Monterey Bay Aquarium

Seafood Watch®

Whiteleg Shrimp

Litopenaeus vannamei

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China

Ponds

December 11, 2015

Cyrus Ma – Seafood Watch

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.

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.

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Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[1] 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 practices for some criteria may lead to more energy-intensive production systems (e.g. promoting more energy-intensive closed recirculation systems).

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

Once a score and rank has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ranks 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.

Final Seafood Recommendation

Whiteleg Shrimp
Litopenaeus vannamei
China
Intensive shrimp ponds

Criterion	Score (0-10)	Rank	Critical?
C1 Data	3.33	YELLOW	
C2 Effluent	3.00	RED	NO
C3 Habitat	2.75	RED	NO
C4 Chemicals	0.00	RED	NO
C5 Feed	3.44	YELLOW	NO
C6 Escapes	3.00	RED	NO
C7 Disease	2.00	RED	NO
C8 Source	10.00	GREEN	
3.3X Wildlife mortalities	-5.00	YELLOW	NO
6.2X Introduced species escape	-2.00	GREEN	
Total	**20.53**		
Final score	**2.57**		

OVERALL RANKING

Final Score	2.57
Initial rank	RED
Red criteria	5
Interim rank	RED
Critical Criteria?	NO

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. Color ranks: red = 0 to 3.33, yellow = 3.34 to 6.66, green = 6.66 to 10. Criteria 9X and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects very poor performance. Two or more red criteria trigger a red final result.

Summary

The final numerical score for intensively farmed *Litopenaeus vannamei* in China is 2.61 out of 10, where the presence of 5 red criteria (Effluent, Habitat, Chemicals, Escapes, and Disease) results in an overall Red “Avoid” recommendation.

Executive Summary

In China, the introduction of whiteleg shrimp has resulted in an almost complete shift in production away from the previously dominant native giant tiger prawn (*Penaeus monodon*). Although China initially exported most of its farmed shrimp, ~70% of Chinese shrimp production is now purchased domestically. Due to increasing local demand and the establishment of import restrictions for antibiotic residues, the focus in China's shrimp farming industry has shifted from exporting farmed shrimp to further development of domestic markets. Shrimp production systems in China are diverse and operate at different levels of intensity. About 15% of shrimp farms in China are intensive systems, which tend to produce products destined for export markets, while the remaining 85% are semi-intensive or extensive shrimp farms, which tend to supply to domestic markets. Generally, while more domestic-oriented shrimp production systems tend to be located in northern regions, *L. vannamei* are typically cultured in intensive farms located in southern China. This report focuses on the environmental impact of intensive shrimp farming, as this system produces the bulk of farmed shrimp intended primarily for export to the US market.

In addition to peer-reviewed journals, literature by FAO and communications with industry experts are particularly important data sources for a range of subjects in this assessment. Nonetheless, cumulative effluent and habitat impacts, current chemical use, associated wildlife mortalities, and the broader ecological impacts of non-native shrimp introduction have neither been well-studied nor well-documented. Overall, data accessibility and availability for intensive *L. vannamei* farming in China is variable (depending on the subject matter) and is scored poorly based on current information availability. The final score for the Data Criterion is 3.33 out of 10 for *L. vannamei*.

The Effluent Criterion combines the total amount of waste released per ton of production with an assessment of applicable management measures and their implementation to provide a measure of the ecological impact from discharged wastes. For intensive *L. vannamei* farms, the total waste discharged (using nitrogen as a proxy) is estimated to be 73.92kg N t^{-1}. Regarding regulatory management, administrative agencies are focused primarily on maximizing the economic benefits from aquaculture rather than environmental protection. Despite the presence of cumulative impact considerations at the national level, in practice, there is no effective monitoring mechanism for aquaculture-based effluent discharges. Additionally, poor enforcement and the absence of any penalty for the release of farm effluents has resulted in frequent infringements on carrying capacity limits for receiving waterbodies. Overall, pond systems in China produce moderate impacts to the environment from effluent discharge. When combined with poor management of cumulative impacts, these conditions result in a final Criterion 2 – Effluent score of 3 out of 10 for intensively farmed *L. vannamei*.

In China, shrimp aquaculture has historically been sited in high value, sensitive habitats such as mangroves, mudflats, estuaries and coastal intertidal areas. However, given the absence of coastal areas available for shrimp farm expansion, Chinese *L. vannamei* farmers have rapidly expanded to inland agricultural areas (the dominant production area for the sector since 2008).

Given the minimum farm-size requirement for environmental impact assessment (EIA) in China, only a limited number of *L. vannamei* farmers are required to participate in environmental assessment. Failure to complete the EIA process is met with a minimal penalty and a “make-up” EIA can be processed after construction is completed. Furthermore, under the decentralized policy-setting in China, the implementation and enforcement of existing habitat management regulations is considered to be both ineffective and inappropriate for the scale of the industry. Combining the degree of habitat conversion with management effectiveness results in a Habitat Criterion score of 2.75 out of 10 for intensive *L. vannamei* farms.

In China’s shrimp farming industry, ineffective chemical regulations have resulted in the ongoing use of banned antibiotics and antimicrobials such as gentian violet, malachite green, and chloramphenicol (illegal in both China and the US). Furthermore, chloramphenicol is recognized as highly important to human health by the World Health Organization. Overall, these conditions result in a low Criterion 4 – Chemical Use score of 0 out of 10 for intensive *L. vannamei* farms in China.

In intensive *L. vannamei* culture, farm stock is fed formulated, industrially-manufactured pellets, and there is industry-wide reliance on commercial feeds. Using a feed conversion ratio (FCR) of 1.6, and an average of 30% fishmeal and 1.5% fish oil in the feeds, the average Fish In: Fish Out ratio (based on fishmeal) is 2.13. A FI:FO of 2.13 indicates that 2.13 tons of fish are required in order to supply sufficient feed to grow 1 ton of farmed shrimp. With a moderate source fishery sustainability score (-6 of -10), the final adjusted Wild Fish Use score for intensive *L. vannamei* farming is 3.39 out of 10. In addition to a 40% protein content of feed, the assumption that all non-marine protein components are from edible crops results in a net edible protein loss of ~73%. Furthermore, a combined ocean and land area of 13.52 ha is required to supply the amount of feed ingredients necessary to produce one ton of farmed shrimp. Overall, this feeding strategy results in a low-moderate Criterion 5 – Feed score of 3.44 out of 10 for farmed *L. vannamei*.

There is an inherent risk of escape in pond-based shrimp aquaculture due to the exchange of pond water with the surrounding waterbody. *L. vannamei* are non-native to China, and despite repeated introductions and the ongoing presence of escaped *L. vannamei* in the wild, there is no evidence that they have become established. However, as a foreign shrimp species with an unestablished yet persistent presence in the wild, *L. vannamei* escapes nonetheless present a strong likelihood for ecological disturbance from competition with other species for food and space between farmed and wild penaeids. With no direct data on recapture efforts or on significant mortality levels in escaped shrimp, the overall Criterion 6 – Escape score is 3 out of 10 for farmed *L. vannamei*.

Due to the openness of the production system and the prevalence of multiple diseases known to occur on Chinese shrimp farms, the potential risk of transmitting farm-based shrimp diseases to wild populations is considered to be high. Given the growing nature of the Chinese shrimp farming industry and the lack of effective biosecurity measures to prevent the ongoing spread of disease (including EMS), the score for Criterion 7–Disease is a moderate-high 2 out of 10 for intensive *L. vannamei* farms in China.

In China, intensive *L. vannamei* farms are considered to be 100% reliant on hatchery production for farm stock. Based on their independence from wild stocks, the score for Criterion 8 – Source of Stock is 10 out of 10 for intensively farmed *L. vannamei*.

In China, data on wildlife mortalities from interactions with shrimp farms is absent. Given the scarcity of information regarding the wildlife impacts associated with *L. vannamei* farming in China, more robust data from similar shrimp farming regions in Asia are used in this assessment to evaluate Chinese shrimp farms by proxy. In Indonesia, many wildlife species are deterred or eliminated to increase productivity. While the impact of shrimp farms on low-productivity species (predatory fish, amphibians, reptiles, birds) are unknown, the farm-related mortalities of competitive species (polychaetes, insects, shrimps, snails, herbivorous fishes) and destructive pests (mud crabs) are not considered to be significant given the highly productive nature and large population of each of these species. Using a precautionary approach to scoring this criterion, these conditions result in a Criterion 9X – Wildlife and Predator Mortalities penalty score of -5 out of -10 for intensive *L. vannamei* farms in China.

In the *L. vannamei* farming industry, broodstock are sourced directly from SPF-certified hatcheries in Hawaii. While intensive shrimp farms are considered to be production systems with a moderate risk of escape, the more robust biosecurity measures present at SPF-certified hatcheries reduces the overall risk of unintentional introductions. Despite the international and trans-waterbody movement of *L. vannamei* broodstock between Hawaii and China, the overall potential for escapes is considered to be low and results in a final C10X–Escape of Unintentionally Introduced Species penalty score of -2 out of -10 for intensive *L. vannamei* culture in China.

The final numerical score for intensively farmed *Litopenaeus vannamei* in China is 2.61 out of 10, where the presence of 5 Red criteria (Effluent, Habitat, Chemicals, Escapes, and Disease) results in an overall Red “Avoid” recommendation.

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Species Overview

The whiteleg or Pacific white shrimp (*L. vannamei*) is a penaeid shrimp native to tropical marine habitats along the eastern Pacific Coast, from Peru to Mexico, where water temperatures are normally >20^{o}C throughout the year (Wyban and Sweeney 1991, Rosenberry 2002, Briggs et al. 2005, FAO 2013). While adults live and spawn in the open ocean, post larvae (PL) migrate inshore to spend their juvenile, adolescent, and sub-adult stages in coastal estuaries, lagoons, or mangrove areas. Male *L. vannamei* become mature at 20 g and females are considered fully grown at 28 g at the age of 6–7 months (FAO 2013).

L. vannamei was introduced into mainland China in 1988 and commercial production has rapidly increased since the late 1990s (Huang et al. 2009). As a result, *L. vannamei* has become the most widely cultivated shrimp species in China due to its favorable and efficient culture characteristics when compared to other species such as the giant tiger prawn (*Penaeus monodon)* (Cheng et al. 2006, Sævarsson 2007, Zhang et al. 2009, FAO 2013). These characteristics include their ability to grow in a wide range of water salinities (1 to 40 ppt) (Liang et al. 2008, Zhou et al. 2012, Dong 2012), a lower risk of disease (Dong 2012), shorter culture periods before reaching a marketable size (Cao 2012), faster growth rates (Briggs et al. 2005, Dong 2012), lower dietary protein requirements (Briggs et al. 2005, Dong et al. 2013), higher larval survival (Briggs et al. 2005), and greater availability of specific-pathogen-free (SPF) broodstock (Briggs et al. 2005, Liao and Chien 2011).

Chinese shrimp farms are distributed along almost 18,000 km of coastline from Hainan Province in the southern tropics and north to Liaoning Province in the temperate zone (Figure 1).

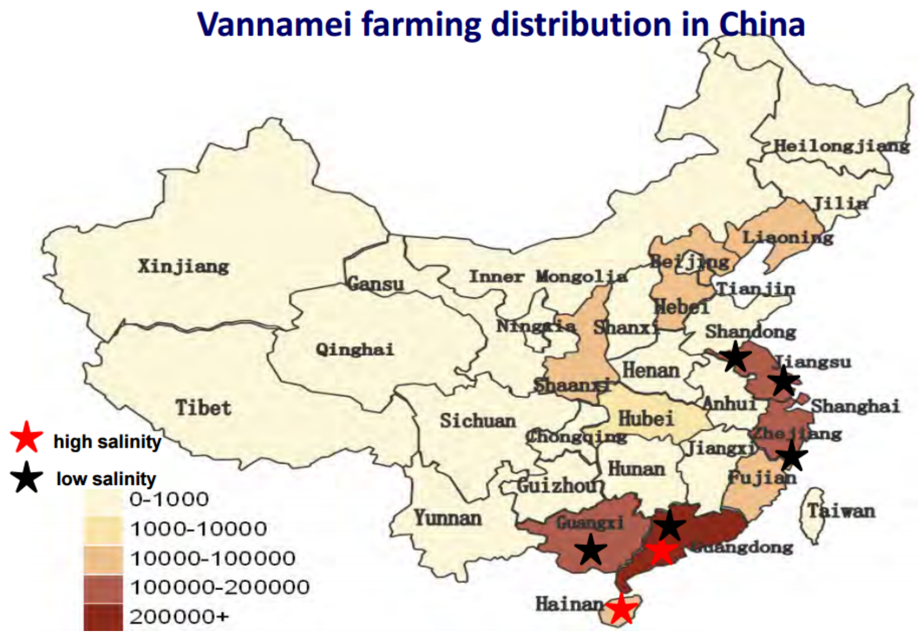

Figure 1. Salinity and production (mt) of *L. vannamei* farming regions in China. (Zhang et al. 2011)

The leading shrimp production regions in China include Guangdong, Guangxi, Zhejiang, Jiangsu, Shandong, Fujian, and Hainan (Yuan et al. 2006, Cao 2014 pers. comm., Zhang 2014 pers. comm.). *L. vannamei* is produced primarily in Guandong, Jiangsu, Zhejiang, Hainan, and Guanxi, but also to a lesser degree in Shandong, Fujian and other provinces (Figure 2) (Ma and Bao 2011). Since 2003, approximately 50% of *L. vannamei* production in China has been done in freshwater ponds (FAO 2011, Valderrama and Anderson 2011, Zhejiang Aquatic Product Trade 2011, Cao 2014 pers. comm.). In southern China, *L. vannamei* are typically cultured in intensive pond systems (GAO et al. 2012).

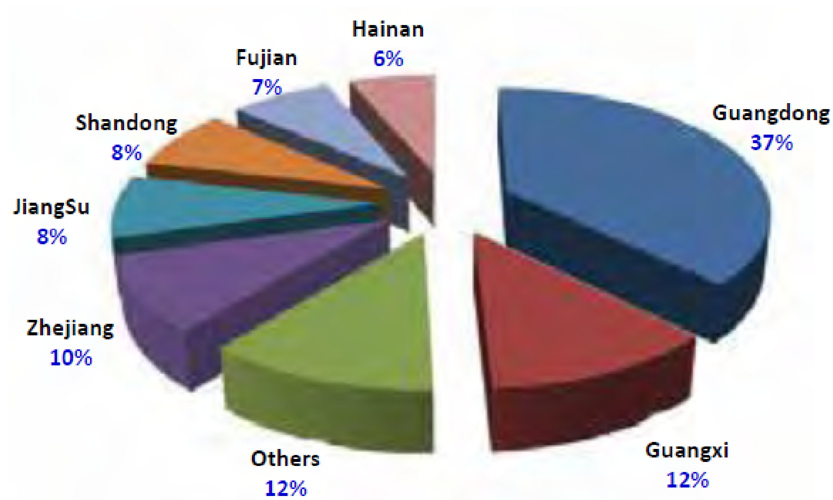

Figure 2. Distribution of *L. vannamei* production in China. (Dong 2012)

Given the strong freshwater tolerance of *L. vannamei*, Chinese shrimp farms have rapidly expanded to many inland agricultural areas since 2001 (Zhu et al. 2004). Since the end of 2008, freshwater (inland) production has overtaken brackish water (coastal) production (White et al. 2013).

Production Statistics

On a global scale, China produces the largest amount of farmed shrimp of any country (Fuchs et al. 1999, Mungkung 2005, Tacon et al. 2012) and accounts for ~32% of worldwide production (~1.4 million tons–Figure 1) (FIGIS 2015). In 2013, *L. vannamei* accounted for ~84% of shrimp production in China (FIGIS 2015). The other shrimp species include *P. monodon*, *P. japonicus*, *P. chinensis* and, to a much smaller extent, *P. merguinsis*, *P. penicillatus* and *Metapenaeus ensis* (Xie and Yu 2007, Ma and Bao 2011, Dong et al. 2013).

Production of *L. vannamei* in China has followed a general trend of increasing production since 2000 (Figure 1) (FIGIS 2015). This increase in shrimp production was achieved with intensification of farming systems by large commercial companies (Prein 2007, Cao 2012). In 2012, *L. vannamei* production exceeded 1.37 million tons (up from 1.3 million tons in 2011) and accounted for 40% of farmed shellfish production nationally (Meador and Wu 2012). Despite the growing trend in *L. vannamei* production, increases in the number of farm sites have occurred only in more recent years (Zhang 2014 pers. comm.).

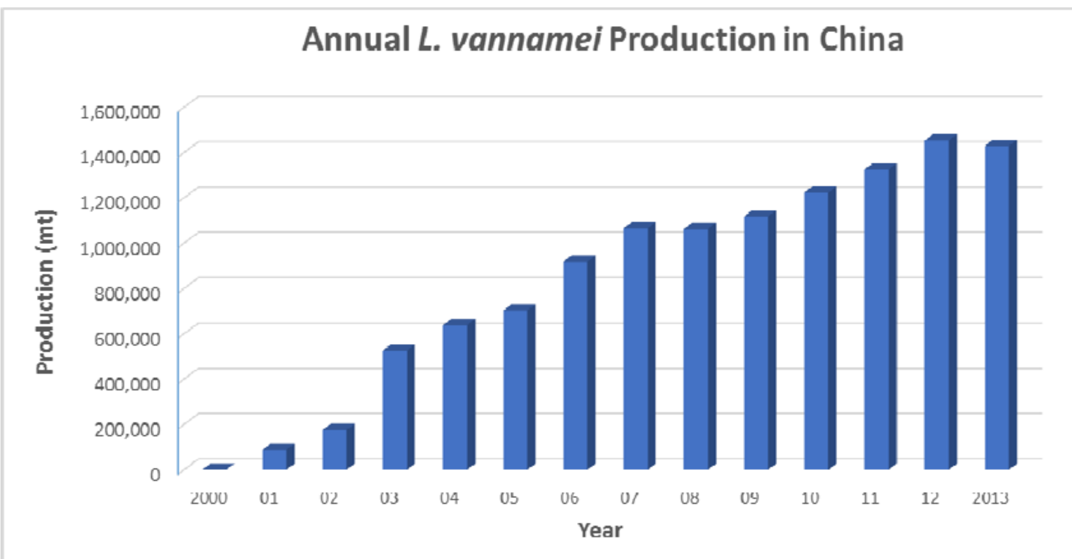

Figure 1. Production of *L.vannamei* in China, 2000-2013 (FIGIS, 2015)

Import and Export Sources and Statistics

Although China was the second largest exporter of farmed shrimp in 2010 (Mungkung 2005, FAO 2010), China has recently begun shifting its focus toward domestic market growth (Yun et al. 2010, Anonymous 2014). This shift from exporting the majority of its farmed shrimp to further development of domestic markets is driven by increasing demand within China (Cao 2014), as well as the establishment of US and EU import restrictions for antibiotic residues (Briggs et al. 2005). Dong et al. (2013) and Dong (2012) report that ~70% of the total Chinese farmed shrimp are now purchased domestically, and that this number will likely continue to increase. Although growing demand for farmed shrimp in US, European, and Japanese markets has increased export-oriented shrimp production in newly industrialized Asian countries in recent years (Cao et al. 2011), China is expected to transition from being a major exporter to a net importer of shrimp (Yun et al. 2010, Cao 2014, pers. comm., Zhang 2014, pers. comm., Anonymous 2014).

In 2014, the US imported ~71,775 tons of shrimp from China, worth ~$271,481,000 (USDA 2015). This quantity is ~5.7% of all US farmed shrimp imports (1,253,410 tons) in 2014. From January to September 2015, the US imported only 44,036 tons of farmed shrimp from China (USDA 2015).

Import data from the U.S. Department of Commerce and the U.S. Census Bureau do not distinguish between shrimp species, farmed versus wild-caught product, or the type of production system employed (NMFS 2013, Harvey 2013 pers. comm., Liddel 2013 pers. comm.). Because *L. vannamei* is not native to China and the majority of Chinese shrimp exports to the US are *L. vannamei* from intensive production systems, it is assumed that all Chinese shrimp imported to the US consists of *L. vannamei* farmed in intensive production systems. However, shrimp production systems in China are diverse and operate at different levels of intensity (Cao 2012). Therefore, without further data, it is unlikely, but possible, that some farmed Chinese shrimp available in the US market are *P. monodon* or may have been raised in lower intensity or combined production systems (i.e., polyculture).

Common and market names

Scientific Name	*Litopenaeus vannamei*
Common Name	Pacific white shrimp, white shrimp, western white shrimp, or shrimp
United States	**Whiteleg shrimp** (FDA, 2015b)
China	*南美白对虾*
Spanish	*Camarón patiblanco*
French	*Crevette pattes blanches*
Japanese	*Banamei-ebi (ばなめいえび)*

Product Forms

Shrimp from China are available in a number of product forms, including frozen or thawed, cooked or raw, head-on or head-off, tail-on or tail-off, shell-on, peeled, and deveined. They may also be present in value-added goods such as breaded shrimp or ready-made products.

Analysis

Scoring guide

- With the exception of the exceptional factors (9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional factors result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available here http://www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_AquacultureCriteraMethodology.pdf
- The full data values and scoring calculations are available in Annex 1.

Production system

Rapid growth of aquaculture production in the People's Republic of China has been driven by technical progress (e.g., commercial feeds, mechanical aeration, etc.) since the late 1990s. Although the People's Republic of China has the largest aquaculture industry in the world, there are very few large-scale aquaculture corporations domestically and most of the production comes from millions of small-scale farms owned by individual farmers. The mass expansion of farming scale has not brought mass benefit, but instead has caused frequent outbreaks of anoxia, HAB, epidemic fish diseases and mass mortality (White et al. 2013).

Chinese shrimp farming is a diverse industry utilizing different pond production systems (Cao 2012). Pond production systems are typically classified by stocking density and food source. In China, 85% are classified as semi-intensive and 15% as intensive farms (Cao 2012). Xie and Yu (2007) similarly reported that 85% of farms as semi-intensive, while 5% were considered intensive and 10% were extensive. Furthermore, variations in these classifications also exist, including Integrated multi-trophic aquaculture (IMTA). Importantly, Cao (2012) reports that farmed shrimp destined for export are raised primarily in intensive production systems in China. As a result, although the majority of Chinese shrimp farms are classified as less intensive production systems, the focus of this report is on intensively farmed shrimp which are destined for export to the US market. Nonetheless, it is important to note that only a complete global value chain analysis would be required to confirm the source production systems of shrimp imported from China. Further complicating the supply chain, there is evidence that Chinese seafood processors may buy raw shrimp from sources outside of China (e.g., India), and process and sell these product as Chinese (Anonymous 2014, pers. comm.).

Most farming operations for *L. vannamei* do not employ transitional nurseries, but instead transport PLs from local hatcheries at a reduced temperature either in plastic bags or transportation tanks and introduce them directly to grow-out ponds (FAO 2013). Although ponds are often earthen, liners made of plastic or concrete may be used in intensive systems to reduce erosion and improve water quality. Ponds are generally small (0.1 to 1 ha) with water depths around 1.5-2 m (Cao 2012, FAO 2013). Chinese intensive shrimp farms do not use fertilizers during growout (Cao 2012), but instead rely only on commercial shrimp feeds. Compared to less intensive systems, which use a combination of both feed and fertilizers, intensive farms are characterized by higher stocking densities (about 160-200 PL/m^2, although the range can be wider), greater aeration requirements, and elevated water exchange rates (8–15% daily).

Although semi-intensive and extensive shrimp farms can be found throughout China (Zhang 2014, pers. comm.), more intensive shrimp farms are generally located in southern China and less intensive systems tend to be located in northern regions (Gao et al. 2012). In southern China, *L. vannamei* are typically cultured in intensive pond systems (Gao et al. 2012). While southern farms generally have 2-3 production cycles per year, northern farms usually have only one cycle per year due to cooler temperatures during the winter season (Cao 2012).

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: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.*

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	5	5
Effluent	Yes	2.5	2.5
Locations/habitats	Yes	2.5	2.5
Predators and wildlife	Yes	2.5	2.5
Chemical use	Yes	5	5
Feed	Yes	2.5	2.5
Escapes, animal movements	Yes	2.5	2.5
Disease	Yes	2.5	2.5
Source of stock	Yes	5	5
Other – (e.g., GHG emissions)	No	Not relevant	n/a
Total			**30**

C1 Data Final Score	**3.33**	**YELLOW**

In addition to peer-reviewed journals, literature by FAO and communications with industry experts are particularly important data sources for a range of subjects in this assessment. Nonetheless, cumulative effluent and habitat impacts, current chemical use, associated wildlife mortalities, and the broader ecological impacts of non-native shrimp introduction have neither been well-studied nor well-documented. Overall, data accessibility and availability for intensive *L. vannamei* farming in China is variable, depending on the subject matter, and is scored poorly based on current information availability. The final score for the Data Criterion is 3.33 out of 10 for *L. vannamei*.

Justification of Ranking

Production Statistics

For farmed *L. vannamei*, national production statistics were publicly available from the Food and Agriculture Organization of the United Nations (FAO). While this data source covers relevant timeframes, there is an inherent level of aggregation in calculating national production statistics. Furthermore, statistics by FAO do not extend to production in 2014. As such, the data availability and quality of production statistics for the China shrimp farming industry is assessed a score of 5 out of 10.

Effluent

While there is evidence in the literature indicating that large portion of the nutrients in the waterbodies surrounding shrimp farms are generated from commercial feeds and fertilizers, direct information on the resulting environmental impact from the industry is largely unavailable and a risk-based assessment was performed for farmed *L. vannamei*. Pond discharge characteristics and waste production calculations are generated from peer-reviewed literature (Boyd et al. 2007, Cao 2012, Dong 2012, Dong et al. 2013). Furthermore, data on the content and effectiveness of regulatory measures were sourced primarily from FAO (Phillips et al. 2009; White et al. 2013; FAO 2013a, b, c) with supplemental information provided by an industry expert (Zhang 2014, pers. comm.). Despite these data sources, no information could be found describing requirements for monitoring or its enforcement throughout a complete production cycle. As such, the data availability and quality for effluent impact and management for farmed *L. vannamei* also receives a score of 2.5 out of 10.

Habitat

For habitat conversion by *L. vannamei* farms, scoring relies on peer-reviewed literature (Zhu et al. 2004, Wang 2005, Yang 2009, Zhang 2009) and FAO reports (White et al. 2013), which describe the impact of shrimp farming on China's coastal mangrove forests. To assess farm siting management and regulatory enforcement, this report relies primarily on literature from FAO (Phillips et al. 2009, White et al. 2013, FAO 2013) and Cao (2012). Given the similarity in source data to the Effluent Criterion, the data availability and quality for habitat impact and management of *L. vannamei* is assessed a score of 2.5 out of 10.

Chemicals

For intensive *L. vannamei* farming in China, illegal antibiotic use is the driving factor in the chemical use score, and is supported by personal communications with an industry expert as well as a number of different reports, including those by the FDA (2015, 2015a), Gale and Buzby (2009), Broughton (2010), and Xie *et al* (2013). Information on chemicals highly important to human health were provided by the World Health Organization (2011). Overall, the chemical data score is 5 out of 10 for Chinese farmed *L. vannamei*.

Feed

Specific data on commercial shrimp feed characteristics were primarily sourced from reports by FAO (2007), Tacon and Metian (2008), Cao (2012), and Dong et al. (2013). However, data are absent on percentages of fishmeal and fish oil from byproducts, fishmeal and fish oil yield, the percentage of protein from nonedible sources (in terms of edibility to humans), and the proportion of nonedible crop and land animal ingredients in shrimp feeds. Furthermore, Chinese feed mills are reluctant to share information regarding the diverse variety of fisheries that supply their fishmeal and fish oils, and most sources are currently unknown. Given the minimal information on specific feed components and the unknown nature of fishmeal, sourcing produces a low level of confidence in the data being assessed, and results in a feed data score for farmed *L. vannamei* of 2.5 out of 10.

Escapes and Animal Movements

The escape risk posed by *L. vannamei* farms is described in peer-reviewed literature (Boyd 2008) and published reports by FAO (Briggs et al. 2004, 2005; FAO 2013c). Currently, there is no direct data on recapture or mortality of escapees for China's shrimp farming industry. In terms of invasiveness, scoring is based largely on literature that indicates an unestablished but persistent presence of these shrimp in the wild in Thailand. (Score combined with Animal Movements)

Criterion 10X assesses the availability of data regarding live animal movements between ecologically distinct waterbodies and between countries. Data on the international movement of farmed *L. vannamei* are described primarily by Cao (2012). Data on the biosecurity of Hawaiian SPF-certified L. vannamei hatcheries was provided by an industry expert (Yamasaki 2013, pers. comm.). Data on the biosecurity of Chinese L. vannamei farms was also described by Cao (2012, pers. comm., 2014).,

Given the absence of direct data on the impacts of escaped shrimp in China and the potential for unregulated animal movements, *L. vannamei* receive a final Escapes and Animal Movement score of 2.5 out of 10.

Disease

While there is ample literature on the major diseases affecting farmed shrimp in China, studies concerning disease transmission between farmed shrimp and native, wild populations are absent. As such, the scoring of the Disease Criterion is based primarily on production systems' characteristics (frequent discharges–Cao 2012) and both the diversity and amplification of diseases in *L. vannamei* shrimp ponds (Flegel and Fegan 2002, Briggs et al. 2005, Rosenberry 2006, Xie and Yu 2007, FAO 2013b, Anonymous 2013). These data limitations produce a score of 2.5 out of 10 for *L. vannamei*.

Source of Stock

This factor assesses an aquaculture industry's reliance on wild capture for broodstock and farm stock. Information on the supply of farmed *L. vannamei* were obtained from Cao (2012) and the Hawaii Department of Agriculture (HDOA 2013). These data sources indicate that this shrimp species has yet to become established in China, and that export-oriented farm stock are sourced primarily from hatcheries in Hawaii. Given the lack of available data, the Source of Stock data score is 5 out of 10.

Predators and Wildlife Interactions

While interactions between a variety of wildlife species and shrimp ponds have been documented in China, there is no recently published, peer-reviewed literature that specifically addresses the population-level impact of shrimp farms on affected wildlife species. Given the scarcity of information regarding the wildlife impacts associated with *L. vannamei* farming in China, more robust data from similar shrimp farming regions in Asia (Indonesia) were used in this assessment to evaluate Chinese shrimp farms by proxy. Under these conditions, *L. vannamei* farming in China is given a Predator and Wildlife Interaction data score of 2.5 out of 10.

Data Criterion — Conclusions and Final Score

Data accessibility and availability for intensive *L. vannamei* farming in China is variable depending on the subject matter and current information availability. The final score for the Data Criterion is a moderate 3.33 out of 10 for *L. vannamei*.

Criterion 2: Effluents

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: aquaculture operations minimize or avoid the production and 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.*

Effluent Risk-Based Assessment

Effluent parameters	Value	Score	
F2.1a Biological waste (nitrogen) production per of fish (kg N ton-1)	73.92		
F2.1b Waste discharged from farm (%)	51		
F2 .1 Waste discharge score (0-10)		6	
F2.2a Content of regulations (0-5)	2.25		
F2.2b Enforcement of regulations (0-5)	0.25		
F2.2 Regulatory or management effectiveness score (0-10)		0.225	
C2 Effluent Final Score		**3.00**	**RED**
Critical?	NO		

The Seafood Watch Effluent Criterion combines the total amount of waste released per ton of production with an assessment of applicable management measures and their implementation to provide a measure of the impact from discharged wastes. For intensive *L. vannamei* farms, the total waste discharged (using nitrogen as a proxy) is estimated to be 73.92kg N t^{-1} as administrative agencies are focused primarily on maximizing the economic benefits from aquaculture rather than environmental protection. Despite the presence of cumulative impact considerations at the national level, in practice, there is no effective monitoring mechanism for aquaculture-based effluent discharges. Additionally, poor enforcement and the absence of any penalty for the release of farm effluents have resulted in frequent infringements on carrying capacity limits for receiving waterbodies. Overall, pond systems in China produce moderate impacts to the environment from effluent discharge. When combined with poor management of cumulative impacts, these conditions result in a final Criterion 2 – Effluent score of 3 out of 10 for intensively farmed *L. vannamei*.

Justification of Ranking

In this assessment, data quality regarding the effluent-related environment impacts of Chinese shrimp farms are not considered robust. In the absence of robust data for intensive *L. vannamei* farms in China, the risk-based assessment method (as opposed to evidence-based) is employed in this Seafood Watch report and nitrogen is used as a proxy indicator of waste.

Factor 2.1a Biological Waste Production Per Ton of Shrimp
Intensive shrimp farming faces a number of issues related to discharged waste, including "water intake and outputs to the same waterbody (self-pollution), cumulative pollution between farms in the region, as well as impacts to the coastal environment" (Zhu and Dong 2013). According to pond owners, there is no standardized production pattern for feed management and water exchange (Herbeck et al. 2013).

In China, intensive shrimp farms do not use fertilizers during grow-out, and rely solely on commercial shrimp feeds (Cao 2012). The protein content of commercial *L. vannamei* shrimp feeds typically range from 39%–41% (Dong et al. 2013, Dong 2012), and the average feed conversion ratio (FCR) in intensive pond production is 1.6 (Cao 2012). Based on research by Boyd et al. (2007), the protein content of a whole harvested farmed shrimp is 17.8%. Based on these values, a calculated 73.92kg of nitrogen-based waste is produced per ton of *L. vannamei*.

Factor 2.1.b Production System Discharge
Relative to soluble wastes, a large proportion of the nutrients generated by farmed shrimp are suspended solids (World Bank et al. 2002), and their collection, treatment, or otherwise appropriate disposal can mitigate environmental impacts during water exchanges or pond drainage. Under Seafood Watch criteria, the waste that is discharged by a production system is determined using a basic score that can be adjusted by production and management techniques.

A study by Cao (2012) reports that intensive shrimp ponds are typically flow-through systems with a high daily water exchange rate of 8%–15%. The basic, unadjusted production system waste discharge score for ponds with daily water exchange is 0.51 (approximately 51% of the waste generated leaves the production system as effluent). Without clear information indicating mechanisms to reduce waste discharge into the environment (i.e., proper sludge disposal or the use of settling ponds), the final waste discharge score for intensive *L. vannamei* farms was not adjusted and remains at 0.51. As such, 51% of the waste produced in intensive *L. vannamei* ponds is considered to be directly discharged from the farm and into the surrounding environment.

Factor 2.2a Content of Effluent Regulations and Management Measures
In China, federal environmental laws are supplemented by additional management measures set by local environmental protection bureaus at the provincial, municipal, district, and township level (FAO 2013b). Working under the federal framework for environmental management, local bureaus are responsible for permitting, monitoring and enforcing regulations of aquaculture operations.

Although established effluent regulations and maximum control limits are being applied to the aquaculture industry, these management measures more broadly protect water quality (i.e., oil pollution parameters and heavy metal concentrations) rather than being specifically designed for aquaculture (Phillips et al. 2009). For example, there are no restrictions prohibiting the salinization of freshwater resources by inland farm sites (White et al. 2013). Although aquaculture pollution regulations are reportedly under development (Zhang 2014, pers. comm.), there is currently no mention of aquaculture in any of the relevant water quality laws in China (FAO 2013a, 2013b, 2013c), and there are no known requirements for effluent monitoring throughout the shrimp production cycle.

At the national level, China addresses cumulative impacts from aquaculture through strategic environmental assessment (SEA) (Phillips et al. 2009). Whereas an EIA generally considers the environmental impact of individual projects, an SEA considers development plans on a regional scale. Implemented in 2003, the Environmental Impact Assessment Law expanded EIA requirements to include strategic environmental assessment of large-scale, government-based aquaculture developments. In addition to increasing mandatory SEA requirements, China has also established an environmental monitoring network, the Fishery Environment Monitoring Network, for aquaculture areas (Phillips *et al* 2009).

For Factor 2.2a, these regulatory conditions result in a score of 2.5 out of 5 for intensively farmed *L. vannamei*.

Factor 2.2b – Enforcement of Effluent Regulations and Management Measures
In China, aquaculture is strongly viewed as an important economic activity and infringing on effluent regulations is often overlooked by local governments (Liu et al. 2008, Phillips et al. 2009, White et al. 2013). As Chinese *L. vannamei* farmers have rapidly expanded to many inland agricultural areas (Zhu et al. 2004), freshwater from these regions are repeatedly salinized to accommodate better survival and faster growth rates in *L. vannamei* (White et al. 2013). Although adding large amounts of salt into freshwater resources has the potential to threaten habitat functionality in these inland areas, *L. vannamei* culture is nonetheless being strongly promoted by both local and national aquaculture-related agencies in China (Wang 2005, Yang 2009, Zhang 2009).

Despite the presence of cumulative impact considerations at the national level, in practice, there is no effective monitoring mechanism for aquaculture-based effluent discharges and poor enforcement has resulted in frequent infringements on carrying capacity limits and the absence of any penalty for the release of farm effluents (Zhu and Dong 2013, White *et al* 2013). In the legal system itself, aquaculture-related laws and regulations lack practical punitive measures for violating effluent regulations (Liu et al. 2008, Dong 2009). While enforcement mechanisms exist, they are both ineffective and inappropriate to the scale of the industry and do not demonstrably result in compliance with established limits.

Overall, these regulatory enforcement conditions result in a final Factor 2.2b score of 0.25 out of 5 for Chinese farmed *L. vannamei*.

Combining Factor 2.2a and 2.2b results in an overall regulatory enforcement and management effectiveness score of 0.23 out of 10 for *L. vannamei* farmed in China.

Effluent Criterion—Conclusions and Final Score

The total nitrogen waste produced per ton of production is ~73.92kg for *L. vannamei*.

Approximately 51% of the nitrogen-based waste from intensive *L. vannamei* production systems (i.e., 37.7kg N per ton of production) leaves the farm boundary. This quantity of discharged waste results in a discharge score of 6 out of 10 *L. vannamei*.

Combining the overall waste discharge score with the overall management effectiveness score results in a low effluent score of 3 out of 10 for *L. vannamei*. This score reflects the waste discharged from intensive pond production systems, along with effluent regulations which have been undermined by poor enforcement, and the uncertainties with respect to potential cumulative impacts on a regional scale.

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: aquaculture operations are located at sites, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats.*

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		4.00	
F3.2a Content of habitat regulations	1.25		
F3.2b Enforcement of habitat regulations	0.50		
F3.2 Regulatory or management effectiveness score		0.25	
C3 Habitat Final Score		**2.75**	RED
Critical?	NO		

In China, shrimp aquaculture has historically been sited in high value, sensitive habitats such as mangroves, mudflats, estuaries and coastal intertidal areas. However, given the absence of coastal areas available for shrimp farm expansion, Chinese *L. vannamei* farmers have rapidly expanded to inland agricultural areas (the dominant production area for the sector since 2008). Given the minimum farm-size requirement for EIA in China, only a limited number of *L. vannamei* farmers are required to participate in environmental assessments. Failure to complete the EIA process is met with is minimal penalty and a "make-up" EIA can be processed after construction is completed. Furthermore, under the decentralized policy-setting in China, the implementation and enforcement of existing habitat management regulations is considered to be both ineffective and inappropriate for the scale of the industry. Combining the degree of habitat conversion with management effectiveness results in a Habitat Criterion score of 2.75 out of 10 for intensive *L. vannamei* farms.

Justification of Ranking

Factor 3.1. Habitat Conversion and Function

Historically, Chinese shrimp farms were first sited in high value, sensitive habitats such as mangroves, mudflats, estuaries and coastal intertidal areas. This conversion may have been either through direct habitat alteration from pristine environments, or more likely as part of a pattern of sequential transition from a consumptive industry (producing agricultural commodities) and (opportunistically) to shrimp farming. Regardless of whether shrimp farming is responsible for the initial habitat conversion or whether it became a subsequent use, conversion of coastal mangrove forests and other high value habitats is considered a significant loss of habitat functionality with major ecological impacts under Seafood Watch criteria.

While current research indicates that further conversion of mangroves and other sensitive habitats in Southeast Asia has virtually stopped (Jory and Cabrera 2012), it is difficult to confirm whether mangrove destruction for shrimp farming has completely ceased in China.

Overall, the timeframe of mangrove habitat loss due to *L. vannamei* farming is considered to be historic (more than 10 years ago). Although inland farm sites now represent the primary production area for *L. vannamei* production, the destruction of critical mangrove habitat can still be attributed to intensive shrimp farms presently sited along the coast. These conditions result in a low-moderate Factor 3.1 score of 4 out of 10 for intensive *L. vannamei* farms in China.

Factor 3.2a–Habitat and Farm Siting Management Effectiveness

In China, the use of land and water areas for aquaculture are restricted by local 'functional zoning schemes' (White et al. 2013). After approval by provincial governments, these area-based management plans specify zones for aquaculture, and guidelines for aquaculture development and management are established by local environmental authorities (Phillips et al 2009, White et al. 2013). Although specific legislation for aquaculture zone siting has yet to be established, relevant provisions exist in other legislation regulating fisheries and aquatic environments (White et al. 2013). While a license has been required for any new farm development in aquaculture zones since 2002 (Phillips et al. 2009), licensing of established farms is not a mandatory requirement (White et al. 2013).

Environmental Impact Assessment (EIA)

According to Phillips et al. (2009), "The State Environmental Protection Administration now has a well-developed EIA procedure and technical guidelines are in place, but these are not specific for aquaculture."

The scope of environmental assessment depends on the degree of a proposed farm's potential environmental impact and actual requirements depend largely on the scale of the farm (Phillips et al. 2009). Under *The Law of the People's Republic of China on Environmental Impact Assessment*, shrimp farms within approved aquaculture zones are required to participate in the EIA process only if above 13.3 ha in size (Phillips et al. 2009). As such, only a limited number of farms are relevant to the EIA requirement, given that intensive *L. vannamei* ponds are generally small (0.1 to 1 ha) (Cao 2012, FAO 2013).

Environmental Monitoring

Monitoring is a compulsory part of the EIA process in China and it is carried out during both the project construction and operation phases (Phillips et al. 2009). Both provincial environmental authorities and farmers share the responsibility for monitoring. However, it is unclear if any guidelines exist specifically for environmental monitoring of aquaculture projects (Phillips et al. 2009).

Cumulative Impacts
At the national level, China addresses cumulative impacts from aquaculture through strategic environmental assessment (SEA) (Phillips et al. 2009). Whereas an EIA generally considers the environmental impact of individual projects, an SEA considers development plans on a regional scale. Implemented in 2003, the *Environmental Impact Assessment Law* expanded EIA requirements to include strategic environmental assessment of large-scale, government-based aquaculture developments. In addition to increasing mandatory SEA requirements, China has also established the Fishery Environment Monitoring Network for aquaculture areas (Phillips et al. 2009). Although the network comprehensively covers both inland and coastal areas, the data collection is based primarily on preserving water quality standards rather than maintaining habitat functionality (Phillips et al. 2009).

Critical Habitat Protection
Due to heavy population pressure, farmers have exploited most of the habitat that is suitable for aquaculture in China (White et al. 2013). Although aquaculture development on environmentally sensitive habitats is prohibited under the *Regulations for Implementation of the Fisheries Law (1987)*, China has nonetheless allowed shrimp farms into protected areas. In 2003, for example, shrimp farms were observed in Zhanjiang Mangrove National Nature Reserve—a designated Ramsar site in 2002 (Earth Island Journal 2003, World Rainforest Movement 2004). Other than EIA-based monitoring requirements for aquaculture in sensitive areas (Phillips et al. 2009), there are no known environmental management measures specifically requiring farmers to restore high-value habitats or critical ecosystem services once they have been degraded.

For Factor 3.2a, these regulatory conditions result in a score of 1.25 out of 5 for intensively farmed *L. vannamei*.

Factor 3.2b – Siting Regulatory or Management Enforcement
In China, the administrative system for aquaculture consists of the State Environmental Protection Administration and the Ministry of Agriculture at the national level, and local environmental protection bureaus at the provincial, municipal, district, and township level, which serve as base institutes (Phillips et al. 2009). Federal laws are implemented by the State Environmental Protection Administration, but regulations are typically supplemented by additional management measures set by local aquaculture agencies (FAO 2013b). At the end of 1999, there were already 2,100 fisheries law enforcement agencies with 30,000 enforcement staff (FAO 2001). Under this policy of decentralization, relevant environmental agencies and enforcement organizations for shrimp farming are numerous and difficult to identify.

Regulatory Enforcement
Despite the growing inventory of environmental legislation related to aquaculture siting in China, reports indicate that the growth of the industry has occurred at a rate that exceeds the ability of government policies, legislation, and enforcement to ensure its sustainable development (Cao et al. 2007, Miao & Jiang 2007, Wang 2007, Zhang 2007, NZTE 2011, SEPA 2013, 12th Five-Year Plan 2011). According to White et al. (2013), throughout China, "many

provinces have yet to comply with federal environmental regulatory requirements and have not developed their functional zoning schemes for water areas, and in provinces where schemes are in place, enforcement is often poor as administrative agencies are focused primarily on maximizing the economic benefit of aquaculture." The result of this disparity between the intent of environmental legislation and its implementation is a lack of coherence between agencies managing the same coastal region and the poor management for cumulative impacts throughout the sector (White et al. 2013). Under the decentralized policy-setting in China, the implementation and enforcement of existing habitat management regulations is considered to be both ineffective and inappropriate for the scale of the industry.

Public Access, Transparency, and Enforcement of the EIA Process and Monitoring Network
Although the legal basis for EIA requirement is comprehensive in China's environmental legislation, the current bottleneck in effective management relates primarily to implementation, particularly at the local level. A common theme in several reports evaluating the EIA process in China indicates that there is poor environmental management capacity among local governments (White et al. 2013). For example, Luo et al. (2009) reported that pre-construction EIAs were still lacking for new farms. Furthermore, if a farmer fails to complete an EIA prior to development, there is minimal penalty and a "make-up" EIA can be processed after construction is completed (Wang 2007).

While public access and transparency for environmental assessment in China has been strengthened over the years by the release of several different pieces of legislation (i.e., *Environmental Assessment Law, Measures for the Disclosure of Environmental Information*, etc.) (Moorman and Ge 2006, Phillips et al. 2009), in practice, access to regulatory data is likely limited given the ongoing prioritization of economic growth far in advance of environmental protection (i.e., the actual enforcement rate for China's environmental laws and regulations was an estimated 10% in 2005(Gu 2005)).

Overall, these regulatory enforcement conditions result in a final Factor 3.2b score of 0.5 out of 5 for intensively farmed *L. vannamei*.

Combining Factor 3.2a and 3.2b results in an overall regulatory enforcement and management effectiveness score of 0.25 out of 10 for Chinese *L. vannamei*.

Habitat Criterion—Conclusions and Final Score
Historically, Chinese shrimp farms were first sited in high value, sensitive habitats such as mangroves, mudflats, estuaries and coastal intertidal areas. More recently, however, Chinese shrimp farms have expanded rapidly into inland agricultural areas, since nearly all viable coastal sites are currently being farmed. Under these conditions, farmed *L. vannamei* receives a low habitat conversion score of 4 out of 10.

Although the legal basis for regulating the ecological impact of shrimp farming is comprehensive in China's environmental legislation, the focus of administrative agencies is largely based on maximizing the economic benefits rather than environmental protection.

Furthermore, the policy to decentralize authority for implementing aquaculture regulations has resulted in weak enforcement capabilities at both national and local levels of government.

Combining the overall habitat conversion score with the overall Management Effectiveness score results in a Red Habitat Criterion score of 2.75 out of 10 for intensive *L. vannamei* farms, and reflects the destruction of coastal mangrove forests and the ongoing institutional and enforcement problems in the management system regulating China's shrimp farming industry.

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: aquaculture operations by design, management or regulation avoid the discharge of chemicals toxic to aquatic life, and/or effectively control the frequency, risk of environmental impact and risk to human health of their use.*

Chemical Use parameters	Score	
C4 Chemical Use Score	**0.00**	
C4 Chemical Use Final Score	**0.00**	**RED**
Critical?	NO	

In China's shrimp farming industry, ineffective chemical regulations have resulted in the ongoing use of banned antibiotics and antimicrobials such as gentian violet, malachite green, and chloramphenicol (illegal in both China and the US). Furthermore, chloramphenicol is recognized as highly important to human health by the World Health Organization. Overall, these conditions result in a low Criterion 4 – Chemical Use score of 0 out of 10 for intensive *L. vannamei* farms in China.

Justification of Ranking

As the aquaculture industry continues to grow on a global scale, concerns regarding the use (and misuse) of drugs and chemicals in aquaculture have increased substantially (FDA 2007b, Lumpkin 2007).

In China, shrimp farmers use a variety of antibiotics and antimicrobials in pond production to prevent and treat a number of diseases, including white spot syndrome virus, taura syndrome virus, infectious hypodermal and hematopoietic necrosis virus, yellow head virus, white feces syndrome, infectious myonecrosis disease, abdominal segment deformity disease and, more recently, early mortality syndrome. In intensive farms, chemical therapeutants are used specifically to reduce the elevated risk of outbreaks and disease amplification generated by high stocking densities.

To date, the aquaculture industry in Asia has grown faster than the development of tools to regulate chemical use within the industry. Models that aim to estimate the environmental fate and distribution of chemical residues specifically designed for pond aquaculture systems are very rare (Rico et al. 2012), and the division of tasks and responsibilities among different sectors (e.g., public health and food safety, agriculture, animal health services, environment) contributes to the overall weakness of many legal and institutional frameworks for chemical use (Van Houtte2000).

Although chemical management for China's aquaculture industry includes a national list of banned chemicals, which (among others) includes chloramphenicol (antibiotic), gentian violet (antimicrobial), and malachite green (antimicrobial) (Gale and Buzby 2009, Broughton 2010, Xie et al. 2013), these restrictions appear to be poorly enforced as residues of all 3 of these chemicals have been found in Chinese farmed shrimp imported to the US as recently as October 2015 (Anonymous, 2014 pers. comm., FDA 2015, FDA 2015a). Also considered illegal in the United States, the FDA continues to issue country-wide import alerts for these chemicals and mandates that shipments of Chinese farmed shrimp be detained at the border until they are proven to be residue-free.

Antibiotic Use

A major concern with the use of antibiotics is the development of resistant strains of bacteria, which can compromise treatment effectiveness (Rico et al. 2012), and alter microbial communities in the ecosystem. In a global survey regarding antimicrobial resistance in aquaculture (25 countries), shrimp was the species respondents most often reported resistance across all antimicrobials (Tuševljak et al. 2013). The ongoing use of chloramphenicol in Chinese shrimp farms and its accumulation in sediments can significantly alter the ecological structure of microbial communities in surrounding waterbodies (Kautsky et al. 2000, Rico and Van den Brink 2014). Furthermore, chloramphenicol is considered to be highly important to human health by the World Health Organization (WHO 2011).

Chemical Use Criterion—Conclusions and Final Score

In China's shrimp farming industry, ineffective chemical regulations have resulted in the ongoing use of banned antibiotics and antimicrobials such as gentian violet, malachite green, and chloramphenicol (illegal in both China and the US). Furthermore, chloramphenicol is recognized as highly important to human health by the World Health Organization. Overall, these conditions result in a low Criterion 4 – Chemical Use score of 0 out of 10 for intensive *L. vannamei* farms in China.

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: aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the nonedible portion of farmed fish.*

Feed parameters	Value	Score	
F5.1a Fish In: Fish Out ratio (FIFO)	2.13	4.67	
F5.1b Source fishery sustainability score		-6.00	
F5.1: Wild Fish Use		3.39	
F5.2a Protein IN	54.83		
F5.2b Protein OUT	14.73		
F5.2: Net Protein Gain or Loss (%)	-73.13	2	
F5.3: Feed Footprint (hectares)	13.52	5	
C5 Feed Final Score		**3.44**	**YELLOW**
Critical?	NO		

In intensive *L. vannamei* culture, farm stock are fed formulated, industrially-manufactured pellets, and there is industry-wide reliance on commercial feeds. Using an FCR of 1.6, and an average of 30% fishmeal and 1.5% fish oil in the feeds, the average Fish In: Fish Out ratio (based on fishmeal) is 2.13. A FIFO of 2.13 indicates that 2.13 tons of fish are required in order to supply sufficient feed to grow 1 ton of farmed shrimp. With a moderate source fishery sustainability score (-6 of -10), the final adjusted Wild Fish Use score for intensive *L. vannamei* farming is 3.39 out of 10. In addition to a 40% protein content of feed, the assumption that all non-marine protein components are from edible crops results in a net edible protein loss of ~73%. Furthermore, a combined ocean and land area of 13.52 ha is required to supply the amount of feed ingredients necessary to produce one ton of farmed shrimp. Overall, this feeding strategy results in a low-moderate Criterion 5 – Feed score of 3.44 out of 10 for farmed *L. vannamei*.

Justification of Ranking
In China, farmed shrimp are fed 4–6 times daily in the early stage of culture and later reduced to 3–4 feedings per day (FAO 2007). The use of floating frames and feeding trays are common methods used to monitor and adjust daily rations (FAO 2007)

Factor 5.1 Wild Fish Use
Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed *L. vannamei* with the sustainability of the fisheries from which they are sourced.

Globally, the percentage of fishmeal used in shrimp feeds has decreased over the last 20+ years (Tacon 1998, Tacon and Barg 1998, Venero et al. 2008) as it tends to be an expensive ingredient and global supplies are becoming increasingly limited. In 1995, marine shrimp feeds contained 35% fishmeal, 25% in 2000 (Tacon and Barg 1998), and remained 25% in 2007 (Venero et al. 2008).

In China, however, Dong et al. (2013) report fishmeal still accounts for at least 30% of the ingredients in commercial shrimp feeds. The fish oil content for Chinese shrimp feeds is 1%–2% (FAO 2007, Tacon and Metian 2008). Although several reports indicate that feed conversion ratios (FCR) for a variety of Chinese shrimp farms range from 0.9 to 2.1 (Xie and Yu 2007, Zhang et al. 2011, Dong 2012, Edwards 2013), research by Cao (2012) specifically on intensive *L. vannamei* farms identifies an FCR of 1.6.

Data values	**Dong *et al* 2013 Cao 2012 Tacon and Metian 2008**
Average fishmeal inclusion level	30.00%
Percentage of fishmeal from byproducts	Not specified (0% used in calculation)
Fishmeal yield (from wild fish)	Not specified (22.55% used in calculation)
Average fish oil inclusion level	1.50%
Percentage of fish oil from byproducts	Not specified (0% used in calculation)
Fish oil yield (from wild fish)	Not specified (5% used in calculation)
Feed Conversion ratio (FCR)	1.6
Calculated values	
Fish In : Fish Out ratio for fishmeal	2.13
Fish In : Fish Out ratio for fish oil	0.64
Seafood Watch FIFO score (0-10)	**4.67**

Table 1 Wildfish Use data and calculated values

With approximately 30% fishmeal and 1.5% fish oil in the feeds, the average Fish In: Fish Out ratio is 2.13 (Table 1). This FIFO indicates that 2.13 tons of fish are required in order to supply sufficient feed (fishmeal in particular) to grow 1 ton of farmed shrimp. These feed characteristics result in a low-moderate FIFO factor score of 4.67 out of 10.

Factor 5.1b – Source Fishery Sustainability

For the aquaculture industry in China, fishmeal is both imported and produced locally. Imported fishmeal is from primarily Peru, Chile, and Russia (FAO 2007). While most of the locally produced fishmeal is produced from various clupeid species such as Japanese anchovy (*Engraulis japanicus*), Indian oil sardine (*Sardinella longiceps*), knife fish (*Coilia ectenes*), South American pilchard (*Sardinops sagax melanosticta*), other major fishmeal sources include estuarine tapertail anchovy (*Coilia nasus*), pollock (*Pollachius pollachius*), and squid (FAO 2007). Occasionally, fishmeal from other various species is also available. Although Vietnam is China's top supplier of fish oil (Godfrey 2012), the source fisheries that are utilized remain unknown.

Despite the species information above, data is absent on specific source fisheries that directly contribute fishmeal and fish oil to Chinese shrimp feeds. As such, there remains uncertainty in the number of fisheries that are utilized and the sustainability of each source. Under these conditions, a precautionary score of -6 out of -10 is applied for unknown source fisheries and the subsequent unknown sustainability of those stocks. This reduces the FIFO score by -1.28 and generates a final Wild Fish Use score of 3.39 out of 10, indicating a moderate-high conservation concern regarding wild fish use in *L. vannamei* feeds.

Factor 5.2 Net Protein Gain or Loss

In Factor 5.2, a net protein value is quantified by calculating protein inputs and outputs in a typical shrimp farming cycle. Using data from Dong (2012) and Cao (2012), the protein content of feed was calculated using an average protein content of 40% and an average FCR of 1.6. Without specific information, it is assumed from the data provided that 100% of the feed protein from both marine and crop ingredients is edible (in regards to human consumption), and that no protein is sourced from fisheries byproducts, terrestrial animals, or crop byproduct ingredients. As such, 49.9% of the feed protein is considered to be from edible marine sources (i.e., fishmeal from whole fish), and the remaining 50.1% of feed protein is considered to be from edible crop sources (e.g., soybean meal). The protein generated by shrimp farming is calculated using a protein content of 17.8% of a whole, harvested farmed shrimp, and an edible yield of 65.5% (Briggs et al. 2005, Rosenberry 2006) for *L. vannamei*. It is assumed that 50% of the inedible byproducts from harvested *L. vannamei* are used in other food production processes. Overall, these feed ingredients produce a calculated 73.1% loss in edible protein, and result in a low Factor 5.2 score of 2 out of 10 (Table 2).

Data values	Range	Final value	Reference
Protein content of feed	39-41%	40%	Dong 2012
Percentage of total protein form non-edible sources (by-products, etc.)	-	(0% used in calculations)	Unknown
Percentage of protein from edible sources	-	100%	Dong 2012 FAO 2007
Percentage of protein from edible crop sources	-	50.1%	-
Feed conversion ratio (FCR)	0.9 to 2.1	1.6	Xie and Yu 2007 Zhang et al 2011 Cao 2012 Dong 2012 Edwards 2013
Protein content of whole harvested shrimp	-	17.8	Boyd et al 2007
Percentage of farmed shrimp by-products utilized	-	(50% used in calculations)	Unknown
Calculated values			
Protein INPUT per ton of farmed shrimp		54.8%	
Protein OUTPUT per ton of farmed shrimp		14.7%	
Net protein loss		-73.1%	
Seafood Watch protein score (0-10)		**2**	

Table 2: Net protein data and calculated values

Factor 5.3 Feed Footprint

This factor is an approximate measure of the global area required to produce feed ingredients. By considering the marine, terrestrial crop, and terrestrial land animal ingredients, this factor provides an estimate of the ocean area and land area required to produce the ingredients necessary for the production of feed required per ton of farmed shrimp. Without specific data, it is assumed that all non-marine ingredients are edible crop, (i.e., for human consumption), and that no inedible land animal byproducts are utilized as ingredients. As such, 31.5% of the feed is sourced from marine ingredients and the remainder (68.5%) is composed of edible crops. For *L. vannamei*, 13.11 ha of ocean area and 0.42 ha of land area are required to supply the amount of feed ingredients necessary to produce 1 ton of farmed shrimp. These conditions result in a moderate Factor 5.3 score of 6 out of 10 (Table 3).

Parameter	**Dong *et al* 2013 Cao 2012 Dong 2012 Tacon and Metian 2008**
Marine ingredient inclusion in feed	31.5%
Crop ingredients inclusion in feed	68.5%
Land animal ingredient inclusion in feed	0%
Ocean area used per ton of farmed shrimp	13.11ha
Land area	0.42ha
Total area	13.53ha
Seafood Watch Footprint score (0-10)	**5**

Table 3: Feed footprint data and calculated values

Feed Criterion—Conclusions and Final Score

In an intensive *L. vannamei* culture, there is an industry-wide reliance on commercial feeds, where a FIFO of 2.13 indicates that 2.13 tons of fishmeal are required in order to supply sufficient feed to grow 1 ton of farmed shrimp. The consequence of this process is a net protein deficit, where 73.1% of protein inputs are not utilized. The inefficiency of shrimp feeds for *L. vannamei* is further compounded by the 13.52 ha/ton production of ocean and land area appropriated for feed ingredients. Overall, the extractive nature of intensive farmed *L. vannamei* results in a final C5 – Feed Criterion score of 3.44 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: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species.*

Escape parameters	Value	Score	
F6.1 Escape Risk		2.00	
F6.1a Recapture and mortality (%)	0		
F6.1b Invasiveness		4.5	
C6 Escape Final Score		**3.00**	**RED**
Critical?	NO		

There is an inherent risk of escape in pond-based shrimp aquaculture due to the exchange of pond water with the surrounding waterbody. *L. vannamei* are non-native to China, and despite repeated introductions and the ongoing presence of escaped *L. vannamei* in the wild, there is no evidence that they have become established. However, as a foreign shrimp species with an unestablished, yet persistent presence in the wild, *L. vannamei* escapes nonetheless present a strong likelihood for ecological disturbance through competition with other species for food and space between farmed and wild penaeids. With no direct data on recapture efforts or significant mortality levels in escaped shrimp, the overall Criterion 6 – Escape score is 3 out of 10 for farmed *L. vannamei*.

Justification of Ranking

Factor 6.1a. Escape Risk

There is an inherent level of escape risk in pond-based shrimp aquaculture due to the nature of the production system. Throughout Asia, the escape of farmed shrimp into the surrounding environment can be expected as a result of water exchanges (8%–15% daily), accidental release during harvest (typically 2-3 times per year in China), release from hatcheries and during transport, as well as mass escape during flooding events and levee breaches (Briggs et al. 2004, 2005, Boyd 2008). Nonetheless, intensive shrimp farms are increasingly being sited in non-tidal areas located farther from the sea (FAO 2013c). In China, it is currently unknown if any additional biosecurity measures aside from water gates are being used to prevent shrimp escapes. As a result, intensive *L. vannamei* farms in China are considered to be moderate escape-risk systems with questionable escape prevention measures. These conditions produce an Escape Risk factor score of 2 out of 10 for Chinese *L. vannamei* farms.

Recapture and Mortality Score

While evidence of recaptures and mortality of escapees can improve the Escape Risk score, there is no evidence indicating that escapees are recaptured by farmers with any regularity. With no specific recapture or mortality data available to indicate a significant reduction in the risk of escape in the shrimp farming industry, no adjustment was applied to the Escape Risk score for intensive *L. vannamei* farms.

Factor 6.1b. Invasiveness

Currently, little is known about the impacts of cultured shrimp on wild populations and biodiversity. Although potential impacts have been widely observed in the literature, they have not been quantitatively assessed for *L. vannamei* in China.

As a non-native species in China, *L. vannamei* were originally introduced in 1988 and have been imported commercially since 1996 (Briggs et al. 2005). Despite the escape of farmed *L. vannamei* since 1988, a comprehensive study of the literature by Briggs et al. in 2005 did not find any evidence of *L. vannamei* becoming established outside of its home range in the East Pacific (i.e., not an easily invasive species). Although it is uncertain whether the establishment of viable populations will occur over time, the ecological impact of escaped *L. vannamei* nonetheless could include competition with other species for space (because it could tolerate the range of natural environmental conditions) and food (dietary overlap with native shrimp species) (Chavanich et al. 2008, Molnar et al. 2008, Senanan et al. 2009, Panutrakul et al. 2010), and studies in Thailand have concluded that ongoing *L. vannamei* escapes produce a persistent presence in waterbodies surrounding farm sites (Senanan et al. 2010). Additionally, food competition experiments showed that *L. vannamei* approached and captured food faster than all other native shrimp species (Panutrakul et al. 2010, Senanan et al. 2010). These conditions suggest that repeated escapes have the potential to produce a persistent *L. vannamei* presence in the wild that have similar impacts to an established population.

As a non-native shrimp species which has the potential to generate an unestablished, yet persistent presence in the wild, the escape of farmed *L. vannamei* is considered to present a strong likelihood for ecological disturbance, resulting in a non-native species score of 0.5 out of 5 for Factor 6.1b, Part B. However, given that *L. vannamei* do not provide additional predation pressure or disturb breeding behavior in other native species, these conditions result in a score of 4 out of 5 for Part C of the Invasiveness factor. When Part B and Part C are combined, the final 6.1b Invasiveness score for *L. vannamei* escapes is 4.5 out of 10.

Escape Criterion—Conclusions and Final Score

Overall, when the Escape Risk and Invasiveness factors are combined, and with no adjustment for Recapture and Mortality, the environmental impacts of escape are considered low-moderate and result in a Criterion 6 - Escape score of 4 out of 10.

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 waterbody.*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	**RED**
Critical?	**NO**	

Due to the openness of the production system and the prevalence of multiple diseases known to occur on Chinese shrimp farms, the potential risk of transmitting farm-based shrimp diseases to wild populations is considered to be high. Given the growing nature of the Chinese shrimp farming industry and the lack of effective biosecurity measures to prevent the ongoing spread of disease (including EMS), the score for Criterion 7–Disease is a moderate-high 2 out of 10 for intensive *L. vannamei* farms in China.

Justification of Ranking

Shrimp production systems in China are open to the environment and intensive shrimp farms exchange 8%–15% of their pond water with the surrounding waterbody on a daily basis (Cao 2012). As a result of this connectivity, the industry suffers from high rates of pathogen-related infections and mortality (Briggs et al. 2005, Rosenberry 2006, Xie and Yu 2007, FAO 2013b, Anonymous 2013). Historically, on an industry-wide basis, Chinese shrimp farms have been highly susceptible to a number of diseases and at least some of these are known to be transferable to wild shrimp populations, such as taura syndrome virus (TSV). TVS spread to China in ~1999 (Flegel and Fegan 2002) and was believed to have caused mass mortalities in cultured *L. vannamei* (Briggs et al. 2005). In Thailand, evidence shows that TSV in farmed *L. vannamei* has made the jump across species to local stocks of *P. monodon* (Briggs et al. 2005).

More recently, early mortality syndrome, a bacterial disease, caused shrimp farms in Hainan, Guangdong, Fujian and Guangxi to suffer production losses of ~80% in 2011 (FAO 2013b). Other diseases that have been known to affect Chinese shrimp farms include infectious hypodermal and haematopoietic necrosis, yellow head virus, lymphoid organ vacuolization virus, reo-like viruses, *Baculovirus penaeii*, white feces syndrome, infectious myonecrosis virus, and abdominal segment deformity disease. These conditions indicate that any biosecurity measures that are in place, including the use of SPF broodstock (Liao and Chien 2011, Cao 2012, HDOA 2013), are ineffective at stemming the introduction and transmission of pathogens between Chinese *L. vannamei* farms.

Although there is currently no direct evidence of disease interactions between farmed and wild shrimp in China, the prevalence and amplification of disease throughout the Chinese shrimp farming industry (both currently and historically) and the openness of the production system result in a high risk of disease transmission between farmed and wild shrimp stocks.

Disease Criterion—Conclusions and Final Score

Due to the openness of the production system and the prevalence of multiple diseases known to occur on Chinese shrimp farms, the potential risk of transmitting farm-based shrimp diseases to wild populations is considered to be high. Given the growing nature of the Chinese shrimp farming industry and the lack of effective biosecurity measures to prevent the ongoing spread of disease, the score for Criterion 7–Disease is a moderate-high 2 out of 10 for intensive *L. vannamei* farms in China.

Criterion 8: Source of Stock – Independence from Wild Fisheries

Impact, unit of sustainability and principle

- *Impact: the removal of fish from wild populations for ongrowing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks, use minimal numbers, or source them from demonstrably sustainable fisheries.*

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock, natural (passive) settlement, or sourced from sustainable fisheries	100	
C8 Source of stock Final Score	**10.00**	**GREEN**

In China, intensive *L. vannamei* farms are considered to be 100% reliant on hatchery production for farm stock. Based on their independence from wild stocks, the score for Criterion 8 – Source of Stock is 10 out of 10 for intensively farmed *L. vannamei*.

Justification of Ranking

In China, *L. vannamei* are a non-native species and broodstock must be imported or grown domestically in hatcheries within the country (Cao 2012). While shrimp from domestic hatcheries are more likely to be sold in local markets, intensive farms relevant to the US market source their broodstock from SPF-facilities in Hawaii (Cao 2012, HDOA 2013). As such, all *L. vannamei* broodstock and post larvae originate from hatcheries and the *L. vannamei* farming industry does not collect farm stock from wild populations. Overall, these conditions result in a high Criterion 8 – Source of Stock score of 10 out of 10 for the P. monodon farming industry and a high score of 10 out of 10 for intensively farmed *L. vannamei*.

Criterion 9X: Wildlife and predator mortalities

A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife.

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.

Wildlife and predator mortality parameters	Score	
F9X Wildlife and predator mortality Final Score	**-5.00**	**YELLOW**
Critical?	NO	

In China, data on wildlife mortalities from interactions with shrimp farms is absent. Given the scarcity of information regarding the wildlife impacts associated with *L. vannamei* farming in China, more robust data from similar shrimp farming regions in Asia are used in this assessment to evaluate Chinese shrimp farms by proxy. In Indonesia, many wildlife species are deterred or eliminated to increase productivity. While the impact of shrimp farms on low-productivity species (predatory fish, amphibians, reptiles, birds) are unknown, the farm-related mortalities of competitive (polychaetes, insects, shrimps, snails, herbivorous fishes) and destructive pests (mud crabs) are not considered to be significant given the highly productive nature and large population size of each of these species. Using a precautionary approach to scoring this criterion, these conditions result in a Criterion 9X – Wildlife and Predator Mortalities penalty score of -5 out of -10 for intensive *L. vannamei* farms in China.

Justification of Ranking

Although interactions between wildlife and shrimp farms have been frequently observed, recently published, peer-reviewed literature that specifically addresses this issue in Chinese shrimp farms is absent. In general, however, shrimp farming often requires the control of pests and predators that can impact the cultured shrimp either directly through predation or indirectly through competition for resources (FAO 1986). Given the scarcity of information regarding the wildlife impacts associated with L. *vannamei* farming in China, more robust data from similar shrimp farming regions in Asia (Indonesia) are used in this assessment to evaluate Chinese shrimp farms by proxy.

In Indonesia, a variety of native wildlife species are found in ponds other than the cultured shrimp, including both high productivity (polychaetes, insects, shrimps, snails, mud crabs, herbivorous fishes) and low-productivity species (predatory fish, amphibians, reptiles, birds) (Taslihan and Sunaryanto 1990, Gräslund and Bengtsson 2001, Pers. comm., Peet 2015). Many of these wildlife species are deterred or eliminated because they are likely to lower productivity by consuming shrimp directly, by competing for the use of available resources, or by causing damage to the ponds (Taslihan and Sunaryanto 1990). Predator control methods include passive exclusionary systems, such as screens on inlets, fencing, pond linings, dike enhancement, or bird-scare lines, as well as active control systems, such as direct capture and the application of pesticides or disinfectants (Florina and Sukardi 2012, Bunting et al. 2013, pers. comm., Peet 2015).

Wildlife and Predator Mortalities Criterion—Conclusions and Final Score

In general, a variety of wildlife species are present in shrimp aquaculture. While interactions between marine wildlife and shrimp ponds have often been observed, there is little recently published, peer-reviewed literature that specifically addresses this issue for Chinese shrimp farms and so similar shrimp farming regions in Asia were used in this assessment to evaluate Chinese shrimp farms by proxy. Data from Indonesian shrimp farms indicate that active control wildlife control methods result in wildlife mortalities. Nonetheless, the lack of statistical data available for farm-related mortalities results in a precautionary approach to scoring this criterion.

In this assessment, the impact of shrimp farms on low-productivity species (predatory fish, amphibians, reptiles, birds) are unknown (warranting a score of -6). Farm-related mortalities of competitive (polychaetes, insects, shrimps, snails, herbivorous fishes) and destructive pests (mud crabs) are not considered to be significant given the highly productive nature and large population size of each of these species (which warrants a score of -4).

Note that this is an Exceptional criterion and the scoring range is from 0 (no concern) to -10 (very high concern). Accounting for the different types of wildlife species affected, the final score for this Exceptional criterion is a penalty of -5 out of -10 for intensive *L. vannamei* farms in China.

Criterion 10X: Escape of unintentionally introduced species

A measure of the escape risk (introduction to the wild) of alien species other than the principle farmed species unintentionally transported during live animal shipments.

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.

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	0.00	
F10Xb Biosecurity of source/destination	8.00	
C10X Escape of unintentionally introduced species Final Score	**-2.00**	**GREEN**

In the *L. vannamei* farming industry, broodstock are sourced directly from SPF-certified hatcheries in Hawaii. While intensive shrimp farms are considered to be production systems with a moderate risk of escape, the more robust biosecurity measures present at SPF-certified hatcheries reduces the overall risk of unintentional introductions. Despite the international and trans-waterbody movement of *L. vannamei* broodstock between Hawaii and China, the overall potential for the escape of unintentionally introduced species is considered to be low and results in a final C10X–Escape of Unintentionally Introduced Species penalty score of -2 out of -10 for intensive *L. vannamei* culture in China.

Justification of Ranking

Factor 10Xa International or Trans-waterbody Live Animal Shipments

In the *L. vannamei* farming industry, broodstock are sourced solely from specific-pathogen-free (SPF) certified hatcheries in Hawaii (Cao 2012, HDOA 2013). Supplied by the Oceanic Institute, these SPF broodstock are imported into Chinese hatcheries and used to produce first generation post-larvae (Cao 2012). Once these post-larvae are sold to shrimp farmers, they may be transported some distance from domestic hatcheries to grow-out ponds, but these shipments are not considered to represent trans-waterbody movements between ecologically distinct waterbodies.

While trans-waterbody movements are absent, the Chinese *L. vannamei* farming industry is considered to be 100% reliant on international imports for their source of broodstock (and hence their farm stock). Under these conditions, a score of 0 of 10 is applied to Factor 10Xa.

Factor 10Xb Biosecurity of Source/Destination

Broodstock Imports from Hawaii

The Hawaii Shrimp Surveillance & Certification Program is managed by the Hawaii Department of Agriculture (HDOA). Participating facilities undergo rigorous monitoring and must continuously test negative for specific pathogens for 24 months to receive SPF status. According to Dr. Yamasaki (pers. comm. 2013), an aquaculture veterinary officer who monitors these facilities and provides export documents, the shrimp facilities that participate in the

Hawaii Shrimp Surveillance & Certification Program are biosecure and do not have contact with wild penaeid populations. Certified facilities in the program are inspected and tested every six months for specific pathogens, which include those listed by the World Organization of Animal Health (OIE) (Yamasaki 2013, pers. comm.).

While Briggs et al. (2005) note that *L. vannamei* have previously escaped culture facilities in Hawaii, the species has yet to become established in Hawaii (Yamasaki 2013, pers. comm.). These conditions produce a biosecurity score of 8 out of 10 for the source of live *L. vannamei* in the Chinese shrimp farming industry.

Biosecurity of Chinese *L. vannamei* farms

Intensive shrimp production systems in China use high water exchange rate between ~8%–15% (Cao 2012) and have no known specific safeguards in place to prevent escapes of farmed animals. Yet increasingly, these shrimp farms are being sited in inland areas that are less prone to flood-based pond breaches (Cao 2014, pers. comm.). As such, the biosecurity score for Chinese *L. vannamei* farms is 4 out of 10.

Under the assumption that more robust biosecurity measures at either the source or destination of farmed *L. vannamei* reduce the overall risk of unintentional introductions, the higher score between the source and destination is applied under Seafood Watch criteria. As such, a Factor 10Xb score of 8 out of 10 was applied to intensive *L. vannamei* farms.

Combining Factor 10Xa and 10Xb results in an overall penalty score of -2 out of -10 for *L. vannamei* farms in China.

Escape of Introduced Species Criterion—Conclusions and Final Score

The scoring structure for this criterion combines the percentage of production reliant on international or trans-waterbody movements of live shrimp with the biosecurity of either the source or the destination of those shipments (whichever is higher). Note this is an Exceptional criterion and the scoring range is from 0 (no concern) to -10 (very high concern).

Under Seafood Watch criteria, F10Xa is combined with the higher biosecurity score in F10Xb. Therefore, the final penalty score for C10X–Escape of Unintentionally Introduced Species is -2 of -10.

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Data Points And All Scoring Calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	5	5
Effluent	Yes	2.5	2.5
Locations/habitats	Yes	2.5	2.5
Predators and wildlife	Yes	2.5	2.5
Chemical use	Yes	5	5
Feed	Yes	2.5	2.5
Escapes, animal movements	Yes	2.5	2.5
Disease	Yes	2.5	2.5
Source of stock	Yes	5	5
Other – (e.g., GHG emissions)	No	Not relevant	n/a
Total			**30**

C1 Data Final Score	3.333333333	YELLOW

Criterion 2: Effluents

Factor 2.1a–Biological waste production score

Protein content of feed (%)	40
eFCR	1.6
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	17.8
N content factor (fixed)	*0.16*
N input per ton of fish produced (kg)	102.4
N in each ton of fish harvested (kg)	28.48
Waste N produced per ton of fish (kg)	**73.92**

Factor 2.1b–Production System discharge score

Basic production system score	0.51
Adjustment 1 (if applicable)	0

Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0
Discharge (Factor 2.1b) score	**0.51**

51 % of the waste produced by the fish is discharged from the farm

2.2 – Management of farm-level and cumulative impacts and appropriateness to the scale of the industry

Factor 2.2a–Regulatory or management effectiveness

Question	Scoring	Score
1–Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Moderately	0.5
2–Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Moderately	0.5
3–Do the control measures address or relate to the cumulative impacts of multiple farms?	Yes	1
4–Are the limits considered scientifically robust and set according to the ecological status of the receiving waterbody?	Partly	0.25
5–Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc.?	No	0
		2.25

Factor 2.2b–Enforcement level of effluent regulations or management

Question	Scoring	Score
1–Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Partly	0.25
2–Does monitoring data or other available information demonstrate active enforcement of the control measures?	No	0
3–Does enforcement cover the entire production cycle (i.e., are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	No	0
4–Does enforcement demonstrably result in compliance with set limits?	No	0
5–Is there evidence of robust penalties for infringements?	No	0
		0.25

F2.2 Score (2.2a*2.2b/2.5)	**0.225**

C2 Effluent Final Score	**3.00**	**RED**
	Critical?	NO

Criterion 3: Habitat

3.1. Habitat conversion and function

F3.1 Score	4

3.2 Habitat and farm siting management effectiveness (appropriate to scale of industry)

Factor 3.2a–Regulatory or management effectiveness

Question	Scoring	Score
1–Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Partly	0.25
2–Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Moderately	0.5
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Partly	0.25
4–Are high-value habitats being avoided for aquaculture siting? (i.e., avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	Partly	0.25
5–Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	No	0
		1.25

Factor 3.2b–Siting regulatory or management enforcement

Question	Scoring	Score
1–Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	No	0
2–Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Partly	0.25
3–Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Partly	0.25
4–Is the enforcement process transparent–e.g., public availability of farm locations and sizes, EIA reports, zoning plans, etc.?	No	0
5–Is there evidence that the restrictions or limits defined in the control measures are being achieved?	No	0
		0.5

F3.2 Score (2.2a*2.2b/2.5)	0.25

C3 Habitat Final Score	2.75	RED
	Critical?	NO

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use Parameters	Score	
C4 Chemical Use Score	0.00	
C4 Chemical Use Final Score	**0.00**	RED
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Factor 5.1a–Fish In: Fish Out (FIFO)

Fishmeal inclusion level (%)	30
Fishmeal from byproducts (%)	0
% FM	30
Fish oil inclusion level (%)	1.5
Fish oil from byproducts (%)	0
% FO	1.5
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.6
FIFO fishmeal	2.13
FIFO fish oil	0.48
Greater of the 2 FIFO scores	2.13
FIFO Score	**4.67**

Factor 5.1b–Sustainability of the Source of Wild Fish (SSWF)

SSWF	-6
SSWF Factor	-1.28

F5.1 Wild Fish Use Score	**3.39**

5.2. Net protein Gain or Loss

Protein INPUTS	
Protein content of feed	40
eFCR	1.6
Feed protein from NON-EDIBLE sources (%)	0

Feed protein from EDIBLE CROP sources (%)		50.125
Protein OUTPUTS		
Protein content of whole harvested fish (%)		17.8
Edible yield of harvested fish (%)		65.5
Non-edible byproducts from harvested fish used for other food production		50
Protein IN		54.83
Protein OUT		14.7295
Net protein gain or loss (%)		-73.1337
	Critical?	NO
F5.2 Net protein Score	**2.00**	

5.3. Feed Footprint

5.3a Ocean area of primary productivity appropriated by feed ingredients per ton of farmed seafood

Inclusion level of aquatic feed ingredients (%)	31.5
eFCR	1.6
Average Primary Productivity (C) required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Average ocean productivity for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	13.11

5.3b Land area appropriated by feed ingredients per ton of production

Inclusion level of crop feed ingredients (%)	68.5
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.6
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.42

Value (Ocean + Land Area)	**13.52**

F5.3 Feed Footprint Score	**5.00**

C5 Feed Final Score	**3.44**	**YELLO**

		W
	Critical ?	NO

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	2

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	0
Recapture & Mortality Score	0
Factor 6.1a Escape Risk Score	**2**

6.1b. Invasiveness

Part A – Native species

Score	0

Part B – Non-Native species

Score	**0.5**

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	Yes
Do escapees act as additional predation pressure on wild native populations?	No
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	No
Do escapees modify habitats to the detriment of other species (e.g., by feeding, foraging, settlement or other)?	No
Do escapees have some other impact on other native species or habitats?	No
	4

F 6.1b Score	**4.5**

Final C6 Score	**3.00**	**RED**
	Critical ?	**NO**

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	RED
Critical?	NO	

Criterion 8: Source of Stock

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock, natural (passive) settlement, or sourced from sustainable fisheries	100	
C8 Source of stock Final Score	**10**	GREEN

Exceptional Factor 9X: Wildlife and predator mortalities

Wildlife and predator mortality parameters	Score	
F9X Wildlife and Predator Final Score	**-5.00**	YELLOW
Critical?	NO	

Exceptional Factor 10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	0.00	
F10Xb Biosecurity of source/destination	8.00	
F10X Escape of unintentionally introduced species Final Score	**-2.00**	GREEN