2016).

The Environmental Protection Law (1989) gives provisions on EIA requirements, and according to this law, appropriate government departments at or above the county level make investigations and assessments of the environment within their jurisdiction. This law was most recently updated in 2014, at which point it was reportedly strengthened, though implementation still appears to be difficult (Chang 2014). The Environmental Protection Law has a broad application and does include aquaculture, specifically, within the scope of its enforcement. Under this law, EIAs of new and expansion construction projects must assess the risk of potential impacts (including nutrient pollution) and describe preventative measures. The Law on the Prevention and Control of Water Pollution (1984) is also applicable to pond aquaculture. This law states that the EIA for aquaculture development should contain a risk assessment on the likely pollution hazards, their impact, and preventative measures (Ministry of Ecology and Environment 2017). The most recent version of this law requires EIAs from all farms constructed or expanded after 2003. The Law for Prevention and Control of Water Pollution (1984) refers to the content of an EIA and outlines its three main levels: EIA registration (self-reporting), brief EIA (a form completed by a third party), and comprehensive EIA (full report) (Environmental Protection Agency of Guangdong Province 2016) (pers. comm., S. Wang, F. Chen, Q. Fang 2018). Aquaculture operations are not required to conduct the comprehensive EIA; however, they are required to have either the EIA registration (self-reporting), brief EIA (a form completed by a third party). The Provincial Environmental Protection Agency will determine which EIA is appropriate for the site, based on whether the farm is located in or near ecologically sensitive areas (e.g., nature reserves, scenic areas, drinking water sources) or not. Most freshwater aquaculture operations require only the EIA registration (self-reporting) option (pers. comm., S. Wang, F. Chen, Q. Fang 2018).

The rules for implementation of the Law for Prevention and Control of Water Pollution (2000) require a pollution discharge report to be written; once the local environmental protection agency has received this report, a pollution discharge license is approved. Licenses must be renewed every three years by applying with a new discharge report to the local environmental protection agency (pers. comm., S. Wang, F. Chen, Q. Fang 2018).

Besides such national regulations, wastewater discharge is regulated and enforced by local governments. Provinces, autonomous regions, and municipalities may establish their own local standards for items that are not specified in national standards (NALO 2012).

Table 2. Laws and Regulations relative to aquaculture effluent management in China. (Adapted from: Hanson et al. (2011), Zou and Huang (2015), and NALO (2004.)

General areas	***Specific regulations***
Basic legislation	The Fisheries Law (1986, amended in 2000, 2004, 2013, 2015)
	Regulation for the Implementation of the Fisheries Law (1987, amended in 2000, 2004, 2009, 2013)
Accessibility legislation	The Water Law (1988, as amended in 2002, 2009, 2016)
	The Sea Area Use Management Law (2002)
Environment Impact Assessment	The Environmental Protection Law (1989, amended in 2014)
	The Law on the Prevention and Control of Water Pollution (1984, amended in 1996, 2008, 2017 to take effect in 2018)
	The Marine Environment Protection Law (1982, amended in 1999, 2013, 2016)
	The Environmental Impact Assessment law (2002, amended in 2017)
Water and wastewater	The rules for implementation of the Law on the Prevention and Control of Water Pollution (2000)
	Regulations on the Prevention of Pollution Damage to the Marine Environment by Land-sourced Pollutants (1990)
	Water Quality Standards for Fisheries (1989)

	Production Area Environment Condition of Freshwater Aquaculture for "Pollution-Free" Aquaculture Food (NY 5361-2010)
	Production Area Environment Condition of Seawater Aquaculture for "Pollution-Free" Aquaculture Food (NY 5362-2010)
National Agriculture Specialized Standards	Water Discharge Criteria for Freshwater Farmed Ponds (SC/T9101-2007)
	Water Discharge Criteria for Seawater Aquaculture (SC/T 9103-2007)

In addition to national and local laws, China publishes Five-Year Fishery Development plans, which include plans for aquaculture, and a recent review of the 12th Five Year Plan (2011–2015), has indicated that:

> *In general the exploration and exploitation of resources exceeds the capacity of the ecological systems and the environment. The protection of water-related resources has given way to economic development in a specific time and area because of the versatility of water. The extensive use of water in hydropower, shipping and aquaculture leads to irreparable adverse effects on the environment and its ecology* (Zhao and Shen 2016).

An updated version of this plan was launched in March 2016 (the 13th Five Year Plan 2016–2020), and despite indications that there will be an introduction of management measures for aquaculture with improved accountability (Cao et al. 2017), the details are not publicly available.

There is a lack of information demonstrating the existence of site-level or site-specific effluent limits across the entire aquaculture industry, and although regulations have been amended to include issues related to sustainability, regulations remain largely guidelines and are not demonstrably based on ecological principles. Additionally, there is little ongoing management of effluent from farms. Therefore, the content of effluent management is considered limited and the score for Factor 2.2a is 2 out of 5.

<u>Factor 2.2b: Enforcement of effluent management measures</u>
Enforcement of regulations is coordinated by the Fisheries Law Enforcement command of China, who are led by the Bureau of Fisheries under the guidance of the Ministry of Agriculture. In 2013, a reported 2,949 law enforcement agencies across provinces existed, with over 35,139 staff (Zou and Huang 2015). As the laws and regulations related to aquaculture are largely guidelines that lack defined limits, legal repercussions have been described as difficult to impose and focus largely on economic growth of the sector (Cao et al. 2007) (Zou and Huang 2015). Although local environmental authorities should control effluents by unscheduled inspections, effective monitoring is absent. Therefore, most companies have not taken significant measures to reduce waste discharge (Chen et al. 2011). Additionally, criticism of

several environmental regulations indicates that they lack effective punitive and enforcement measures (e.g., fees for exceeding limits) (Zhu and Dong 2013) (Chang 2014) (Xia 2014).

With the most recent update (2017) to the Law on the Prevention and Control of Water Pollution, there are stricter repercussions for farms that do not have an EIA (pers. comm., S. Wang, F. Chen, Q. Fang 2018); however, the enforcement of these repercussions remains to be seen as the law has come into effect. There have been reports of higher government enforcement on environmental laws relating to aquaculture effluents throughout China (*China Fishery News Network* 2017) (*Agricultural Products Futures Network* 2016). In particular, the central government has announced and begun to implement a campaign to enforce environmental regulations, specifically for aquaculture sites since January of 2018 (Godfrey 2018a, 2018b).

In 2016, the Chinese Ministry of Agriculture released the 13th Five-year (2016–2020) Plan, which has placed importance on greening economic development, and emphasis on improving law enforcement (Wang et al. 2015). Despite this, well-defined and evidenced enforcement measures are not publicly reported, which prevents assessment of the effectiveness of law enforcement. Enforcement agencies appear regionally fragmented and there is little evidence of monitoring or compliance data; overall, the effectiveness of effluent management is considered minimal. The increased enforcement specifically for aquaculture effluents is a recent development, since historically the enforcement for these laws has been low. Therefore, the score for Factor 2.2b is 1 out of 5.

Conclusions and Final Score

With minimal data on the ecological impact of effluent that is released specifically by tilapia pond-based farms in China, the Risk-Based Assessment was used to estimate the discharge of nitrogen into receiving ecosystems and the regulations and management that govern it. Feed and feeding characteristics and water management strategies result in an estimated 14.09 kg of nitrogen discharged per ton of production; this results in an overall score of 8 out of 10 for waste discharge in Factor 2.1. The legal framework addressing effluent management of aquaculture in China is regionally fragmented and lacking in set standard limits. Despite recent changes to the primary environmental laws, the content and enforcement of regulations lacks evidenced repercussions and monitoring data, resulting in difficulty assessing efficiency of the system, and an overall score of 0.8 out of 10 was given to the management of cumulative effluent impacts in Factor 2.2. The combined scores result in a final score of 5 out of 10 for Criterion 2 – Effluent.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.
- Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.
- Principle: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		4
F3.2a Content of habitat regulations	2	
F3.2b Enforcement of habitat regulations	1	
F3.2 Regulatory or management effectiveness score		0.8
C3 Habitat Final Score (0-10)		**2.93**
Critical?	NO	**RED**

Brief Summary

A large proportion of farms have been converted from agricultural land to aquaculture ponds. Many of these ponds initially became shrimp ponds until the early 1990s, but they were abandoned due to problems with disease and eutrophication of the receiving waters and later became repurposed for tilapia culture. Most information suggests that, due to development of various types, there has been historic loss (>15 years ago) of high-value habitat (i.e., freshwater and wetlands) in China. Though some conversion has been secondary (i.e., from virgin habitat to agriculture to aquaculture), and some specifically for aquaculture has been, anecdotally, for species other than tilapia (e.g., primarily carp or shrimp), there is ultimately a lack of information regarding the tilapia industry's contribution to overall habitat conversion or degradation. Thus, given tilapia's prominence among China's fish aquaculture production, it is a reasonable, precautionary conclusion that tilapia farming has resulted in some loss of ecosystem services in China. The score for Factor 3.1 is 4 out of 10. Current siting regulations and permitting requirements are spread among many levels of government, are vague and not often specific to aquaculture. Environmental impact assessments and habitat connectivity are incorporated into the regulations, though consideration for habitat connectivity is only applicable to new construction after 2017. Enforcement is divided among many government departments and lacks clear punitive measures or documented action against farms that do not comply, resulting in an overall score of 1 out of 10 for Factor 3.2. Because there is evidence of wetland habitat functionality loss in the last 15 years, and enforcement measures are unclear and likely minimal, Factors 3.1 and 3.2 combine to give a final Criterion 3 – Habitat score of 2.93 out of 10.

Justification of Rating

Factor 3.1. Habitat conversion and function

A large percentage of agricultural lands were converted from paddy fields to aquaculture ponds in China in the 1980s and 1990s as aquaculture became more profitable than agriculture (Li and Yeh 2004). Many of these ponds that were originally converted from paddy fields initially became shrimp ponds until the early 1990s. Many were then abandoned due to problems with disease and eutrophication of the receiving waters and later became repurposed for tilapia culture (Qiming and Yi 2004). Aquaculture has now become an integral component of economic growth, heavily promoted by government schemes such as "Green growth" (Zou and Huang 2015).

Much of this conversion can be attributed to secondary conversion to shrimp or carp ponds from agricultural land; however, it is unclear what the actual proportions of conversion to shrimp/carp vs. tilapia ponds occurred (pers. comm., K. Fitzsimmons 2017). In the Pearl River Delta, the largest proportion of land conversion between 1993 and 1997 was from cropland to "fish ponds" though the study does not indicate the species being cultured in said ponds (Li and Yeh 2004). Though this is considered secondary conversion, there is evidence that ponds can still be used by shorebirds for foraging and resting throughout the year or during migrations (Choi et al. 2013). More information regarding the types of birds found utilizing Chinese aquaculture ponds for habitat can be found in Criterion 9X – Wildlife and Predator Interactions.

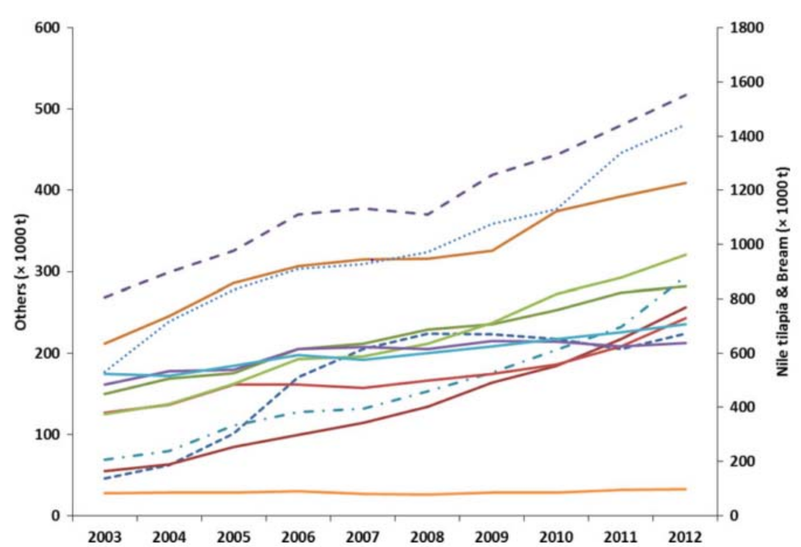
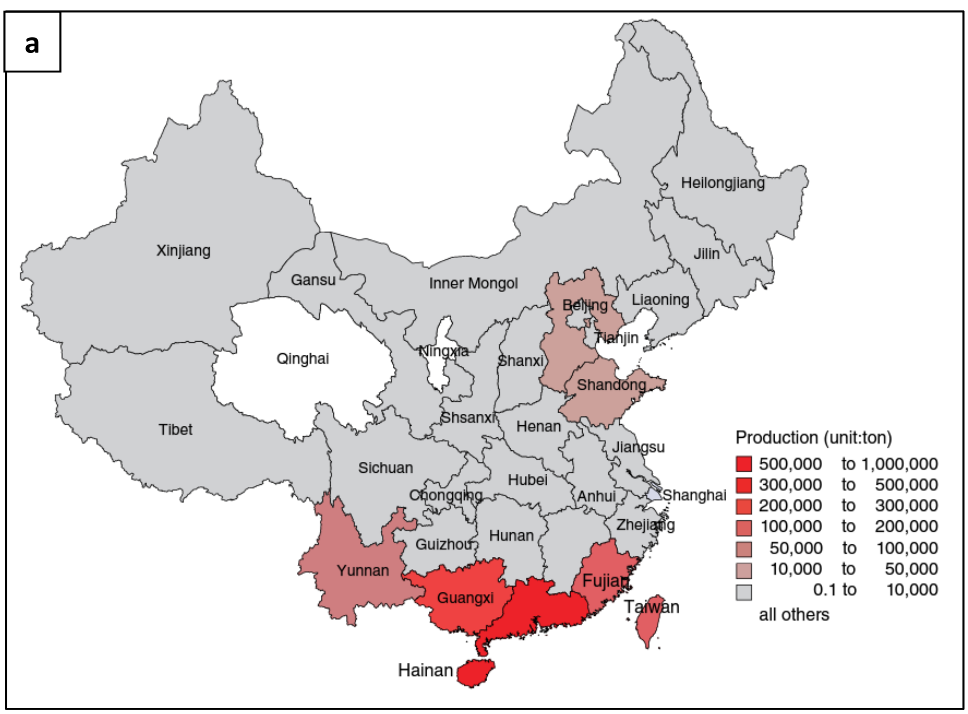


Figure 6 Production trends of major species/species groups contributing (over 25 000 t in any year) to freshwater aquaculture production in China. (----) Channel catfish, (—) Yellow catfish, (—) Mandarin fish, (–·–) Loach, (—) Catfish, (······) Snakehead, (—) Bass, (—) Paddy eel, (—) Eel, (– –) Nile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

Figure 6. Production of freshwater fish in China (Wang et al. 2014).

As a result of rapid growth in the freshwater production of fish in China, high-value wetland areas have also been directly converted to fish ponds to allow for continued growth in the sector. Although Jiangsu province is not identified as a major tilapia-producing region, an existing study regarding the habitat effects of pond production in the province can be used as a proxy for understanding the general effects of aquaculture activities within China in the last 30 years. In this study, it became apparent that wetland fragmentation has been documented in the Yangcheng National Nature Reserve (YNNR), where from 1988 to 2006 the area of reserve utilized for pond aquaculture increased seven-fold, and had the highest rate of increase for any land types in the area (Ke et al. 2011). Deterioration of wetland habitats in the reserve had measurable consequences for wetland birds; however, a recent report has indicated that the Suzhou government has developed a schedule to heavily decrease the scale of aquaculture in the YNNR, affecting 96% of current farmer contracts. The government closed 39 farms between 2013 and 2015, and reports "improved" water quality in more than 200 rivers as a result (Jiangsu Guangdianron Media News Center 2016), though no further detail on that improvement is given in the article. This province is not a major tilapia-producing area, but some evidence of action to manage pond aquaculture and natural areas in recent years indicates a shift toward conservation management at the provincial level in China.

Areas that are producing the largest proportion of tilapia in China include Guangxi, Guangdong, Hainan, and Fujian provinces. Although much tilapia cultivation occurs inland, (Ross et al. 2013), some of the most productive provinces also consist of high-value mangrove habitats (Figure 7). In particular, Guangxi, Guangdong, and Hainan produced more than 500,000 MT of tilapia each in 2014 (Xu and Ming 2018) and are all provinces with reserved mangrove habitats as well as UNESCO Ramsar-recognized wetland sites. Fujian province also produced over 500,000 MT of tilapia in 2014 and though it contains mangroves, they are less densely distributed than in Guangxi, Guangdong, and Hainan (Xu and Ming 2018) (Chen et al. 2009).



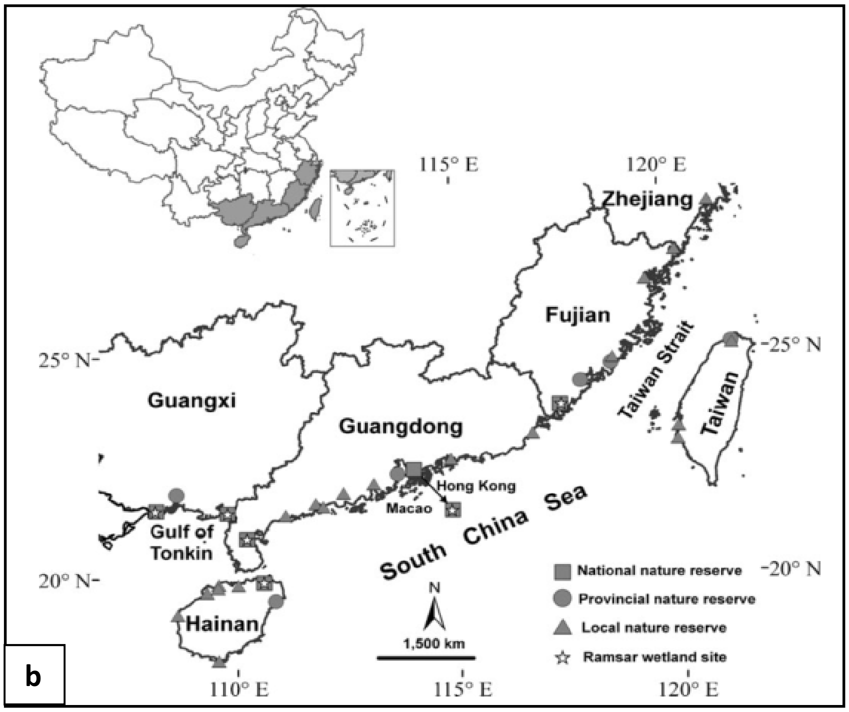


Figure 7. ***a)*** Distribution and intensity of tilapia production in China (from Zhang et. al. 2015); ***b)*** Distribution of mangrove habitats in China (from Jia et. al 2014).

In China, during the 1980s and 1990s, large amounts of mangrove forest were logged for shrimp/fish pond cultivation; for example, 98% of mangroves in Guangdong were converted primarily for shrimp aquaculture (Jia et al. 2014), resulting in the loss of habitat functionality (Che et al. 2009) (Jia et al. 2016) (Zhu and Dong 2013). Despite this, many Chinese mangrove habitats have gradually been getting more research attention (Zhang 2017), and although they were once largely destroyed prior to, and partially during, the 1990s (Lv CX 1998) (Lv J 2013) (Chen 2005) (Lin and Liu 2003), their continued destruction has since been curbed (Chen et al. 2009) (Mao 2011).

Most information suggests that, due to development of various types, there has been historic loss (>15 years ago) of high-value habitat (i.e., freshwater and wetlands) in China. Although some conversion has been secondary (i.e., from virgin habitat to agriculture to aquaculture), and some specifically for aquaculture has been, anecdotally, for species other than tilapia (e.g., primarily carp or shrimp), there is ultimately a lack of information regarding the tilapia industry's contribution to overall habitat conversion or degradation. Thus, given tilapia's prominence among China's fish aquaculture production, it is a reasonable, precautionary conclusion that tilapia farming has resulted in some loss of ecosystem services in China. The score for Factor 3.1 is 4 out of 10.

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

In order to manage the impacts of land conversion in high value habitats such as coastal wetlands and forests, regulatory measures must be appropriate to the scale of the industry, be based on ecological principles, and take into account the cumulative impacts of farms sited within these habitats.

In general, the laws surrounding habitat protection are not specific to aquaculture. Aquaculture licenses are given by the local governments under the jurisdiction of the Ministry of Agriculture (MoA) (pers. comm., F. Chen 2018). An updated version of the Five Year Fishery Development plan was launched in March 2016, and although there are indications that there will be an introduction of management measures for aquaculture with improved accountability (Cao et al. 2017), the details are not publicly available. In the “Aquaculture plans and construction guidebook,” the provisions for management of aquaculture and the environment are included in more general laws and regulations, and plans must be evaluated against these provisions to determine whether the farm site is suitable for the area (Ross et al. 2013).

Appropriate use of both the terrestrial and aquatic marine environment under Chinese jurisdiction is regulated primarily at the federal level; however, some aspects can be regulated at the provincial level. There appears to be variation between provinces and localities regarding the specificity of environmental management of aquaculture, as well as the ecological basis for the regulations. For instance, Guangdong Province has a spatial zoning plan that was passed in 1999, as well as an aquaculture-specific zoning scheme that was enacted in 2004 (Zhu and Dong 2013). However, it is unclear if other provinces maintain this specificity in their zoning regulations. As all land and sea areas are state owned, they fall under local functional zoning schemes that apply in major tilapia producing provinces. The schemes manage the integration of conservation areas and industry, including aquaculture (NALO 2012). It is also unclear whether these regulations account for cumulative impact of aquaculture sites within a zone.

Under the Environmental Protection Law (1989) EIAs are required for any new and expansion construction sites that are inclusive of aquaculture production sites (pers. comm., S. Wang, F. Chen, Q. Fang 2018). There are three main levels of EIA, ranging from a self-reporting form to a third party inspection. Typical tilapia production is usually subject only to the self-reporting EIA, though the larger farms may be subject to an intermediate form of EIA (pers. comm., S. Wang, F. Chen, Q. Fang 2018). Thus, much of the industry that is focused on export of tilapia is likely not subject to an in-depth EIA. Provincial governments determine the complexity of EIA needed for each aquaculture site, primarily based on proximity to ecologically sensitive areas. More information surrounding the requirements and enforcement of EIAs under Chinese law can be found in Criterion 2 – Effluent.

Regarding habitat connectivity for wildlife, the Wildlife Protection Law (revised in 2016) includes provisions for recognizing habitat connectivity and general protection for habitat of rare and endangered species. These provisions have been added in the most recent revision and came into effect in January 2017 (Library of Congress 2016). These provisions indicate that any new construction shall avoid nature reserves and migration or breeding routes. If avoidance is not possible, construction projects must mitigate the adverse impacts of the new construction by building wildlife passages (China Law Translate 2016). Although these provisions account for habitat connectivity and require action to prevent its interruption, their application is only for new construction after they took effect in 2017. Thus, a majority of the farms currently operating do not have to adhere to this regulation.

Regulations that address the siting of new farms are unclear, since many fall under regulations that are unspecific to the aquaculture sector. Some regions and localities do have regulations that are more specific to aquaculture, but the degree of specificity and the basis in ecological principles is variable among regions. Ultimately, the content of habitat management measures is minimal and only recently began to account for habitat connectivity, thus a majority of currently operating farms are unaffected by recent updates to management of aquaculture impacts on habitat. The score for Factor 3.2a 2 out of 5.

Factor 3.2b: Enforcement of habitat management measures

Enforcement of these regulations is divided up among many government departments (NALO 2012), and as discussed in Criterion 2 – Effluent, there is easily accessible information on punitive measures. Current siting regulations require that an application to the fishery bureau is submitted, as well as to the local government to obtain a permit, which can involve writing an assessment report. After that, the relevant authorities will screen and check if the farm passes regulatory standards and will then issue a permit for the aquaculture operation (Baidu Library 2017b). If the farm fails to comply with regulations, punishment measures will follow the relevant regulations listed above in Table 2.

However, enforcement is divided among many government departments and lacks documented action against farms that do not comply. For example, the aim of both the 11th Five Year Fishery Development Plan (2006 to 2010) and the 12th Five Year Fishery Development Plan (2011 to 2015) was to license 100% of aquaculture operations by 2015 (Ministry of Agricultural and Rural Affairs of the People's Republic of China 2011a). However, the predominance of rural, small-scale farms is reported to make licensing difficult (Zou and Huang 2015), and in 2011 only 76 to 79% of farms were thought to be licensed (Meador and Xinping 2012) (USDA FAS 2012) (Ministry of Agricultural and Rural Affairs of the People's Republic of China 2011b).

Additionally, economic development often takes precedence over compliance with environmental regulation (Zhu and Dong 2013) (Xia 2014) and the enforcement of management measure are considered "minimal." This results in a score of 1 out of 5 for Factor 3.2b.

Conclusions and Final Score

Due to general aquaculture practices, there has been mainly historic loss (>15 years ago) of high-value habitat (i.e., freshwater and wetlands), though it is unknown how much of this habitat loss is directly due to tilapia ponds, resulting in a score of 4 out of 10 for Factor 3.1 –

Habitat conversion and function. Many regulations are unspecific to aquaculture, though there is a recent amendment that incorporates habitat connectivity into the environmental impact assessment, resulting in a score of 2 out of 5 for Factor 3.2a. Enforcement of regulations is unclear and likely minimal, resulting in a score of 1 out of 5 for Factor 3.2b. This combines with the Factor 3.2a score, resulting in an overall score of 0.8 out of 10 for Factor 3.2. Factors 3.1 and 3.2 combine to give a final Criterion 3 – Habitat score of 2.93 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.
- Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments
- Principle: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**0**	
Critical?	YES	**CRITICAL**

Brief Summary

There is poor availability of data regarding on-farm use of chemicals in Chinese tilapia production. Furthermore, the regulations that govern chemical use in aquaculture in China appear to be aimed at food safety rather than primary application of chemicals or the potential ecological impacts of their use. There is, however, recent evidence that the banned chemical malachite green is still being used in tilapia production in China, and this was the cause for detention of frozen tilapia fillets entering the US in 2016. Additionally, nine import rejections since 2015 have been imposed on Chinese tilapia due to detection of antibiotics in fish fillets, including several antimicrobials listed as "Highly Important for Human Medicine" by the World Health Organization (WHO): sulfadiazine, trimethoprim, and sulfamethoxazole. The Chinese government has recently begun to implement plans to address overuse of antibiotics, but there is not yet evidence of improvements in management practices. Additionally, there is evidence of antimicrobial resistance in strains of *Aeromonas* and *Streptococcus* bacteria in direct connection with tilapia farms and farming regions. Due to the use of illegal chemicals as defined by the country of production and use of chemicals that are classified by WHO as "Highly Important for Human Medicine," as well as evidence of resistance in bacterial pathogens affecting the tilapia industry, this results in a Critical final score for Criterion 4 – Chemical Use.

Justification of Rating

As aquaculture practices have intensified, the Chinese aquaculture industry has experienced several aquatic animal health challenges (Li et al. 2011). The proliferation of viral, bacterial, and fungal infections, as well as parasitic pests, has resulted in large economic losses (Li et al. 2011) (see Criterion 7 – Disease). Consequently, tilapia farmers have relied on a variety of chemical treatments to prevent and treat disease outbreaks, promote growth, and improve the environmental conditions of the production systems. These include water and soil treatment compounds, disinfectants, pesticides, and antibiotics (Rico et al. 2012, 2013) (Li, Liu et al. 2013) Li et al. 2016) (Liu et al. 2017).

A variety of regulations in China pertain, or are applicable to, the use of chemicals in aquaculture. However, it appears that these regulations are aimed at food safety (i.e., the end product) rather than regulating the primary application of chemicals and the potential risk they pose to the ecosystem if released. These include the Food Safety Law (2009, amended in 2015) (Xinhua News Agency 2015), the Law on Agricultural Product Quality Safety (2006), Special Provisions of the State Council on Strengthening the Safety Supervision of Food and Other Products (2007), Aquatic Product Safety Regulations (2003), Tracing Procedures for the Export of Aquatic Products (2004), and Regulation 5017–2002 on Pollution-Free Aquatic Products in the Fishery Drugs Application Guidelines (NALO 2014). Since 2002, more than 60 technical standards for "pollution-free" aquaculture and over 40 standards for allowable levels of drug residues have been implemented (Wang et al. 2014). Another regulation regarding chemical residues is NY5070-2002 "Fisheries Product Medicine Residual Limit Regulation Standard," which specifies MRLs (Maximum Residue Limit) to common antibiotics used in Chinese aquaculture. However, reviews of these policies have indicated that regulations specific to antibiotic use were not being followed (Broughton and Walker 2010).

There has been a growing awareness and effort to prevent overuse of antibiotics in China, as many are available over the counter (i.e., without a health professional's prescription) and are unregulated for use in aquaculture (Li et al. 2013b) (Xiao et al. 2013). In response to this growing awareness and international pressure, the Chinese government issued a national action plan in 2016 to contain antimicrobial resistance. Under this five-year plan, several of the goals include improving surveillance on antimicrobial use, and also requiring a prescription for antibiotics sold for animal husbandry, though it will only apply to half of all Chinese provinces (Litovsky 2016) (Rousseau 2016) (Xiao 2017). The results of this increased surveillance and stringency remain to be seen, since the plan is currently being implemented and will be reviewed and updated in 2020.

In general, an overview of qualitative and quantitative data on the use of the chemicals used in Chinese aquaculture is lacking in the public domain. For this reason, Rico et al. (2012) compiled country-specific information for the top seven Asian aquaculture-producing countries, based on field surveys and national reviews published since 2000. Four of the reviewed publications—(Yulin 2000) (Zheng and Xiang 2002) (Yang and Zheng 2007) and (Qi et al. 2009)—referenced chemicals and biologics used in China (Table 3). Although the chemicals were not specified regarding environment, culture system, or species, the report documented the wide variety of products used. Of these, disinfectants, pesticides, and antibiotics have been shown to be the most environmentally hazardous compounds because of their high toxicity and potential for bioaccumulation.

Table 3. Chemicals used in Chinese aquaculture (Rico et al. 2012).

Antibiotics	***Water and sediment treatments***
Gentamycin	Calcium oxide
Streptomycin	EDTA
Ampicillin	Sodium chloride
Penicillin	Zeolite
Erythromycin	***Disinfectants***
Furazolidone[1]	Benzalkonium chloride
Ciprofloxacin	Calcium hypochlorite
Enrofloxacin	Calcium peroxide
Norfloxacin	Chlorine
Oxolinic acid	Chlorine dioxide
Sulfamethazine	Copper chloride
Sulfamethoxazole	Copper complex solution
Chlortetracycline	Formaldehyde
Doxycycline	Iodine
Oxytetracycline	Potassium permanganate
Chloramphenicol[1]	Povidone iodine
Rifampicin	Sodium dichloroisocyanurate
Pesticides	Trichloroisocynuric acid
Copper sulfate	***Other***
Malachite green[1]	Amino acids
Methylene blue	Local herbs
Nystatin	Polysaccharides
Trichlorfon	Probiotics

[1] Currently banned for use in most countries.

A 2013 chemical use study covering several species, culture systems, and countries in Asia included interviews of farm staff from 25 intensive and semi-intensive polyculture tilapia farms in the Maoming province of China. According to Rico et al. (2013), 16% of the Chinese tilapia farmers reported to use antibiotics, 32% reported to use disinfectants (predominantly for water disinfection and disease prevention), and 8% reported the use of parasiticides. A maximum of two antibiotics were reported to be applied on any individual tilapia farm, though the study did not identify which antibiotics were being reported specifically for the tilapia farms. In all cases, antibiotics were reported to be applied once per day, mixed with feed, for a period ranging between 3 and 8 days, and that 95% of farms were only using antibiotics to treat disease outbreaks rather than prophylactically. Disinfectants were generally applied to disinfect water and prevent disease rather than for treatment, and parasiticides were only reported to be used in 8% of tilapia farms. This evidence demonstrates the availability of a wide variety of chemicals and difficulty in defining which chemicals are currently in use in the region (Table 3).

FDA Inspection

Evidence from the US Food and Drug Administration (FDA) Detention Without Physical Examination (DWPE) database between 2010 and 2018 shows there is ongoing use of banned chemicals and antibiotics as evidenced in their detection in imported Chinese tilapia fillets. Recently detained products imported from China are listed in Table 4; they have included the widely-banned malachite green and gentian violet, and since 2015, the antibiotics sulfadiazine, trimethoprim, sulfamethoxazole, and the metabolized form of malachite green, leucomalachite green. Of particular note regarding antimicrobials, sulfadiazine, sulfamethoxazole, and trimethoprim are listed as “Highly Important for Human Medicine” by the World Health Organization (WHO) (WHO 2017). Although solutions have been proposed in the literature to combat illegal chemical use (Zhao et al. 2008), there is no evidence for acting on these solutions (or others) and no evidence of improvement in the management practices leading to reductions in use or the risk of impacts.

As mentioned previously, sulfadiazine, trimethoprim, and sulfamethoxazole are reported to be used by tilapia farmers in the Guangdong province (Liet al. 2013) (Li et al. 2016), and imported fish have been detained by US FDA in recent years for containing them. Although malachite green has been used in aquaculture in the past as a parasiticide, it has been widely banned for use in food-fish production due to evidence that it is a carcinogen (Srivastava et al. 2004) (Donya et al. 2012). The most recent occurrence of an FDA import refusal for this substance occurred in 2016 when its metabolite, leucomalachite green, was found in detained frozen tilapia from China.

Table 4. US FDA Detention Without Physical Examination (DWPE) for tilapia imported from China.[1]

Company	Region	Date Published	Problem
Haikou Quanyong Aquatic Frozen & Process	*Hainan*	09/16/2009	MALACHITE GREEN
Hainan Evernew Foods Co., Ltd.	*Hainan*	08/13/2010	MALACHITE GREEN
Hainan Taisheng Fishery Co., Ltd.	*Hainan*	01/14/2010	GENTIAN VIOLET
Sihui Pengcheng Freezing Foods Co., Ltd.	*Guangdong*	04/23/2010	MALACHITE GREEN
Zhanjiang Tianrun Seafood	*Guangdong*	08/20/2010	MALACHITE GREEN
Zhongshan Dai Sing Frozen Food Company Ltd.	*Guangdong*	08/30/2010	MALACHITE GREEN
Maoming Changxing Foods Co. Ltd.	*Guangdong*	03/07/2012	GENTIAN VIOLET
Zhangzhou Quanfeng Foods Development Co, Ltd.	*Fujian*	01/23/2013	MALACHITE GREEN
Beihai Anbang Seafood Co., Ltd.	*Guangxi*	09/09/2013	MALACHITE GREEN
Gallant Ocean (Nanhai), Ltd.	*Guangdong*	02/11/2015	SULFADIAZINE; TRIMETHOPRIM

[1] https://www.accessdata.fda.gov/cms_ia/importalert_27.html

Guangdong Mingji Aquatic Product Co., LTD.	*Guangdong*	01/28/2016	GENTIAN VIOLET
Beihai Evergreen Aquatic Product Sci. & Tech. Co.,Ltd.	*Guangxi*	03/04/2016	SULFADIAZINE
Qingdao Seaflying Food Co., Ltd.	*Shandong*	04/07/2016	LEUCOMALACHITE GREEN
Shanwei Cathay Food Freezing and Processing Co., Ltd.	*Guangdong*	08/10/2016	SULFAMETHOXAZOLE
Huazhou Boao Aquatic Products Co., Ltd.	*Guangdong*	09/08/2016	SULFADIAZINE
Zhongshan Metro Frozen Food Co	*Yandongsheng*	11/09/2016	LEUCOMALACHITE GREEN
Huazhou Boao Aquatic Products Co., Ltd.	*Guangdong*	02/17/2017	SULFADIAZINE
Guangxi Nanning Baiyang Food Co., Ltd.	*Guangxi*	02/28/2017	SULFADIAZINE
Guangxi Nanning Baiyang Food Co., Ltd.	*Guangxi*	04/03/2017	SULFADIAZINE
Maoming Yuantian Aquatic Refrigeration Company	*Guangdong*	04/10/2018	SULFADIAZINE
Zhanjiang Evergreen Aquatic Product	*Guangdong*	03/07/2018	SULFADIAZINE

Antibiotic resistance

Antibiotic resistance has become a major research area in relation to Chinese aquaculture, and is an important consideration given the historically poor governance of antibiotic use in the sector. Various studies investigating and demonstrating the prevalence of antibiotic resistance in relation to Chinese aquaculture operations have been published in recent years. For example, while not directly implicating tilapia culture, Chen et al. (2017) have demonstrated the presence of 11 antibiotic compounds and 9 types of resistance genes (including those for tetracyclines and sulfonamides) are present near mariculture facilities in southeast China. Similar findings have been reported in freshwater aquaculture in the Yangtze River region, mainly for shrimp and crab polyculture (Song et al. 2016). Additionally, as outlined in the Seafood Watch assessment of catfish raised in ponds in China, there is overwhelming evidence to support the presence of developed resistance to several antibiotics classified as highly or critically important for human medicine: oxytetracycline, doxycycline, ampicillin, and penicillin (Seafood Watch 2017).

More specific to tilapia culture, there is evidence of resistance in *Aeromonas* (Li and Cai 2011) and *Streptococcus* (Zhang et al. 2018) bacteria, which are pathogens commonly observed in tilapia production in China (see Criterion 7 – Disease). Serotypes isolated from a *Streptococcosis* outbreak in tilapia in Guangdong Province in 2015 demonstrated resistance to penicillin and sulfonamide (Zhang et al. 2018). Interestingly, a serotype that previously had not been associated with tilapia culture (serotype IX) was also detected and it showed resistance to erythromycin. There is also some indication that antibiotic resistance genes can be more prevalent in areas where fish ponds (including tilapia) are integrated with poultry farms, though this type of integration has been decreasing in China (Zhong et al. 2018).

A survey investigating disease management measures conducted in Guangdong province of 25 tilapia farms found that the diseases streptococcosis, exophthalmia, enteritis, and liver enlargement were "frequently" treated using medicated feeds that included sulfadiazine, trimethoprim, oxytetracycline, florfenicol, and amoxicillin (Li et al. 2016). In addition to using these antibiotics, there was also reported reduction in efficacy against *Aeromonas* bacteria: "*Several farmers stated that the effectiveness of sulfadiazine, and also amoxicillin and florfenicol, in treating streptococcosis was reduced compared with the efficacy seen a few years ago, even at increased dosage"* (Li et al. 2016).

Based on several accounts of confirmed antibiotic resistance in bacteria isolated from tilapia and tilapia-farming regions, as well as reports of reduced efficacy of several antimicrobials, there is evidence that overuse of antimicrobials in the tilapia industry is contributing to overall antimicrobial resistance in China.

Conclusions and Final Score

In Chinese tilapia production, there is evidence of illegal chemical use, the use of chemicals that are highly and critically important for human medicine in significant quantities, and importantly, indications that there is increasing resistance to such treatments. These lead to a Critical score for Criterion 4 – Chemical Use.

Criterion 5: Feed

Impact, unit of sustainability and principle

- Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary

Feed parameters	Value	Score
F5.1a Fish Feed Equivalency Ratio (FFER)	0.18	9.56
F5.1b Source fishery sustainability score	–7.00	
F5.1: Wild fish use score		9.32
F5.2a Protein IN (kg/100kg fish harvested)	28.07	
F5.2b Protein OUT (kg/100kg fish harvested)	15.47	
F5.2: Net Protein Gain or Loss (%)	–44.87	5
F5.3: Feed Footprint (hectares)	1.25	9
C5 Feed Final Score (0-10)		**8.16**
Critical?	NO	**GREEN**

Brief Summary

The inclusion levels of fishmeal (FM) (1.5%) and fish oil (FO) (0.5%) in feeds used in tilapia production in China are relatively low in comparison to other fed finfish species. The combination of a low eFCR (1.4) and low FM and FO inclusion gives a low Feed Fish Efficiency Ratio (FFER) of 0.18, and an overall score for Factor 5.1a of 9.56 out of 10. Regarding the use of wild fish, China is a significant importer of feed from South America, in particular Peru. However, a significant amount of feeds are produced domestically using unknown "trash fish," or fisheries that are fully exploited, overexploited, or depleted. Since the FishSource score for the most widely reported source of imported feeds, the Peruvian Anchovy, are all >6, but there are still significant concerns over the use of marine ingredients in domestic feeds and the score for Factor 5.1b is –7 out of –10, the result is a final Factor 5.1 score of 9.32 out of 10. Protein in feeds used for tilapia in China is sourced from approximately 70% from edible sources, and approximately 30% from sources not suitable for human consumption. There is an overall net edible protein loss of –44.87%, leading to a Factor 5.2 score of 5 out of 10. When combined, the total area of land and ocean appropriated to produce one ton of tilapia in China is 1.25 ha. These values equate to a final score of 9 out of 10 for Factor 5.3. When combined, factors 5.1, 5.2 and 5.3 result in a final Criterion 5 – Feed score of 8.16 out of 10.

Justification of Rating

Factor 5.1. Wild fish use

Tilapias represent the second-largest fed species group of freshwater fish, and production has been increasingly based on commercial feeds (Tacon et al. 2011). The imports of fishmeal to China equate to one third of the world's production (Cao et al. 2015a) and China produces approximately 60% of global aquaculture products. Of the fishmeal that is produced domestically, approximately 40% (250,000 MT) is derived from processing wastes; however, there are large variations in domestic production annually making it a less reliant source of feeds (Chiu et al. 2013) (Cao et al. 2015a). Fishmeal is also sourced from other Asian (unspecified) fisheries, mostly from non-targeted fisheries including "trash" fish (Cao et al. 2015a).

<u>Factor 5.1a – Feed fish efficiency ratio (FFER)</u>

The level of fishmeal (FM) inclusion in tilapia feeds is low in comparison to other cultivated fed finfish species, and although inclusion levels can vary 0 to 3% (Tacon et al. 2011), 2.5% (Chiu et al. 2013), 1% (Xu and Ming 2018), an average of 1.5% is used to calculate wild fish use. The level of fish oil (FO) required in feeds is very low, and in some cases is not included as a feed ingredient (Xu and Ming 2018); however, on average, a 0.5% inclusion is reported by Tacon et al. (2011) and Chiu et al. (2013). The inclusion of by-products in domestically produced fishmeal is estimated to be approximately 40% (Cao et al. 2015a), and as domestic feed use varies but can make up approximately half of feed use in tilapia production in China (Chiu et al. 2013), an average by-product inclusion rate of 20% is used to calculate wild fish use. As there is no information regarding the use of fish oil by-products, it is not included in calculating wild fish use. There are imported feed ingredients, but the inclusion of imported by-products is unknown and therefore the inclusion rate only represents what is known of domestic by-product use. Ultimately, a ("whole fish") fishmeal inclusion of 1.2% and fish oil inclusion of 0.5% are used.

The global average of fishmeal and fish oil yield, which includes the large volume of import to China, is reported to be 22.5% and 5% respectively (Tacon and Metian 2008). However, the yields for lower quality domestically produced marine ingredients are reportedly lower, at 20% for fishmeal and 3% for fish oil (Chiu et al. 2013). As the use of domestically produced feeds can be up to half of all feed used across China (Chiu et al. 2013), these yields were averaged to give 21.25% for fishmeal and 4% for fish oil.

A review by Chiu et al. (2013) of feeds and FCRs from intensive tilapia farms in Hainan—a region producing a large proportion of tilapia in China (Zhang et al. 2015)—found an average FCR was between 1.4 and 1.6. Additionally, Cao et al. (2015a) found an average eFCR of 1.6 for intensive monoculture throughout China (Cao et al. 2015a). In 2018, a detailed review of the current status of numerous aspects of Chinese tilapia aquaculture indicated the range of typical eFCRs to be between 1.2 and 1.5 (Xu and Ming 2018). Given the range of possible values, and the most recent range being 1.2 to 1.5, a value of 1.4 is used for all calculations in this report.

Table 5. Summary of Feed Factor 5.1 Wild Fish Use data.

Parameter	Data
Fishmeal inclusion level	1.5%
Percentage of fishmeal from byproducts	20%
Fishmeal yield (from wild fish)	21.25%
Fish oil inclusion level	0.5%
Percentage of fish oil from byproducts	0%
Fish oil yield	4%
Economic Feed Conversion Ratio (eFCR)	1.4
Calculated Values	
Feed Fish Efficiency Ratio (FFER) (fishmeal)	0.08
Feed Fish Efficiency Ratio (FFER) (fish oil)	0.18
Seafood Watch FFER Score (0-10)	**9.56**

The combination of a low eFCR and low fishmeal and fish oil inclusion gives a low Feed Fish Efficiency Ratio (FEER) of 0.08 for fishmeal and 0.18 for fish oil. The higher value, 0.18 for fish oil, is used and results in an overall score for Factor 5.1a of 9.56 out of 10.

Factor 5.1b – Sustainability of the source of wild fish

To measure the sustainability of the fisheries providing fishmeal and fish oil, the origins of both imported commercial feeds and domestically produced feeds are considered. There are significant concerns over the sustainability of the sources of fishmeal and fish oil from domestic fisheries, as notable declines in catches within China's Exclusive Economic Zone (EEZ) are influencing shifts towards products from non-targeted fisheries, including trash fish (Cao et al. 2015a) (Chun 2017). Given the variable quality and quantity of domestic feeds, future supplies of high quality commercial feeds have been secured by Chinese businesses and government subsidiaries by purchasing fishing rights in the Eastern Pacific, largely from the Peruvian anchovy fishery (Cao et al. 2015a, b). Products from the Eastern Pacific fisheries can be used in Chinese aquafeeds; however, since they tend to be higher quality, they are reserved for the high-value farmed species (Chiu et al. 2013). These products can also be used for tilapia and whiteleg shrimp feeds, often in conjunction as a mixture of domestic and imported fishmeal from other Asian countries as well as the US, Russia, and New Zealand depending on price and availability (Chiu et al. 2013). Thus, fishery products for Chinese tilapia feeds likely contain material from non-targeted fisheries, including trash fish, though the proportion to products from targeted fisheries is unknown. The species composition of this fishmeal can be very broad, as indicated by Cao et al. (2015b), who identified 71 trash fish species that have been included in aquafeeds in China, a majority of which have not been assessed for sustainability, and those that have are classified as overfished or fully fished (Cao et al. 2015a).

The FishSource scores for the most widely reported source of imported fishery products, Peruvian anchovy, are all >6 which warrants a Factor 5.1b score of –4 out of –10. However, there are significant concerns over the sustainability of domestic multi-species fisheries, whose unknown composition, unassessed sustainability, or demonstrable unsustainability warrant a score of –10 out of –10. Given that domestic and imported sources each equate to roughly 50% of national feed ingredients (Cao et al. 2015a), an intermediate Factor 5.1b score of –7 out of –10 is given.

The score for Factor 5.1b (–7 out of –10), when combined with Factor 5.1a (9.56 out of 10), results in a numerical deduction of –0.25 and a final Factor 5.1 score of 9.32 out of 10.

Factor 5.2. Net protein gain or loss

The production of tilapia in China results in a net loss of edible protein. This is due to a relatively high proportion of edible protein in feeds compared to a low protein content of the harvested fillet, and although much of the by-products are utilized from tilapia, they are largely for inedible purposes (e.g., cosmetics). The protein content of grow-out feeds is low in comparison to other fed finfish species and is estimated to be 28.5% (Weimin and Mengqing 2007) (Chiu et al. 2013). Although there is some information publicly available regarding the content and source of protein in the feeds of tilapia produced in China (listed in Table 6), there is no definitive or average formula for the country, and variation in ingredients makes it difficult to accurately calculate the average edible and non-edible protein content of a diet. For example, there was a reference made to the inclusion of poultry by-product in China (Weimin and Mengqing 2007), but since this was not included as an ingredient in either the most recent survey made by Tacon et al. (2011) or in a recent publication covering common tilapia aquaculture practices in China (Xu and Ming 2018), it is not included in the current assessment calculations.

To calculate the edible protein gain or loss, the fishmeal and crop ingredient inclusions (accounting for the percentage from edible and non-edible sources), the total protein content of feeds, and the eFCR were used. The edible content of the average feed was calculated by combining the ingredients listed for each that are considered fit for human consumption according to the Seafood Watch Aquaculture Standard (e.g., corn, distiller's grains, soybean meal). The percentage of edible protein was then averaged among the reported feed types. The only non-edible sources in the cited literature is represented in the non-edible fishmeal byproducts. This resulted in an average of 7% of total feed protein derived from marine ingredients (i.e., whole-fish fishmeal, rather than by-product-derived fishmeal), and the total feed protein from non-marine ingredients was calculated to be approximately 93%, figures which are generally in line with reported feed mixes (Tacon et al. 2011) (Chiu et al. 2013) (Ng and Romano 2013).

The protein content of whole harvested tilapia is 14% (Boyd et al. 2007). The edible yield of cultivated tilapia can be between 37 and 47% (Rutten et al. 2005) (Nguyen et al. 2010) (Gjerde et al. 2012) (El-Zaeem et al. 2012); therefore, an average of 42% was used in the calculations. This results in an average of 39.9 kg of protein inputs, of which 28.07 kg (70.34%) are edible and

15.47 kg of utilized edible protein outputs (all per kg of protein per 100 kg of harvested farmed tilapia), and an overall net protein loss of –44.87%. Although there is an overall loss of edible proteins for human consumption, many of the by-products of tilapia are utilized for non-edible purposes, including leather goods, cosmetics, nutraceuticals and chemical ingredients (Hanson et al. 2011). In particular, tilapia skin is rich in collagen, and this is reused as a major ingredient in cosmetics where it is processed into high-value albumen powder (Hanson et al. 2011). Xu and Ming (2018) outline in detail the typical processes and end products for tilapia byproducts use in China (Figure 10); however, the percentages for utilization are not included. Without knowing the exact percentage of typical tilapia by-product utilization for further protein production, this value is assumed to be 50%.

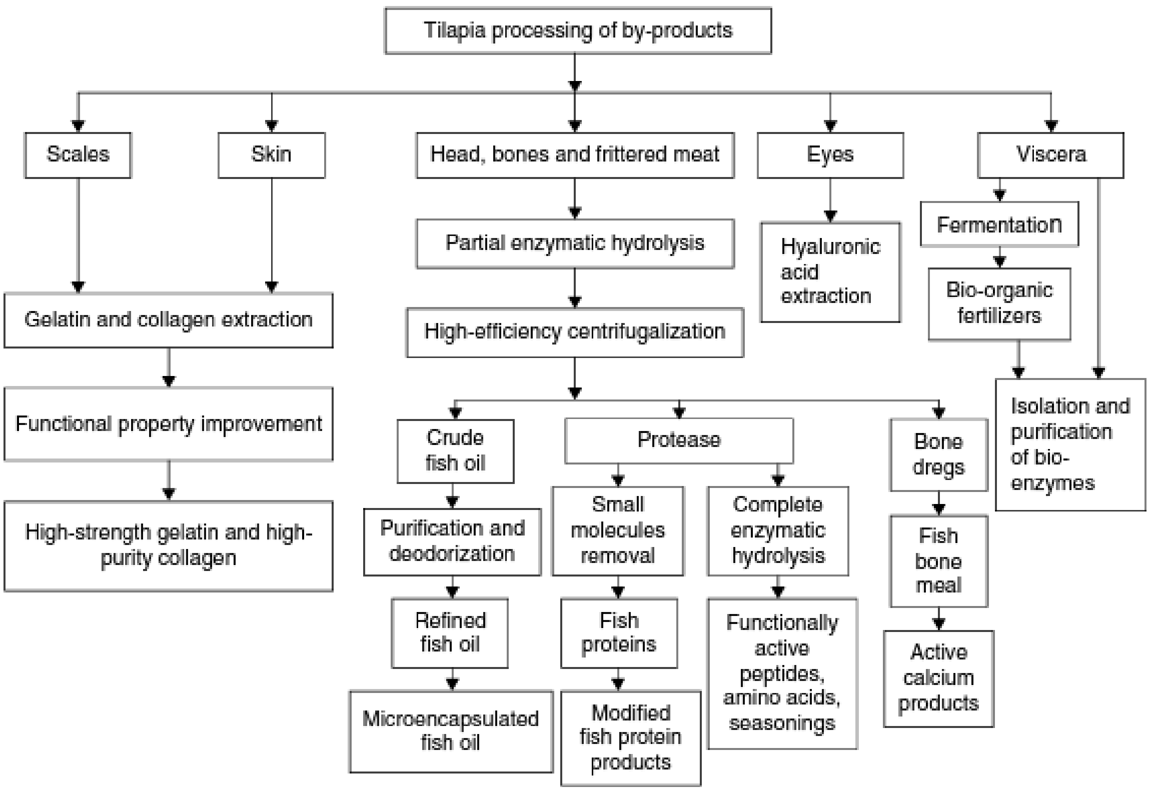


Figure 8. Production and utilization of tilapia processing byproducts (Source: Xu and Ming 2018).

Table 6. Ingredients and inclusion levels reported to be used in Chinese tilapia production. *Note:* mineral and multi-vitamin levels are not included as they are not used for calculating net protein gain or loss.

Ingredient (reference)	Inclusion Level	Edible?
(Weimin & Mengqing 2007)		
Fishmeal	4	-
Soybean meal	34	Yes
Wheat middling	30	Yes

Corn	22.1	Yes
Poultry by-product meal	6	No
Vegetable oil	0.5	Yes
(Tacon et al. 2011)		
Fishmeal	0–3	-
Soybean meal	0–25	Yes
Wheat bran	0–25	Yes
Corn	0–15	Yes
Rapeseed/canola meal	20–40	No
Cotton seed meal	0–25	No
Spirit based distillers grain	0-8	Yes
(Xu and Ming 2018)		
Fishmeal	1	-
Soybean meal	20	Yes
Peanut meal	5	Yes
Wheat	31	Yes
Barley	9.5	Yes
Rice bran	16	Yes
Soybean oil	0.5	Yes

Table 7. Summary of Feed Factor 5.2 Net protein gain or loss data.

Parameter	Data
Protein content of feed	28.5%
Percentage of protein from edible sources (whole fish FM, edible crops)	70.34%
Percentage of total protein from non-edible sources (byproducts, etc.)	29.66%
Feed Conversion Ratio	1.4
Edible protein INPUT per ton of farmed tilapia	39.90 kg
Protein content of whole harvested tilapia	14%
Edible yield of harvested tilapia	42%
Percentage of farmed tilapia byproducts utilized	50%
Utilized protein OUTPUT per ton of farmed tilapia	15.47 kg
Net protein loss	-44.87%
Seafood Watch Score (0-10)	**5**

Protein in grow-out feeds used for tilapia in China is sourced from approximately 70% from edible sources, with the remaining 30% considered to come from sources not suitable for human consumption. There is an overall net edible protein loss of 44.87%, leading to a Factor 5.2 score of 5 out of 10.

Factor 5.3. Feed footprint

The feed footprint area is an approximate measure of the global primary productivity resources required to produce feeds for tilapia in China; it is based on the global ocean and land area used to produce the feed ingredients required to grow one ton of farmed fish. The area of ocean primary production appropriated by feed ingredients per ton of farmed tilapia in China was calculated using the inclusion level of fishmeal and fish oil together at 2% and an eFCR of 1.4. The average primary production (carbon) required for aquatic feed ingredients at 69.7 tCt^{-1} and the average ocean productivity for continental shelf areas at 2.68 tCt^{-1}. Using the formula presented in the Seafood Watch Aquaculture Standard, it is calculated that Chinese tilapia feed requires 0.73 ha of ocean area for every ton of harvested fish.

In order to calculate the land area appropriated by feed ingredients of tilapia produced in China, the inclusion of both terrestrial crop and land animal ingredients in feeds are used. With no indication of land animal inclusion and minimally detailed information regarding crop ingredients, the inclusion level of marine ingredients (2%) was used to assume an inclusion rate of 98% (i.e., 100% minus 2%) for crop ingredients. Using the eFCR of 1.4, and the average yield of major feed ingredient crops 2.64 t ha^{-1}, the land area appropriated to produce one ton of tilapia in China is 0.52 ha^{-1}.

When combined, the total area of land and ocean appropriated to produce one ton of tilapia in China is 1.25 ha^{-1}. This value equates to a final score of 9 out of 10 for Factor 5.3.

Table 8. Summary of Feed Factor 5.3 Feed Footprint data.

Parameter	Data
Marine ingredients inclusion	2%
Crop ingredients inclusion	98%
Land animal ingredients inclusion	0%
Ocean area (ha) used per ton of farmed tilapia	0.73
Land area (ha) used per ton of farmed tilapia	0.52
Total area (ha)	1.25
Seafood Watch Score (0-10)	**9**

Conclusions and Final Score

The inclusion levels of FM (1.5%) and FO (0.5%) used in tilapia production in China are low in comparison to other fed finfish species. China is a significant importer of feed from South America, in particular Peru, and Peruvian anchovy stocks are generally rated as having moderate sustainability. However, a significant amount of feeds are produced domestically using unknown “trash fish” species, or products from fisheries whose sustainability is unknown or poor. Tilapia have a low fillet yield (42%) and although protein in feeds require low wild fish use, they have high inclusion rates of edible crops such as soy, wheat, and corn. Tilapia by-products can be used in cosmetic and pharmaceutical products, but it is assumed that 50% are used for further protein production. The low volumes of marine ingredients included and use of land crops for protein in feeds results in a small feed footprint of 1.25 ha to produce feed for one ton of tilapia production in China. Factors 5.1, 5.2, and 5.3 combine to result in a final Criterion 5 – Feed numerical score of 8.16 out of 10.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Escape parameters	Value	Score
F6.1 System escape risk	2	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		2
F6.2 Competitive and Genetic Interactions		0
C6 Escape Final Score (0-10)		**0**
Critical?	YES	**CRITICAL**

Brief Summary

Tilapia are considered highly invasive outside their native range and this includes the most commonly cultivated species in China (blue tilapia and Nile tilapia), which are named on the IUCN Global Invasive Species Database. Reports on tilapia escapes at the farm level in China are unavailable, therefore the risk of escapes from a pond system is measured by both the openness of the system and the vulnerability of the ponds to flooding events. Although ponds are generally only drained externally at harvest, recent literature provides evidence that tilapia cultivation occurs in regions where ponds are vulnerable to river flooding events and that escapes do indeed occur. Large areas where tilapia is cultivated are now known to have well-established (>10 years) populations (e.g., Hainan and Guangdong provinces). There are, however, still some regions in China where tilapia have not yet become established but are showing signs of developing establishment. Additionally, there are documented examples of tilapia populations vastly outcompeting local fish species for resources in Chinese waterways. Given the risk of extending the range of establishment and the invasiveness of the species, as evidenced by their competition with native species in China, the final score for Criterion 6 – Escapes is a Critical score of 0 out of 10.

Justification of Rating

Factor 6.1. Escape risk

Since 2014, Nile tilapia has been listed as an Alien Invasive Species in China and has specifically been listed by the government as a species that needs to be controlled to prevent the spread of invasive species. China has already had 18 provinces build specific offices/regulations to strengthen control and curb expansion of alien species (Ministry of Ecology and Environment of the People's Republic of China 2014) (Baidu Library 2015). Despite this, public reports on tilapia escape events at the farm, provincial, or national level are unavailable, and there is no information available regarding regulations for requirements to mitigate or report escapes. Therefore, the risk of escapes from a pond system is measured by both the openness of the system and the vulnerability of the ponds to flooding events.

Tilapia ponds are typically completely drained once per cycle (Liu et al. 2018). Evidence for the escape of farmed tilapia is observed across China and is thought to be primarily a result of river flooding events (Gu et al. 2014a, 2015, 2016, 2018) (Hu et al. 2015) (Xu et al. 2006), and in the Guangdong province there is evidence of the spread of Nile tilapia as a result of river flooding (Gu et al. 2014b).

Although pond culture systems for tilapia in China are typically only drained externally at harvest, there is evidence that tilapia cultivation occurs in regions where ponds are vulnerable to river flooding events and escapes do occur. Pond systems are considered a moderate-risk system; however, due to the evidence of tilapia escapes, this brings into question the robustness of the escape prevention measures implemented. Therefore, the score for Factor 6.1 is 2 out of 10.

Factor 6.2. Competitive and genetic interactions

Tilapia are considered highly invasive, and this includes the most commonly cultivated species in China (blue tilapia and Nile tilapia), which are named on the IUCN Global Invasive Species Database.[2] In China, *O. mossambicus* tilapia were first introduced in 1957 from Vietnam for aquaculture; since then, there has been an introduction of more than nine tilapia species, some specifically for aquaculture (Gu et al. 2014). Many introductions of tilapia species, however, occurred decades ago to control aquatic vegetation and stock for food in rivers, lakes and ponds. The introduction of Nile tilapia in Yunnan and Guangxi provinces are two such examples (Xu et al. 2006).

When initially introduced, it was thought that tilapia were unable to invade the temperate environments of China because they could not survive the winter temperatures, but recent evidence suggests low temperatures do not limit the year-round survival of tilapia (Gu et al. 2014) (Shuai et al. 2015), and overwintering and reproducing populations now exist in many rivers of Guangdong province, such as the Pearl, Hanjiang, Jianjiang, and Tinjiang rivers (Gu et al. 2014, 2018). There is also evidence that they have established populations in Hainan province, and there may be an emerging population in some areas of the Jiulong River in Fujian province (Xu and Ming 2018).

Since their introduction to China, tilapia have been able to establish and extend their range, which is thought to be due to both their large numbers in aquaculture and favorable biological

[2] http://www.iucngisd.org/gisd/

characteristics (Gu et al. 2016, 2018). Such characteristics have caused environmental impacts through competition with native fish for food (including invertebrates, small fish, decomposing organic matter, plants, and plankton), and their aggressive nature, which enables them to out-compete native fish species, such as mud carp (*Cirrhina molitorella*) in the rivers of South China (Canonico et al. 2005) (Martin et al. 2010) (Gu et al. 2014a, b 2015).

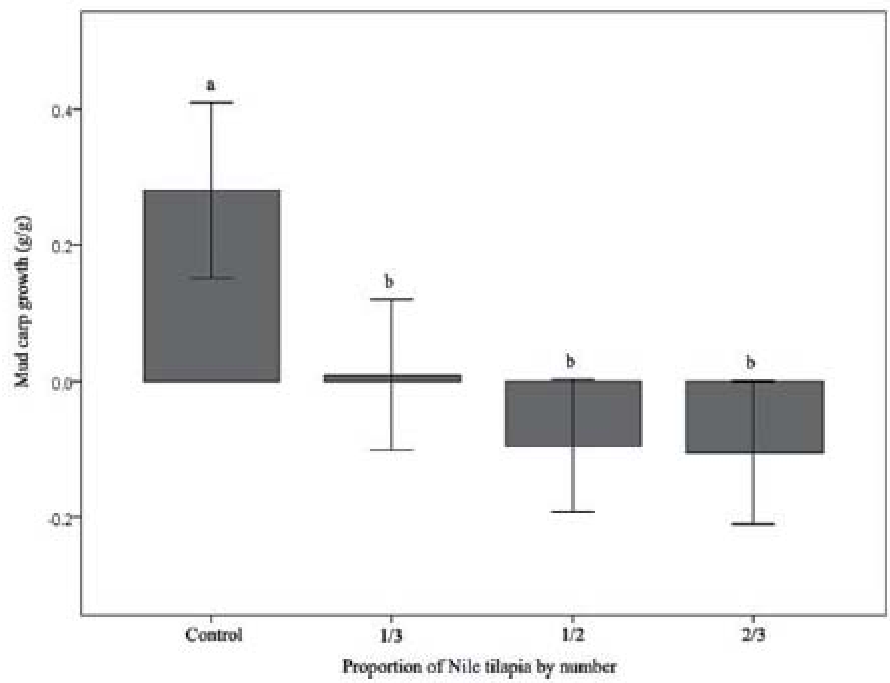


Figure 9. Native mud carp growth in the presence of Nile tilapia (Gu et al. 2017).

Tilapia biomass in rivers has also been associated with decreased water quality, primarily by increasing the total nitrogen, phosphorus, and chlorophyll levels (Gu et al. 2017). Activities like digging and nest building increase turbidity while excretions increase nutrient loading and promote phytoplankton growth. All of this leads to reduced light availability in the water column, which can modify the environment that the native species have adapted to (Gu et al. 2017) (Senanan and Bart 2010).

Although established more than 10 years ago in many areas of tilapia production, a forecast of the expansion of Nile tilapia in the Pearl River, where in some tributaries their occurrence remains rare, showed it likely to be an increasingly invasive species between 2013 and 2019 (Shuai et al. 2015). While this study represents a forecast, rather than a direct measurement, the data were based on already-established populations in this area and their likelihood to reproduce, and the resultant prediction for range expansion demonstrates the ability of tilapia to invade and establish in new areas and ecosystems, which is currently being observed in Fujian province (Xu and Ming 2018).

Despite the fact that there are still some regions in China where tilapia have not yet become established (Shuai et al. 2015) (Xu and Ming 2018), large areas where tilapia are cultivated are now known to have well-established (>10 years) populations (Gu et al. 2015, 2016, 2017). These non-native species have become fully ecologically established in the major production region of Guangdong by demonstrating survival in the winter temperatures and successful reproduction in the wild, both of which were previously not considered to be feasible for tilapia in the region. However, there is evidence that in some regions tilapia are not yet established, and given the historical and ongoing expansion of the range, this indicates a risk for continued expansion of the range.

Due to evidence of competition with mud carp in Chinese waters, the risk and ongoing expansion of the established range, and the invasiveness of tilapia, this results in a score of 0 out of 10 for Factor 6.2.

Conclusions and Final Score

There is evidence to suggest that tilapia cultivation occurs in regions where ponds are vulnerable to river flooding events, and escapes do indeed occur. Tilapia have now become fully ecologically established in the most productive region of Guangdong and Hainan; however, there still remain regions where production occurs and tilapia are not yet established. There is also evidence that populations are in the process of establishing in Fujian province. The risk of ecological impact is therefore considered to be high, and Factors 6.1 and 6.2 combine to give a final numerical score of a Critical 0 out of 10 for Criterion 6 – Escapes.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Disease Risk-Based Assessment

Pathogen and parasite parameters	Score	
C7 Disease Score (0-10)	3	
Critical?	NO	RED

Brief Summary

Because there is a lack of information about the impact of on-farm disease in Chinese tilapia production on wild fish, the Risk-Based Assessment is utilized. The intensification of tilapia cultivation in China has increased the risk and incidence of diseases through higher stocking densities and higher feeding rates, leading to decreased water quality and increased stress on the cultivated fish. Additionally, the GIFT strain selective breeding did not include characteristics related to disease resistance. The main diseases of tilapia in Asia include bacterial diseases caused by *Streptococcus* and *Aeromonas* species, of which *S. agalactiae* is reported as the most prevalent cause of mortalities, including in China. Other diseases are also known to be present in the industry. There are currently very few vaccines approved for aquatic use in China, few of which are relevant to the more prevalent known disease problems in the tilapia industry. The regulations for the control of disease in Chinese aquaculture are largely aimed at protecting farmed stocks from epidemics, and although these regulations may protect wild fish by reducing the prevalence of disease at the farm level, there is little detail on the enforcement measures for these regulations. In addition, there is evidence of a lack of enforcement on reporting requirements, which makes understanding current industry-wide disease incidence difficult. Pond systems are typically drained once at harvest, which reduces the risk of transmission to wild fish populations. However, there is growing evidence for disease outbreaks and resistance to treatments on farms, unknown implementation of biosecurity protocols, and little research regarding the impact this is having on wild fish populations. The final numerical score is 3 out of 10 for Criterion 7 – Disease.

Justification of Rating

As disease data quality and availability is low (i.e., Criterion 1 score of 2.5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment was utilized.

Although tilapia has long been considered a hardy and disease resistant species, the intensification of the industry has presented significant disease challenges. Intensification of tilapia cultivation in China has increased the risk of diseases through higher stocking densities and higher feeding rates that lead to decreased water quality and increased stress on the cultivated fish (Li et al. 2011, 2016) (Wang et al. 2014) (Mo et al. 2015), as well as selective breeding in GIFT strains for growth and skin color, but not for disease resistance (Wang and Lu 2015). This increased risk has resulted in disease outbreaks within the farm; however, there is currently no information regarding whether there has been amplification of disease in wild fish as a result.

The primary diseases affecting tilapia in Asia include bacterial diseases caused by *Streptococcus* and *Aeromonas* species (Li and Cai 2011) (Ye et al. 2011) (Zhao 2011a) (Li et al. 2016). The spread of *Streptococcus* bacterial infections in industries in the US, Israel, Kuwait, Brazil, Thailand, and China demonstrates its threat to the future of the industry (Ye et al. 2011). Of the *Streptococcus* species, *S. agalactiae* is reported as the most prevalent cause of mortalities in China (Li, et al. 2013) (Li et al. 2015). It was first reported in Fujian province causing 20 to 30% mortality in the summers of 2009–2010. Outbreaks spread south into Guangdong, Hainan, and Guangxi provinces with high infection rates (>50%), and of those infected, high mortality rates (>95%) in some farms (Ye et al. 2011) (Zhang et al. 2013) (Li et al. 2014). Streptococcosis mainly appears in the summer (May through September) when water temperatures are highest (25 to 37 °C) (Li et al. 2016), and there is currently no chemotherapeutic or immunological measure developed to prevent or control *Streptococcus* effectively (Zhang et al. 2013) (Wang and Lu 2015). One Chinese company has claimed it will be producing a vaccine (Liao and Ly 2017), but it is not yet available as of May 2018.

A number of less prevalent diseases are also reported in Chinese tilapia farms, which include enteritis, tail-rot (caused by *Aeromonas sobria*), fulminant hemorrhagic disease, trichodiniasis, dactylogyriasis, and obesity syndrome (Tang 2016). Enteritis has been reported in the Guangdong region, causing lethargic swimming, distended abdomen, and intestine filled with yellow mucus, as well as reports of unknown diseases that cause exopthalmia and liver enlargement (Li et al. 2016). Tail-rot disease in juvenile tilapia is caused by *Aeromonas sobria*, which has developed confirmed resistance to antimicrobial drugs commonly used in China (Li and Cai 2011). Fulminant hemorrhagic disease has been reported to cause mortalities in hybrid tilapia in Hainan (Yang et al. 2009). In addition, several novel diseases have been noted in tilapia in China. For instance, in Guangzhou, infected fish had white granulomas in the kidney, liver, heart, and spleen, thought to be the result of a *Francisella noatunesis* sub-species (Lin et al. 2016).

While it is not yet publicly reported in mainland China, another disease of global concern, Tilapia Lake Virus (TiLV), has affected tilapia farms and wild stocks on at least three continents and there is a notable global threat for its spread, as outlined by FAO and OIE (FAO 2017) (OIE 2017) (Intrafish 2017) (Kramer 2017). There has been confirmation of TiLV in Chinese Taipei, and mainland China was listed as a high risk for TiLV spread due to destinations of fry from Thai hatcheries where TiLV has been confirmed (Dong et al. 2017). The investigation into the destinations for tilapia fry from TiLV-affected Thai hatcheries did not indicate volumes or any further distinctions, so the frequency of shipments is unknown, neither the precise destination of potentially affected fry. Although China is reportedly monitoring for the disease, there has not been a confirmed case reported (Intrafish 2017) (Kramer 2017). Since TiLV has not been confirmed in China it does not currently impact the score for Criterion 7 – Disease, but monitoring should be prioritized.

Fishborne trematodes have been identified in tilapia farms of Guangdong province, but low prevalence was generally observed with highest rates in nursery monoculture ponds (6.2% prevalence) as opposed to nursery polyculture systems (1.1%), and rates much lower in monoculture and polyculture grow-out ponds at 0% and 0.5% respectively (Liet al. 2013a). However, regarding the impact this disease might have on wild fish, the results of this study indicate that on-farm amplification and to-the-wild transmission are mitigated by biosecurity measures taken by farmers, since the prevalence on-farm was significantly lower in comparison to the prevalence in local wild-caught fish from the surrounding areas.

Regulations on the control of disease in Chinese aquaculture are largely aimed at protecting farmed stocks from large-scale industry epidemics rather than the health of wild fish in the vicinity of farm sites. The Law on Animal Diseases (1997, amended in 2007, 2013) outlines the general requirements for quarantine measures that are administered primarily at the central and provincial government levels and these requirements do specifically include aquaculture (Central Government of the People's Republic of China 2013). This law also describes the procedures required for controlling the spread of animal disease, such as reporting large disease incidents, removing diseased animals after consulting a veterinarian for proper disposal, sanitizing associated equipment, and ensuring personnel working with diseased animals are not granted access to unaffected areas of the farm. The local veterinary department is responsible for enacting the first response to potential epidemics, by delineating the epidemic sites and identifying further threats for the potential to spread. Article 18 of the Fisheries Law (2004), outlines that administrative departments for fisheries at or above the county level will provide technical guidance for aquaculture in the prevention and treatment of diseases.

The Law on Animal Diseases (amended 2013) also states that the veterinary department is responsible for designing and implementing a mandatory immunization program; however, this does not appear to be implemented for aquaculture (pers. comm., F. Chen 2018) (China Aquaculture Network 2014). This is primarily due to the limited number of aquatic vaccines approved for use in China (Sohu 2017) (Table 9). Vaccines to prevent infection from several strains of *Vibrio*, *Edwardsiella*, *Aeromonas*, as well as grass carp hemorrhagic disease are the only aquatic vaccines produced and approved for use in China. Currently, the validity on the approval for vaccine for *Aeromonas* is expired (Sohu 2017).

Table 9. Vaccines produced domestically in China for aquatic use.

Vaccine (Chinese)	Vaccine (English)	Company
牙鲆鱼溶藻弧菌、鳗弧菌、迟缓爱德华菌病多联抗独特型抗体疫苗	*Vibrio alginolyticus, Vibrio anguillarum, Edwardsiella tarda* multi-antibody vaccine	Xi'an Skade Biological Products Co., Ltd.
大菱鲆迟钝爱德华氏菌病活疫苗（**EIBAV1株**）	*Edwardsiella tarda* live vaccine (EIBAV1 strain)	Zhejiang Nuoweiwei Biotechnology Co., Ltd.
草鱼出血病活疫苗（**GCHV-892株**）	Grass carp hemorrhagic disease live vaccine (GCHV-892 strain)	Zhaoqing Dahuanong Biological Pharmaceutical Co., Ltd.
嗜水气单胞菌败血症灭活疫苗	*Aeromonas hydrophila sepsis* inactivated vaccine	Guangzhou Purin Biological Products Co., Ltd.

Source: Sohu 2017

These regulations aim to reduce the prevalence of disease at the farm level and therefore theoretically reduce the potential discharge of pathogens to the environment; they include enforceable metrics in the form of quarantine protocols, mandated reporting and lists of mandatory immunizations. Nonetheless, there is little detail on the enforcement measures for these regulations and there appears to be no enforcement on reporting requirements for incidence of disease at the farm level. Additionally, there is a lack of investigation into transmission of diseases between farm and wild species; therefore, this report relies on incidence of on-farm pathogens and production system details.

Conclusions and Final Score

There is currently no available research into the impacts of on-farm diseases in Chinese tilapia on wild fish; thus, the Risk-Based Assessment was used for this criterion. There have been reported mass mortality events in Chinese tilapia pond cultivation systems. These have largely been the result of *Streptococcus* bacterial infections, and there has been some demonstrated resistance to antimicrobial drugs used to treat them. Also, new and emerging diseases are being reported in major production regions in China, and though disease control regulations are in place from the central government, there is no information on their enforcement or further implementation at lower levels of government. Thus, there is a risk posed to wild fish through the amplification of diseases from infected farmed fish. Pond systems are typically drained once at harvest (see Criterion 2 – Effluent), which reduces the risk of transmission to wild fish populations, but there is evidence of high infection and mortality rates on farms and the implementation and efficacy of biosecurity measures are currently unknown. Therefore, the final score is 3 out of 10 for Criterion 7 – Disease.

Criterion 8X: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

- Impact: the removal of fish from wild populations for on-growing to harvest size in farms
- Sustainability unit: wild fish populations
- Principle: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 8X Summary

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0–10)	0	
Critical?	NO	GREEN

Brief Summary

Seed production of tilapia in China can occur by collecting seedlings from grow-out ponds; however, the predominant method is via large-scale hatchery production. The development of Genetically Improved Farmed Tilapia (GIFT) seed has helped overcome inconsistencies in traditional seed collection from grow-out ponds, increase growth rates, and increase cold and salinity tolerance. There are >200 hatcheries/nurseries nationwide, which includes five national seed hatcheries and >10 tilapia seed brands. Recent literature confirms that (domestic) hatchery production is more than 100 billion fingerlings annually, which is sufficient to meet industry demand. Because this is a closed, domesticated life cycle and 0% of the farmed tilapia stock is dependent on wild broodstock or wild fisheries, the final numerical score for Criterion 8X – Source of Stock is 0 out of –10.

Justification of Rating

There are two methods for seed production of tilapia in China: either by collecting seedlings from grow-out ponds or from large-scale hatchery production (Qiuming and Yi 2004). The production of seedlings (i.e., those fish to be stocked for grow-out) by collecting them from grow-out ponds after natural spawning is less efficient at producing males for grow-out due to impure parent genotype segregation; it is more labor intensive and less dependable (Qiuming and Yi 2004) (Xu and Ming 2018). The collection method for seed production has not been as prevalent in recent years, and large-scale hatchery production is utilized in some of the main producing provinces (Guangdong, Hainan, Guangxi). Primarily in these hatcheries, the collective production of tilapia fingerlings was sufficient to meet the needs of the tilapia industry, based on numbers of approximately 103 billion in 2013 (Xu and Ming 2018). As of 2014, there has been an estimated >200 hatcheries/nurseries, which includes five national seed hatcheries and >10 tilapia seed brands, which are located in Guangdong (100 hatcheries/nurseries), Hainan (40 hatcheries/nurseries) and Guangxi (10 hatcheries/nurseries) (Zhang 2014).

Genetically Improved Farmed Tilapia (GIFT) seedlings were developed to help overcome inconsistency in traditional seedling collection from grow-out ponds, increase the growth of production, and increase cold tolerance (Zhang et al. 2015) (Xu and Ming 2018). Many of the tilapia strains currently being bred in the large hatcheries are hybrids, which are also being selected to produce a large number of males, which primarily improves the growth rate (Xu and Ming 2018).

Because Chinese tilapia production, like that of the industry globally, operates with a closed, domesticated life cycle, and none of the farmed tilapia stock is dependent on wild broodstock or wild fisheries, the final numerical score for Criterion 8X – Source of Stock is 0 out of –10.

Conclusions and Final Score

Because no tilapia farm stock in China is dependent on wild broodstock or wild fisheries, the final numerical score for Criterion 8X – Source of Stock is 0 out of –10.

Criterion 9X: Predator and wildlife mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: aquaculture populations pose no substantial risk of deleterious effects to wildlife or predator populations that may interact with farm sites.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Predator and wildlife mortality parameters	Score	
C9X Predator and wildlife mortality Final Score (0–10)	**–3**	
Critical?	NO	**GREEN**

Brief Summary

Pond cultivation of tilapia is considered to attract a variety of predators and other wildlife: reptiles, birds, and small mammals. However, data on mortalities that occur as a result of this interaction in China are not available. Water birds in Chinese tilapia growing regions have been shown to be closely associated with aquaculture ponds. Despite this documented interaction, there is no information regarding whether control methods are taken by farmers against migratory birds. There is also a lack of research on wildlife interactions with tilapia ponds in China, and current literature suggests there is potential for migratory water birds to utilize ponds for foraging and resting. Chinese law does contain protections for rare and endangered species, yet the level of implementation for these regulations, as well as the specificity for aquaculture activities is unclear. Due to unknown interactions, evidence of the presence of wildlife on the farms, the presence of legal protections yet unclear implementation, and the possibility of migrating birds utilizing ponds for foraging and resting, the score for Criterion 9X – Predator and Wildlife Mortalities is –3 out of –10.

Justification of Rating

Pond cultivation of tilapia is considered to attract a variety of predators, such as reptiles, birds and small mammals (El-Sayed 2006) (Lucas and Southgate 2012). However, data on mortalities that occur as a result of this interaction in China are not available.

There is a lack of research on wildlife interactions with tilapia ponds in China, and current literature suggests the potential for migratory water birds to utilize ponds for foraging and resting (Choi et al. 2013). Many species of water birds in Chinese tilapia growing regions have been shown to be closely associated with aquaculture ponds (Ma et al. 2004, 2009) (Ke et al. 2011) (Choi et al. 2013) (Bai et al. 2015), ranging from the endangered red-crowned crane (*Grus japonensis*) (Ke et al. 2011) to more common dunlin shorebirds (*Calidris alpine*) (Choi et al. 2013). These interactions suggest that ponds can be used for foraging and resting (Choi et al. 2013) throughout the year or during migrations.

Within Chinese regulations, both terrestrial and aquatic wildlife is considered a state resource. The Wildlife Protection Law of the People's Republic of China specifically covers terrestrial and aquatic species that are "rare or near extinction" and terrestrial species that are "of important ecological, scientific, and social value" (Central Government of the People's Republic of China 1988, revised 2016). The list of wildlife that is considered rare or vulnerable in the context of the law is available online.[3] Further protections specifically for wild aquatic animals are covered in the Regulations of the People's Republic of China for the Implementation of Wild Aquatic Animal Protection (1993).

Both regulations require permits for capturing wild animals that are not under special protection and also prohibit the capture or extermination of a wild animal that is considered rare or vulnerable. Nonetheless, the law does indicate that a special permit for hunting some species protected by the Wildlife Protection Law can be granted in special circumstances, though it doesn't indicate what those circumstances would be. Because both of these regulations are not specific to aquaculture, it is unknown to what extent (if any) these special provisions are utilized specifically for the tilapia industry. Additionally, though these regulations do protect the rare and endangered species, it is unclear how the regulations are implemented at a local level.

Despite the known interaction of birds with fish ponds, there is no information regarding whether control methods are, in fact, taken by farmers against migratory birds. Laws are in place protecting rare and endangered species; however, the level of implementation and enforcement is unknown.

Conclusions and Final Score

Tilapia ponds can attract or interact with many species of reptiles, mammals, and water birds, yet there is no information regarding the prevalence of wildlife mortalities and what impact they might have on the populations. Additionally, there is evidence to suggest tilapia ponds can provide sufficient habitat for migrating birds. Chinese law does contain protections for rare and endangered species, but the level of implementation for these regulations, as well as the specificity for aquaculture activities is unclear. Due to unknown interactions, evidence of the presence of wildlife on the farms, the presence of legal protections, yet unclear implementation, and the possibility of migrating birds utilizing ponds for foraging and resting, the score for Criterion 9X – Predator and Wildlife Mortalities is –3 out of –10.

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[3] http://www.fao.org/fishery/shared/faolextrans.jsp?xp_FAOLEX=LEX-FAOC006515&xp_faoLexLang=E&xp_lang=en

Criterion 10X: Escape of Secondary Species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Impact: aquaculture operations by design, management or regulation avoid reliance on the movement of live animals, therefore reducing the risk of introduction of unintended species.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	0	
F10Xb Biosecurity of source/destination	4	
C10X Escape of unintentionally introduced species Final Score (0–10)	**–6.00**	**YELLOW**

Brief Summary

Trans-waterbody movement between ecologically distinct environments risks introducing non-native pathogens, parasites, and non-target species, and the risk is driven by the reliance of production on such movements. In China, international imports of tilapia species for aquaculture breeding programs have occurred historically; however, there is currently a national program for seed production. In this program, seed is produced nationally and distributed locally to farmers of all production scales, which is likely to include trans-waterbody movements, resulting in a factor 10Xa score of 0 out of 10. The biosecurity of the source (hatchery) is presumed to be higher than that at the destination (farm), due to the developed industrial hatchery system and the inherent risks of culture for young life stages, resulting in a moderate score of 4 out of 10 for factor 10Xb. Although Chinese tilapia is self-sufficient in domestic seed production, the dissemination of tilapia broodstock and seed is reliant on trans-waterbody movements. Combining the scores for factors 10Xa and 10Xb results in the final numerical score for Criterion 10X – Escape of Secondary Species of –6 out of –10.

Justification of Rating

Factor 10Xa International or trans-waterbody live animal shipments

Mass movements of animals for aquaculture without appropriate management procedures can lead to the simultaneous unintentional introduction of accompanying animals (Naylor et al.

2001). Trans-waterbody movement between ecologically distinct environments risks introducing non-native pathogens, parasites, and non-target species, and the risk is driven by the reliance of production on such movements.

In China, international imports of species for aquaculture breeding programs have occurred in the past, and this includes the import of tilapia from several Southeast Asian countries, Egypt, Sudan, and the US since the 1940s (Yan et al. 2001) (Xu and Ming 2018). Since the introduction of the Genetically Improved Farmed Tilapia (GIFT) strain to China in the early 2000s, there is now a heavily government-supported infrastructure in place to produce GIFT seed domestically (Xu and Ming 2018) (Kumar and Engle 2016). In the past there have been small-scale imports of tilapia for seed production, including base GIFT populations from Vietnam in 2004 (Thodesen et al. 2011, 2013) and from Taiwan to Fujian province (Jiang et al. 2013). Additionally, Dong et al. (2017) identified China as a destination of fry from Thai hatcheries, but this report did not indicate volumes or destinations, so it is unknown whether this is a common occurrence for tilapia breeding programs in China or a one-time import for research purposes.

As demonstrated by the Fujian provincial government, there has been significant investment in the development of more industrialized seedling production systems (Jiang et al. 2013), and domestic broodstock that are adapted for different production systems in China are maintained domestically (Thodesen et al. 2011, 2013). GIFT seed is produced in provincial hatcheries and distributed to farmers of all production scales across China, which includes trans-waterbody movements (Honglang 2007) (Jiang et al. 2013). In Figure 10, the general framework for the tilapia breeding system in China is outlined, showing the centralized organization and potential for trans-waterbody movement as breeds and strains are disseminated throughout the country.

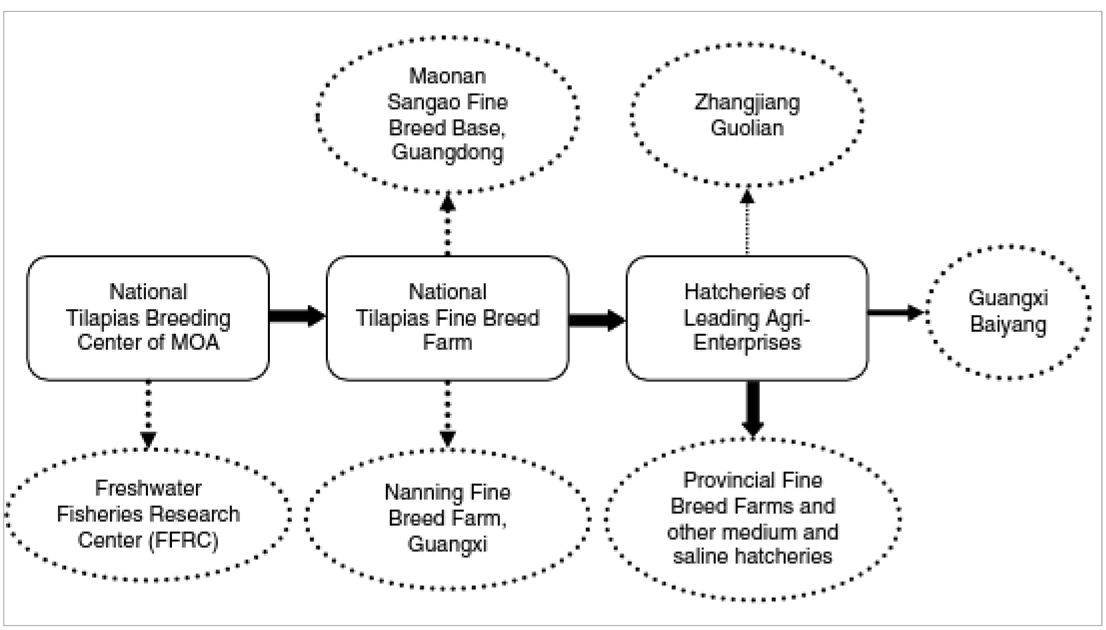

Figure 10. Framework for tilapia breeding systems in China (Xu and Ming 2018).

Although the production of tilapia in China does not rely on international waterbody movement, it does rely on trans-waterbody movement among provinces. Without specific data on the percentage of Chinese tilapia production that is reliant on trans-waterbody movements, based on the aforementioned national breeding systems, it must be assumed that nearly all production is reliant on such movements; therefore, the score for Factor 10Xa is 0 out of 10.

Factor 10Xb Biosecurity of source/destination
The biosecurity of hatcheries, or the source of animal movements, is reportedly high, and assumed to be higher than growout farms due to the sensitivity of eggs and larvae (Thodesen et al. 2011) (Jiang et al. 2013). Hatchery facilities are likely comprised of a combination of systems for different stages of the fish, most notably flow-through tanks or raceways (Xu and Ming 2018). Additionally, biosecurity is inherent in the quality demands and highly controlled environment of large-scale, industrialized hatchery production in China (Xu and Ming 2018) (Jiang 2013). Broodstock are also maintained in research institutes that have strict biosecurity management measures in place (Thodesen et al. 2011) (Jiang et al. 2013). The biosecurity risk for source of animal movements is moderate and scores 4 out of 10.

The biosecurity risk of the destination (farm) is likely variable. Ponds are believed to typically operate as harvest-exchange (Liu et al. 2018), whereby water is drained from the ponds at harvest. However, given the unknown adoption of best-management practices regarding escapes prevention and biosecurity in ponds, the precautionary principle is applied and a biosecurity risk score of 2 out of 10 is given.

As the higher of the two scores, the hatchery biosecurity score of 4 out of 10 is used for Factor 10Xb – Biosecurity of source/destination.

Conclusions and Final Score
Although Chinese tilapia is self-sufficient in domestic seed production, the dissemination of tilapia seed is reliant on trans-waterbody movements. The biosecurity of the source (hatchery) is presumed to be higher than that at the destination (farm), resulting in a moderate score of 4 out of 10. Combining the scores for Factors 10Xa (0 out of 10) and 10Xb (4 out of 10) results in the final numerical score for Criterion 10X – Escape of Secondary Species of –6 out of –10.

Overall Recommendation

The overall recommendation is as follows:

The overall final score is the average of the individual criterion scores (after the two exceptional scores have been deducted from the total). The overall rating is decided according to the final score, the number of red criteria, and the number of critical scores as follows:

- Best Choice = Final Score ≥6.661 **and** ≤10, and no Red Criteria, **and** no Critical scores
- Good Alternative = Final score ≥3.331 and ≤6.66, **and** no more than one Red Criterion, **and** no Critical scores.
- Red = Final Score ≥0 and ≤3.33, **or** two or more Red Criteria, **or** one or more Critical scores.

Criterion	Score	Rank	Critical?
C1 Data	3.64	YELLOW	
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	2.93	RED	NO
C4 Chemicals	0.00	CRITICAL	YES
C5 Feed	8.16	GREEN	NO
C6 Escapes	0.00	CRITICAL	YES
C7 Disease	3.00	RED	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-3.00	GREEN	NO
C10X Secondary species escape	-6.00	YELLOW	
Total	**13.73**		
Final score (0-10)	**1.96**		

OVERALL RANKING

Final Score	1.96
Rank	RED
Red criteria	3
Interim rank	RED
Critical Criteria?	YES

FINAL RANK

RED

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Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org . The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives" or "Avoid". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch®'s sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

Disclaimer
Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[4] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:

- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture
- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving

4 "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

practices for some criteria may lead to more energy intensive production systems (e.g. promoting more energy-intensive closed recirculation systems)

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Appendix 1 - Data points and all scoring calculations

Criterion 1: Data quality and availability

Data Category	Data Quality (0-10)
Industry or production statistics	2.5
Management	2.5
Effluent	2.5
Habitats	2.5
Chemical use	2.5
Feed	5
Escapes	2.5
Disease	2.5
Source of stock	10
Predators and wildlife	2.5
Unintentional introduction	5
Other – (e.g., GHG emissions)	n/a
Total	**40**

C1 Data Final Score (0-10)	**3.636363636**	**YELLOW**

Criterion 2: Effluents

Factor 2.1 - Biological waste production and discharge

Factor 2.1a - Biological waste production

Protein content of feed (%)	28.5
eFCR	1.4
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	14
N content factor (fixed)	0.16
N input per ton of fish produced (kg)	63.84
N in each ton of fish harvested (kg)	22.4
Waste N produced per ton of fish (kg)	**41.44**

Factor 2.1b - Production System discharge

Basic production system score	0.34
Adjustment 1 (if applicable)	0
Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0

Discharge (Factor 2.1b) score (0-1)	**0.34**

\# % of the waste produced by the fish is discharged from the farm

Factor 2.1 Score - Waste discharge score

Waste discharged per ton of production (kg N ton-1)	14.09
Waste discharge score (0-10)	**8**

Factor 2.2 – Management of farm-level and cumulative effluent impacts

2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1
2.2 Effluent management effectiveness	**0.8**

C2 Effluent Final Score (0-10)	**5.00**	**YELLOW**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0-10)	4

Factor 3.2 – Management of farm-level and cumulative habitat impacts

3.2a Content of habitat management measure	2
3.2b Enforcement of habitat management measures	1
3.2 Habitat management effectiveness	**0.8**

C3 Habitat Final Score (0-10)	**3**	**RED**
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	**Score**
C4 Chemical Use Score (0-10)	**Critical**

C4 Chemical Use Final Score (0-10)	Critical	RED
Critical?	YES	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	Score
5.1a Fish In : Fish Out (FIFO)	
Fishmeal inclusion level (%)	1.5
Fishmeal from by-products (%)	20
% FM	1.2
Fish oil inclusion level (%)	0.5
Fish oil from by-products (%)	0
% FO	0.5
Fishmeal yield (%)	21.25
Fish oil yield (%)	4
eFCR	1.4
FIFO fishmeal	0.08
FIFO fish oil	0.18
FIFO Score (0-10)	**9.56**
Critical?	NO
5.1b Sustainability of Source fisheries	
Sustainability score	–7
Calculated sustainability adjustment	–0.25
Critical?	NO
F5.1 Wild Fish Use Score (0-10)	**9.32**
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	28.5
eFCR	1.4
Feed protein from fishmeal (%)	
Feed protein from EDIBLE sources (%)	70.34
Feed protein from NON-EDIBLE sources (%)	29.66
Protein OUTPUTS	
Protein content of whole harvested fish (%)	14
Edible yield of harvested fish (%)	42
Use of non-edible by-products from harvested fish (%)	50
Total protein input kg/100kg fish	39.9

Edible protein IN kg/100kg fish	28.07
Utilized protein OUT kg/100kg fish	15.47
Net protein gain or loss (%)	–44.87
Critical?	NO
F5.2 Net protein Score (0-10)	**5**

5.3. Feed Footprint

5.3a Ocean Area appropriated per ton of seafood	
Inclusion level of aquatic feed ingredients (%)	2
eFCR	1.4
Carbon required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Ocean productivity (C) for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	0.73
5.3b Land area appropriated per ton of seafood	
Inclusion level of crop feed ingredients (%)	98
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.4
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.52
Total area (Ocean + Land Area) (ha)	1.25
F5.3 Feed Footprint Score (0-10)	9

Feed Final Score

C5 Feed Final Score (0-10)	**8.16**	**GREEN**
Critical?	**NO**	

Criterion 6: Escapes

6.1a System escape Risk (0-10)	2	
6.1a Adjustment for recaptures (0-10)	0	
6.1a Escape Risk Score (0-10)	**2**	
6.2. Invasiveness score (0-10)	**0**	
C6 Escapes Final Score (0-10)	**0**	**RED**
Critical?	**YES**	

Criterion 7: Diseases

Disease Evidence-based assessment (0-10)	

Disease Risk-based assessment (0-10)	3	
C7 Disease Final Score (0-10)	**3**	**RED**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	0	
C8 Source of stock Final Score (0-10)	**0**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and predator mortalities

C9X Wildlife and Predator Score (0-10)	**–3**	
C9X Wildlife and Predator Final Score (0-10)	**–3**	**GREEN**
Critical?	NO	

Criterion 10X: Escape of unintentionally introduced species

F10Xa live animal shipments score (0-10)	0.00	
F10Xb Biosecurity of source/destination score (0-10)	4.00	
C10X Escape of unintentionally introduced species Final Score (0-10)	**–6.00**	**YELLOW**
Critical?	n/a	