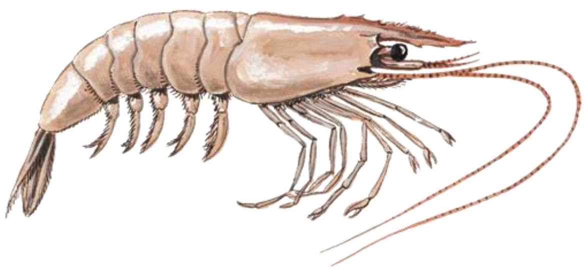
Monterey Bay Aquarium Seafood Watch®

Whiteleg Shrimp

Litopenaeus vannamei



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Thailand
Intensive ponds

July 6, 2020
Seafood Watch Staff

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About Seafood Watch®

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

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Watch Assessment. Each assessment 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." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, 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 assessments 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 Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch® defines "sustainable seafood" as seafood from sources, whether fished or farmed, that can maintain or increase production without jeopardizing the structure and function of affected ecosystems.

Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts available for analysis;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be available for analysis.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms 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.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g., by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.
7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**
   Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.

8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites;**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals;**
    Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

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

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

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

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

Final Seafood Recommendation

Whiteleg shrimp

Litopenaeus vannamei

Thailand

Intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	5.45	Yellow	n/a
C2 Effluent	6.00	Yellow	No
C3 Habitat	4.27	Yellow	No
C4 Chemicals	4.00	Yellow	No
C5 Feed	3.00	Red	No
C6 Escapes	4.00	Yellow	No
C7 Disease	4.00	Yellow	No
C8X Source	0.00	Green	No
C9X Wildlife	-5.00	Yellow	No
C10X Introduction of secondary species	-1.50	Green	n/a
Total	24.22		
Final score (0-10)	3.46		

OVERALL RANKING

Final Score	3.46
Initial rank	Yellow
Red criteria	1
Interim rank	Yellow
Critical Criteria?	0

Final Rank
Yellow

Scoring note – Scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact. Two or more red criteria, or 1 Critical criterion trigger an overall Red recommendation.

Summary

The final numerical score for intensively farmed whiteleg shrimp *(Litopenaeus vannamei)* in Thailand is 3.46 out of 10, which is in the Yellow range. With one Red criterion (Feed), the final rank is Yellow and a “Good Alternative” recommendation.

Executive Summary

Today, the majority of Thai (whiteleg) shrimp pond systems are intensive, low-exchange, and periodically discharge water throughout a cycle and harvest that results in an average exchange rate of <1% of pond water volume per day, though some systems do not discharge water over multiple production cycles. Data are not available to accurately estimate the proportion of the industry that does not discharge water over multiple production cycles, but for the purposes of this report, an average daily exchange of <1% is considered representative of the Thai shrimp industry at large.

Annual production of *L. vannamei* in Thailand steadily rose from roughly 375,000 mt in 2005 to a peak of 603,000 mt in 2011 before rapidly declining in the following years due to disease (Figure 2). In 2018, 357,933 mt of *L. vannamei* were produced, accounting for just under 96% of all Thai shrimp production; the remaining 4% was largely accounted for by the black/giant tiger prawn *P. monodon* (DOF, 2020). In 2017 (the most recent available total statistics), farmed whiteleg shrimp represented roughly 30% of total aquaculture production in Thailand (FAO, 2018; DOF, 2020). Overall, Thailand is currently the sixth largest producer of whiteleg shrimp globally, following China, India, Indonesia, Vietnam, and Ecuador (FAO, 2018).

Overall, the availability and quality of data regarding shrimp farming in Thailand is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. Uncertainty arises from a lack of information regarding the use of chemicals and the feed supply chain, while there are also gaps in data regarding the enforcement of effluent laws, escapes, and impacts to wild species through disease transfer and predator control. For the most part, the data were able to provide a reasonable understanding of the Thai shrimp industry, and the final score for Criterion 1 – Data is 5.45 out of 10.

The discharge of shrimp farm effluent in Thailand is regulated under an area-based, cumulative management system in conjunction with other industries. Receiving waterbodies are managed to meet specific water quality standards based on their intended use and defined class, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture); however, there is uncertainty regarding the extent to which ecological considerations, such as carrying capacity of the receiving waterbody, are considered in the development of water quality standards. It is also unclear how small farms (<10 rai) are managed, though it is known that compliance with the coastal aquaculture effluent standard is not required; the number of these farms is unknown, yet they may be common. Enforcement of these regulations is considered moderately effective, as the DOF and PCD actively monitor farm discharges and water quality for compliance, though concerns regarding a lack of sufficient resources and human capital leave questions regarding the true capacity of these organizations. Overall, coastal and surface water quality in Thailand appears to be improving to some degree over the past five years. The scores for Factor 2.1 (8 out of 10) and 2.2 (3.6 out of 10) are combined using the Risk-Based Assessment matrix, resulting in a final score of 6 out of 10 for Criterion 2 – Effluent.

Shrimp farm siting in Thailand is controlled and restricted to shrimp aquaculture zones, though it is unclear to what degree ecological considerations were factored into the zoning process. All farms are required to register with the DOF and obtain a license prior to operation, and mangrove deforestation for the construction of aquaculture ponds is illegal. The government also is actively working to reclaim land and restore mangroves in affected areas, and has restored over 100,000 hectares since the lowest point in 1996. Enforcement of siting and mangrove conservation laws is somewhat limited due to a lack of capacity. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (4 out of 10) and Factor 3.2 – Farm siting regulation and management (4.8 out of 10), and the final score is 4.27 out of 10.

Overall, chemical use in Thai shrimp aquaculture is common, though most do not pose significant environmental concerns. Most chemicals used for pond preparation and disinfection pose a low risk to the environment, given the low water exchange rates and rapid degradation of these compounds and their by-products. On the other hand, the use of antibiotics in aquaculture can result in the development of antibiotic-resistant bacteria in the environment and pose significant risks to both the environment and human health.

This assessment considers the majority of shrimp farms in Thailand to discharge <1% water volume per day (see Criterion 2 – Effluent), warranting a score of 6 out of 10. While it is understood that most farmers do not use antibiotics, there is evidence that highly important antimicrobials for human medicine are being used in unknown quantities (a score of 0 out of 10) and limited evidence suggesting that critically important antimicrobials may also be used. Therefore, an intermediate score is justified. Antibiotic resistance is evident in coastal Thailand, including on shrimp farms, but is not conclusively driven by on-farm antibiotic use, resulting in some concern of resistance to chemical treatments. Other chemicals used on farms, such as disinfectants, are not believed to cause significant impacts to non-target organisms. As such, the final score for Criterion 4 – Chemicals is 4 out of 10.

Whiteleg shrimp feeds in Thailand use fishmeal and fish oil made from whole wild fish and from by-product sources. The fishmeal inclusion level is moderate (12.0%); three quarters of it (75%) is sourced from fishery and/or aquaculture by-products, and the remainder is sourced from the domestic trawl fleet. The fish oil inclusion level is low at 0.27%, and all comes from by-product sources. The Forage Fish Efficiency Ratio (FFER) is thus very low (0.23), meaning that from first principles, 0.23 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed shrimp. The small mesh trawl fishery in Thailand has a history of high concerns regarding illegal, unregulated and unreported (IUU) fishing practices, and despite encouraging recent management improvements that reduce fishing effort, the fishery remains a high conservation concern (scoring 0 out of 10 for the sustainability score). Nevertheless, the fraction of the total Thai trawl fleet catch that currently enters the shrimp feed supply chain is estimated to be no more than 11% and appears to be decreasing. Overall, despite the low levels of inclusion of these wild fish ingredients in Thai shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10). With a moderate-high net protein loss (-

67.49%; score of 3 out of 10) and moderate feed footprint (20.39 kg CO_2-eq. per kg harvested protein; score of 5 out of 10), the three factors combine to give a final score of 3.00 out of 10 for Criterion 5 – Feed.

Escape risk of shrimp ponds in Thailand is moderate-high, as the majority of the industry is sited in low-lying and/or coastal areas where flooding regularly occurs. Despite this, on-farm escape prevention measures taken by farmers (such as elevated dike construction, screens on outlets, harvesting prior to large storms) and the effectively closed nature of farms (<1% daily water exchange) significantly mitigate the risk of escape.

L. vannamei are non-native in Thailand and have been found in the wild during shrimp population surveys. Despite evidence indicating the ability to outcompete and even consume native shrimp, as well as the development of reproductive organs, there is no indication that *L. vannamei* have established viable populations in Thailand, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a moderate-high risk of escape (a score of 2 out of 10 for Factor 6.1) and a low-moderate risk of competitive impacts (a score of 6 out of 10 for Factor 6.2) results in a final score of 4 out of 10 for Criterion 6 – Escapes.

As data quality and availability regarding the impact of on-farm disease on the ecosystem is moderate/low (i.e. Criterion 1 scored 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment method was utilized. Despite the lack of information regarding the transfer of pathogens from farmed to wild species and the health status of wild species, the risk of such transmission can be estimated by the disease challenges faced by the industry, the biosecurity measures implemented, and the rate and characteristics of water discharged from farms. Farmers employ techniques to limit on-farm pathogen load, such as vector exclusion and water treatment prior to stocking. Water exchange during the production cycle is, on average, less than 1% of pond volume per day, and many farms do not discharge water to the environment over the course of a production cycle except at harvest. Despite these efforts, farms can clearly be considered to suffer from high disease or pathogen related infection and/or mortality. Further, their siting in flood-prone areas and the likelihood that some farms do not adequately treat water after an unplanned, disease-related harvest means that pathogens may be discharged to the environment. Ultimately, the biosecurity protocols in place on farms range in comprehensiveness and efficacy, and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

Whiteleg shrimp farms in Thailand only use hatchery-raised seed from domesticated broodstock, the majority of which are SPF from biosecure hatcheries in Thailand operated by Charoen Pokphand. There is no reliance on wild shrimp for farm production, and as such, the final score for Criterion 8X – Source of Stock, is 0 out of -10.

The data regarding the impact that predator control at shrimp farms has on wild species is poor, and the Risk-Based Assessment method was used. Overall, it is understood that Thai shrimp farms may interact with predators and other wildlife, and farmers primarily utilize nonlethal control methods to exclude predators and limit interactions; thus, it is considered that management practices for non-harmful exclusion are in place. Despite this, there is limited information available to determine whether any mortality (accidental or intentional) occurs beyond the killing of fish as a biosecurity measure, and given the “near-threatened” population status of numerous bird species that interact with shrimp ponds, some concern is warranted. It is unlikely, though, that any mortalities that may indeed occur would significantly impact the population size of the affected species. The final score for Criterion 9X – Wildlife and Predator Mortalities is -5 out of -10.

Given the available evidence, it is determined that 40% of the Thai whiteleg shrimp farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 5 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments. The source of animal movements is mostly from fully biosecure broodstock and/or hatchery facilities, while the destination of animal movements – production ponds – have some uncertainty regarding the implementation and effectiveness of biosecurity measures in place, resulting in an overall score of 7 out of 10 for Factor 10Xb. The final score for Criterion 10x – Escape of Secondary Species is -1.5 out of -10.

Overall, the final numerical score for intensively farmed whiteleg shrimp *(Litopenaeus vannamei)* in Thailand is 3.46 out of 10, which is in the Yellow range. With one Red criterion (Feed), the final rank is Yellow and a “Good Alternative” recommendation.

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Introduction

Scope of the analysis and ensuing recommendation

Species: Whiteleg shrimp (*Litopenaeus vannamei*)
Geographic coverage: Thailand
Production Method: Intensive ponds

Species Overview
Litopenaeus vannamei live in tropical marine habitats and are native to the Eastern Pacific coast from Sonora, Mexico in the north to Tumbes, Peru in the south. As such, they are non-native to Thailand. As for all Penaeid species, adults live and spawn in the open ocean, while postlarvae (PL) migrate inshore to spend their juvenile, adolescent and sub-adult stages in coastal estuaries, lagoons or mangrove areas (FAO 2006).

Production System
Intensive farms are generally characterized as using aeration and manufactured feeds to support elevated stocking and biomass densities of shrimp beyond that which the natural environment can. This is the case in Thai *L. vannamei* production, with the vast majority of production (99.6%) occurring in intensive ponds (356,359 metric tons (mt) out of a total 357,933 mt in 2018; DOF, 2020).

Average intensive Thai shrimp farm size (data are inclusive of *P. monodon*) is just under 2 hectares (ha), with 19,553 intensive farms registered by the Department of Fisheries (DOF) occupying 35,744 ha (DOF, 2020); there is, of course, a range of farm sizes in operation and no "median" value could be obtained, though large farms are often >16 ha in size (Boyd et al. 2017; Na nakorn et al. 2017). Pond size ranges from 0.33 to >1.5 ha, though commonly are 1 ha in size (Boyd et al. 2017; Seafood Watch field research).

The majority of intensive Thai whiteleg shrimp pond systems are low-exchange, and periodically discharge water to the environment (i.e. outside of the farming system) throughout a cycle and harvest that results in an average exchange rate of <1% of pond water volume per day, though some systems do not discharge water over multiple production cycles (Boyd et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; pers. comm. Dr. Putth Songsanjinda, DOF, 2018). Data are not available to accurately estimate the proportion of the industry that does not discharge water over multiple production cycles, but for the purposes of this report, an average daily exchange of <1% is considered representative of the Thai shrimp industry at large.

In order to operate this way, farmers have largely converted old production ponds into reservoirs and sedimentation basins to enable water treatment and reuse (Na nakorn et al. 2017). Raw seawater is pumped into the system and generally passes through one or two reservoirs and is treated (either by natural 'aging', chemical inputs, or both) prior to entering culture ponds. Culture ponds frequently are equipped with polyethylene liners to limit erosion (either on the banks, or on the entire pond, depending on the size of the farm) along with central drains to facilitate the removal of sediment and/or sludge (uneaten feed, feces, etc.). This helps to minimize the accumulation of organic content so as not to support the growth of bacteria, such as VP_{AHPND} (Boyd et al. 2017; Na nakorn et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Water is recirculated and maintained within the system throughout a production cycle, with small additions of water to culture ponds from the treated reservoir(s) to replace water lost through evaporation and sludge removal; this system is sometimes referred to as "intensive 2.0" or "the toilet", with the removal of sludge referred to as "flushing" (pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). See Figure 1 for schematic diagrams depicting this system in small-scale (<8.0 ha culture pond area), medium-scale (8.1-16.0 ha), and large-scale (>16.1 ha) farms in Thailand.

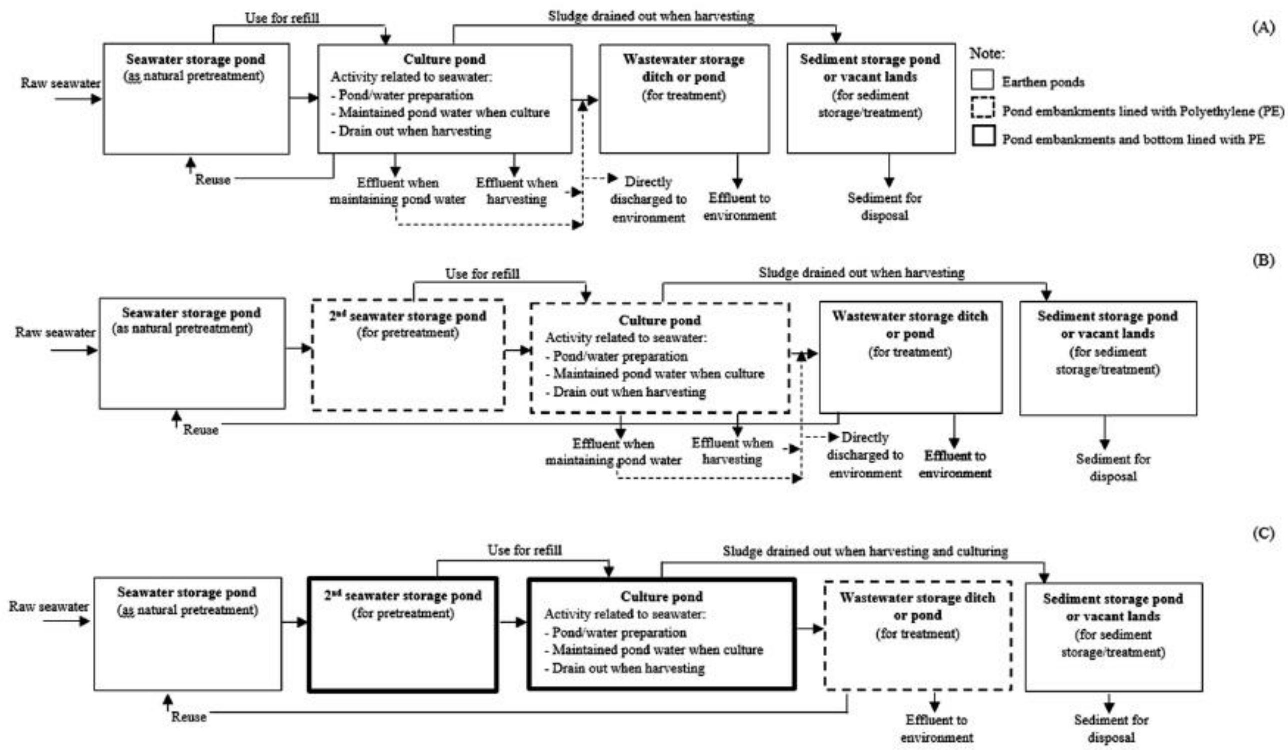

Figure 1. Diagram of used water and water management practices at each scale of shrimp farm at Bandon Bay, Surat Thani province, Thailand: (A) small-scale farms; (B) medium-scale farms; (C) large-scale farms. (Surveyed during January-October, 2013). Figure from Na nakorn et al. (2017).

Production statistics

Annual production of *L. vannamei* in Thailand steadily rose from roughly 375,000 mt in 2005 to a peak of 603,000 mt in 2011 before rapidly declining in the following years due to disease (Figure 2). In 2018, 357,933 mt of *L. vannamei* were produced, accounting for just under 96% of all Thai shrimp production; the remaining 4% was largely accounted for by the black/giant tiger prawn *P. monodon* (DOF, 2020). In 2017 (the most recent available total statistics), farmed whiteleg shrimp represented roughly 30% of total aquaculture production in Thailand (FAO, 2018; DOF, 2020). Overall, Thailand is currently the sixth largest producer of whiteleg shrimp globally, following China, Indonesia, India, Ecuador, and Viet Nam (FAO, 2018).

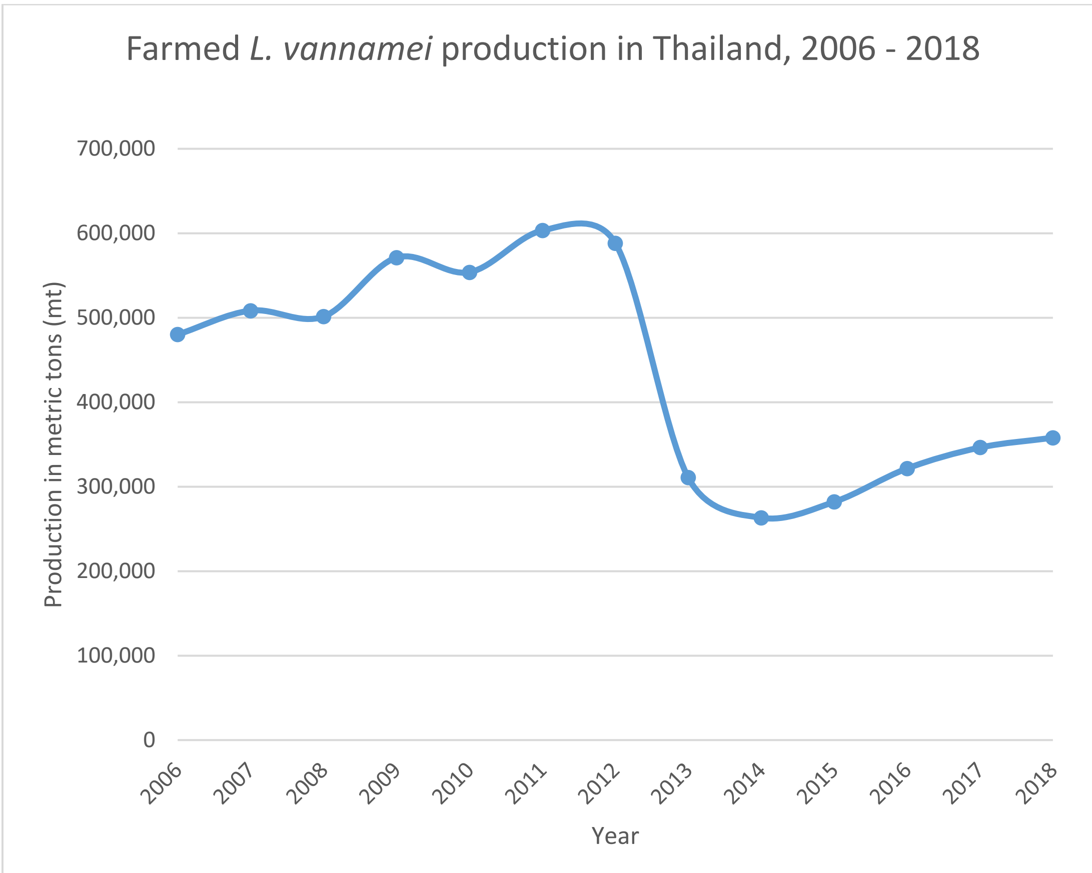

Figure 2. Farmed *Litopenaeus vannamei* shrimp production in Thailand from 2006 to 2018. (DOF, 2020).

Import and export sources and statistics

Despite recent disease challenges that have significantly affected production, Thailand remains one of the world's main shrimp producing nations and the United States (US) is their highest volume importer.

Farmed *L. vannamei* represented roughly 97% of total shrimp exports and totaled 163,925 mt in 2019 according to a summary export document from the Thai Frozen Foods Association (TFFA)[1]. A more detailed breakdown of shrimp exports is available from TFFA for 2017 and shows the US imported 74,605 mt of shrimp from Thailand (fresh, chilled, frozen, prepared, processed), worth $875.2 million USD, out of a total 208,068 mt ($2.04 billion USD) exported shrimp, roughly 35% by volume and 41% by value[2]. The next largest importers of Thai shrimp are Japan, which imported 44,758 mt, nearly 22% of total shrimp exports, followed by Canada, which

[1] https://www.thai-frozen.or.th/index.php/seafood-industry-info/statistic-3/118-summary-statistics

[2] https://www.thai-frozen.or.th/index.php/seafood-industry-info/statistic-3/119-export-2017

imported 10,715 mt, or 5.15%. Though the TFFA export data are inclusive of all species of both farmed and wild-captured shrimp, it is understood that >99% of exports are farmed whiteleg shrimp (Portley, 2016).

US imports of Thai shrimp have closely mirrored production, and dropped by nearly 70% between 2010 and 2014 (Figure 3). Data from the National Marine Fisheries Service (NMFS) show a higher volume of imported shrimp from Thailand than export data from the TFFA. This discrepancy is likely due to the preliminary nature of the TFFA data, though the accuracy of the data coming from the TFFA may be questionable, as the numbers provided are lower than those data reported by NMFS in every year back to 2006.

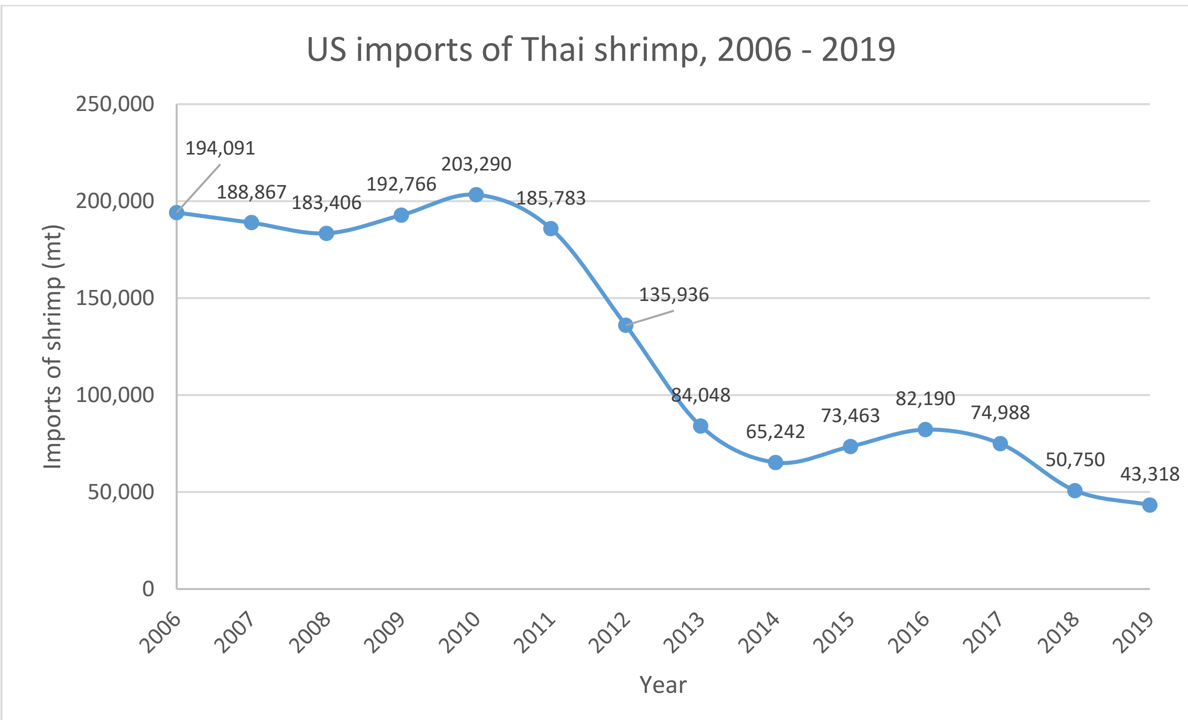

Figure 3. US imports of Thai shrimp, inclusive of all species and wild-capture fisheries. Data from the National Marine Fisheries Service.[3]

Common and market names

Scientific Names	*Litopenaeus vannamei*
Common Names	Pacific white shrimp, whiteleg shrimp, western white shrimp, or shrimp
United States	Whiteleg shrimp
Spanish	*Camarón patiblanco*
French	*Crevette pattes blanches*

[3] https://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/applications/annual-product-by-countryassociation

Japanese	*Banamei-ebi* (バナメイエビ)

Product forms

Shrimp are exported from Thailand in a variety of product forms, primarily frozen (61%), followed by fresh or chilled (23%), and dried, salted, smoked, or in brine (16%)[4]. In the US, over 95% of shrimp imported from Thailand is frozen[5]. The primary form is frozen-raw with shell-on, followed by frozen-peeled – these two make up well over 60% of the market – with other major forms included frozen-breaded and frozen-prepared[6].

[4] http://www.intracen.org/itc/market-info-tools/trade-statistics/

[5] https://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/applications/annual-product-by-countryassociation

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 or enable businesses to be held accountable for their impacts.
- *Unit of sustainability:* The ability to make a robust sustainability assessment.
- *Principle:* Having robust and up-to-date information on production practices and their impacts available for analysis.

Criterion 1 Summary

Data Category	Data Quality	Score (0-10)
Industry or production statistics	7.5	7.5
Management	5	5
Effluent	5	5
Habitat	5	5
Chemical use	5	5
Feed	5	5
Escapes	5	5
Disease	5	5
Source of stock	10	10
Wildlife mortalities	2.5	2.5
Introduced species	5	5
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		**60.0**

C1 Data Final Score (0-10)	**5.45**	Yellow

Brief Summary

Overall, the availability and quality of data regarding shrimp farming in Thailand is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. Uncertainty arises from a lack of information regarding the use of chemicals and the feed supply chain, while there are also gaps in data regarding the enforcement of effluent laws, escapes, and impacts to wild species through disease transfer and predator control. For the most part, the data were able to provide a reasonable understanding of the Thai shrimp industry, and the final score for Criterion 1 – Data is 5.45 out of 10.

Justification of Ranking

Industry or production statistics

Aggregated industry and production statistics are readily available from the Department of Fisheries (DOF), Thai Frozen Foods Association (TFFA), and FAO's FishstatJ software. Information regarding average farm size and the distribution of farms could be obtained from the aforementioned sources, as well as from the literature. There is some uncertainty regarding adoption rates of certain production methodologies within the "intensive" label (such as the use of pond liners, multiple reservoirs, sediment disposal, etc.), but overall, data quality regarding industry and production statistics is moderate-high and receives a score of 7.5 out of 10.

Management and Regulations

A significant amount of information was able to be obtained regarding legislation governing the Thai shrimp industry from official Thai government websites[6], unaffiliated websites[7], the FAO National Aquaculture Legislation Overview, literature, and personal contacts with government officials. There are some gaps in understanding the intent and/or implementation of certain legislation, despite using translation software, as well as limited information in some areas regarding compliance and enforcement of the law. As such, data quality regarding management and regulations is moderate and receives a score of 5 out of 10.

Effluent and Habitat

Information regarding farm siting and effluent discharge practices was able to be obtained, though gaps in the data regarding enforcement remain. A general understanding of the location of farms was obtained through visual tools like Google Maps and an official Thai government database listing farm certifications and locations bolstered this. Reports from the Department of Marine and Coastal Resources (DMCR) and Pollution Control Department (PCD) informed the status of water quality and mangrove area and restoration, and overall confidence in the data for these criteria is moderate. The data scores for the Effluent and Habitat criteria are both 5 out of 10.

Chemical Use

Detailed data regarding chemical use in Thailand were not able to be obtained, though a general understanding of usage across the industry was developed through the literature and personal contacts with government officials, farmers, and industry experts. Uncertainty in actual chemical use exists due to the variability of the production methodologies amongst farmers, as well as opaqueness in the chemical supply chain (e.g. brokers selling antibiotics as probiotics). Little research has been done to understand the link between on-farm chemical use and associated environmental impact, but water discharge in Thai shrimp farming systems is limited, mitigating much of the environmental risk. The data quality and ensuing confidence in understanding the nature of chemical use on Thai shrimp farms is moderate and scores 5 out of 10.

Feed

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[6] https://www4.fisheries.go.th/index.php/dof

[7] www.thailaws.com

Information regarding feed composition, conversation ratios, and the source of wild fish was obtained through personal communications with the Thai Feed Mill Association (TFMA), private feed manufacturers, industry experts, government officials, and the literature. Given the proprietary nature of feed composition, estimates regarding the proximate and ingredient composition were based on a range of data. Significant uncertainty remains regarding the volume and source fisheries of whole-fish fishmeal ingredients, though data sources include published literature, white papers, and personal communications with industry experts that constrain the uncertainty to a reasonable degree. The data quality and confidence in the data is moderate and scores 5 out of 10.

Escapes
Very limited information was obtained regarding the incidence or number of escaped shrimp. The only source of information detailing these numbers were news reports and several studies assessing the presence of *L. vannamei* in the wild in Thailand. Information regarding escape and flood mitigation measures was obtained from the literature and personal communications with government officials and industry experts. The body of literature assessing the competitive and genetic risks to wild species posed by escaped shrimps in Thailand and elsewhere is moderately robust. As such, the data score for Criterion 6 – Escapes is 5 out of 10.

Disease
There is a large body of literature and study detailing the pathogens, biosecurity measures, disease control methods, and water exchange rates in the Thai shrimp industry, but there is limited information regarding the risk and/or evidence of disease transfer to wild species. Disease incidence rates were obtained from the literature, personal communications with government officials, farmers, and industry experts, as well as quarterly reports from the Network of Aquaculture Centers in Asia (NACA). Limited information regarding pathogen prevalence amongst wild shrimp was obtained through the literature. As the focus of this Criterion is on the risk of or actual impact of farm disease on wild populations, the availability and quality of data is considered moderate and scores 5 out of 10.

Source of stock
As is the case for *L. vannamei* production globally, Thai farmed shrimp are produced from domesticated broodstocks and are therefore independent of wild shrimp populations. There is also information specific to the Thai industry available through personal communications detailing selective breeding strategies and programs. The data score for Source of Stock is 10 out of 10.

Wildlife mortalities
No data are available regarding deliberate or accidental mortalities of any animals at shrimp farms. Predator control methods in use on farms were understood through the literature and personal contacts with government officials, farmers, and industry experts. The status of potentially affected species was obtained through the literature and sources like the International Union for Conservation of Nature (IUCN). Overall, the confidence in the data

regarding the impact that predator control at shrimp farms has on wild species is poor, and the score is 2.5 out of 10.

Escape of secondary species
Data regarding the international and/or trans-waterbody movement of live animals were incomplete, though reasonable estimates were able to be made through limited literature and personal communication with industry experts. The biosecurity of both source and destination were somewhat uncertain, though well understood for the majority of the industry, given the variability within the supply and production chains; again, limited literature sources were available and personal communication with industry experts contributed to the understanding of biosecurity. The confidence in the data is moderate, and scores 5 out of 10.

Conclusions and Final Score
Overall, the availability and quality of data regarding shrimp farming in Thailand is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. Uncertainty arises from a lack of information regarding the use of chemicals and the feed supply chain, while there are also gaps in data regarding the enforcement of effluent laws, escapes, and impacts to wild species through disease transfer and predator control. For the most part, the data were able to provide a reasonable understanding of the Thai shrimp industry, and the final score for Criterion 1 – Data is 5.45 out of 10.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- *Impact:* Aquaculture species, production systems and management methods vary in the amount of waste produced per unit of production. The combined discharge of farms, groups of farms or industries contribute to local and regional nutrient loads.
- *Unit of sustainability:* The carrying or assimilative capacity of the local and regional receiving waters.
- *Principle*: Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Effluent Risk-Based Assessment

C2 Effluent parameters	Value	Score
F2.1a Waste (nitrogen) production per of fish (kg N ton^{-1})	59.12	
F2.1b Waste discharged from farm (%)	20.00	
F2.1b Boundary adjustment (0-1)	0.00	
F2 .1 Waste discharge score (0-10)		8
F2.2a Content of regulations (0-5)	3	
F2.2b Enforcement of regulations (0-5)	3	
F2.2 Regulatory or management effectiveness score (0-10)		3.60
C2 Effluent Final Score (0-10)		**6**
Critical?	No	Yellow

Brief Summary

The discharge of shrimp farm effluent in Thailand is regulated under an area-based, cumulative management system in conjunction with other industries. Receiving waterbodies are managed to meet specific water quality standards based on their intended use and defined class, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture); however, there is uncertainty regarding the extent to which ecological considerations, such as carrying capacity of the receiving waterbody, are considered in the development of water quality standards. It is also unclear how small farms (<10 rai) are managed, though it is known that compliance with the coastal aquaculture effluent standard is not required; the number of these farms is unknown, yet they may be common. Enforcement of these regulations is considered moderately effective, as the DOF and PCD actively monitor farm discharges and water quality for compliance, though concerns regarding a lack of sufficient resources and human capital leave questions regarding the true capacity of these organizations. Overall, coastal and surface water quality in Thailand appears to be improving to some degree over the past five years.

The scores for Factors 2.1 (8 out of 10) and 2.2 (3.6 out of 10) are combined using the Risk-Based Assessment matrix, resulting in a final score of 6 out of 10 for Criterion 2 – Effluent.

Justification of Rating
Data quality and availability for effluent impacts is considered moderate (i.e. a Criterion 1 score of 5 out of 10 for the effluent category) and therefore, the Risk-Based Assessment methodology was utilized.

Intensive whiteleg shrimp culture in Thailand represented over 95% of Thailand's total shrimp production in 2018 (DOF, 2020). Higher stocking densities and increased feeding, characteristic of intensive shrimp systems, frequently result in reduced water quality in ponds and discharge of pond water has the potential to affect the surrounding waterbodies in the environment where farms are sited (Nair 2015).

Thailand manages and measures water quality throughout the country through collaboration between the Pollution Control Department (PCD) and Department of Fisheries (DOF). While there is a great deal of information available regarding the water quality status of coastal watersheds, there appears to be a lack of robust analysis relating whiteleg shrimp aquaculture's contribution to the overall impact, or lack thereof, to coastal watersheds. As such, the Risk-Based Assessment method is used in this Criterion.

Factor 2.1 – Biological waste production per ton of shrimp

Factor 2.1a – Biological waste production
The Risk-Based Assessment method estimates the amount of waste nitrogen produced per ton of whiteleg shrimp farmed.

Shrimp excrete waste primarily as a result of incomplete digestion and absorption of their feeds, and only a small portion of the nutrients in feed are consumed, assimilated, and retained for tissue growth. Early research by Briggs and Funge-Smith (1994) and Green et al. (1997) indicated that only 24%–37% of the nitrogen (N) and 13%–20% of the phosphorus (P) from feed was retained by shrimp. Similarly, Lorenzen (1999) also reported that 20%–40% of the fed nitrogen was incorporated into shrimp tissue. These ranges are still considered valid today, though considerable investment has gone into increasing the efficiency of shrimp feeds and have resulted in higher phosphorus retention in shrimp (Dien et al., 2018; Van Nguyen and Maeda, 2015).

To estimate the nitrogenous waste produced by shrimp, nitrogenous inputs and outputs are calculated. Fertilizers are rarely used in intensive shrimp farming in Thailand, as the shrimp receive all required nutrition from formulated feeds (Boyd et al., 2017).

The following data were provided by the Thai Feed Mill Association (TFMA), as well as gathered from personal communications with Charoen Pokphand (a major producer of Thai shrimp feed) and Rubicon Resources (a major US importer of Thai shrimp). The provided data were found to be aligned with and supported by information from the listed primary literature, and are used in the calculations for this criterion:

a) Protein content of feed: 30 – 65% (Boyd et al., 2017; pers. comm. TFMA, 2018; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018)
b) Economic Feed Conversion Ratio (eFCR): 1.3 – 1.6 (Boyd et al., 2017; pers. comm. TFMA, 2018; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018)
c) Protein content of harvested whole shrimp – 17.8% (Boyd et al., 2007)

For the purposes of this assessment, a protein content of 36.5% and an eFCR value of 1.5 are considered representative of the Thai whiteleg shrimp farming industry – please see Criterion 5 – Feed for further details regarding these figures. The calculations that were carried out using these figures and used in assessing the production and effects of effluents are:

N input per ton of shrimp produced = a x N content factor (0.16) x b x 10 =	87.60 kg N t^{-1}
N content of harvested shrimp = c x N content factor (0.16) x 10 =	28.48 N t^{-1}
Waste N produced per ton fish produced (2.1a) = N input – harvested N =	59.12 kg N t^{-1}

Therefore, the net excretion of nitrogen in soluble and particulate wastes is 59.12 kg N per ton of whiteleg shrimp production.

Factor 2.1b – Production system discharge

Historically, pond management schemes resulting in daily water exchange rates of >10% and discharge at harvest were characteristic of the Thai shrimp farming industry (SFW, 2010; Flaherty and Vandergeest, 1999).

Today, the majority of Thai shrimp pond systems are low-exchange and periodically discharge water throughout a cycle and harvest that results in an average exchange rate of <1% of pond water volume per day, though some systems do not discharge water over multiple production cycles (Boyd et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; pers. comm. Dr. Putth Songsanjinda, DOF, 2018; Seafood Watch field research, March 2018). Data are not available to accurately estimate the proportion of the industry that does not discharge water over multiple production cycles, and therefore a basic (unadjusted) production system discharge score of 0.42, representing an average annual daily exchange of <3%, is utilized.

Additionally, Thai shrimp producers are required by law to meet water quality standards for discharged water (Fishery Royal Ordinance, 2015). To meet these standards, sedimentation ponds/basins are frequently utilized to improve water quality prior to discharge outside the farm boundary (Boyd et al., 2017; Songsanjinda, 2016).

A range of management practices exist and vary from farm to farm throughout Thailand, but in general, any water that is being discharged from a culture pond will pass through at least one sedimentation basin prior to its release to the environment or its reuse (Boyd et al. 2017; Na nakorn et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Residence times in sedimentation basins vary, and reported values range from as low as 12 hours to greater than one week (pers. comm. Robins McIntosh, Charoen Pokphand, 2018; Seafood Watch field research, March 2018). This warrants the application of adjustments to the basic production system discharge score by -0.14 and -0.08, for the use of a settling pond for daily exchange and harvest discharge, respectively, as determined by the Seafood Watch Aquaculture Standard.

Sediment/sludge that settles in these basins is then removed, yet its fate is uncertain. Historically (pre-2013), settled material was used to rebuild dikes, as the composition of this material was equal amounts sludge (organic waste material, such as uneaten feed or feces) and sediment (pond walls washed away with exchange) (pers. comm. Robins McIntosh, Charoen Pokphand, 2018). Today, however, with generally reduced water exchange in ponds and an increased number of ponds utilizing pond liners, the primary composition of settled material is organic sludge material, which does not make good building material (pers. comm. Robins McIntosh, Charoen Pokphand, 2018). It was suggested that most of this sludge is used as an organic soil amendment for nearby agricultural farms, but its usability would depend on its salinity (pers. comm. Robins McIntosh, Charoen Pokphand, 2018); otherwise, it may be brought to a disposal area or spread around a marsh area (pers. comm. Robins McIntosh, Charoen Pokphand, 2018; Yuvanatemiya et al., 2011), though no information could be found regarding the suitability of these sites. It is noteworthy that the Thai GAP for marine shrimp, to which certification is required for shrimp producers selling to exporting processors, mandates that sediment shall not be disposed of in public or “non-permitted” areas (MoAC, 2014); however, the effectiveness and enforcement of this standard is somewhat uncertain (more in Factor 2.2b). As such, the application of an adjustment for proper sludge disposal is not warranted at this time.

Considering the adjustments detailed above (i.e. 0.42 – 0.14 – 0.08, meaning 0.20 or 20% of the waste produced by the shrimp is considered to be discharged to the environment), the estimated total waste discharged per ton of shrimp produced is 11.8 kg N t^{-1}. This equates to a final score for Factor 2.1 – Waste discharged per ton of shrimp of 8 out of 10.

Factor 2.2 – Management of farm-level and cumulative impacts

Factor 2.2a – Content of effluent management measures

In this factor, effluent regulations or other management measures are considered to assess how discharged wastes from shrimp farms are being managed at the farm and industry level.

Effluents from shrimp farms are regulated at the national, provincial, and district level, with legislation primarily administered and enforced through the Department of Fisheries (DOF), housed within the Ministry of Agriculture and Cooperatives (MoAC) in conjunction with several other government bodies, such as the Ministry of Natural Resources and Environment (MoNRE). The DOF has a main office in Bangkok, with a provincial office in each of the 76 provinces, 22 of which are coastal[8]. Each province has a Provincial Fishery Officer, as well as multiple District Fishery Offices (527 total in Thailand) and officers; the District Office and its officers report to the Provincial Officer, which in turn reports to the central Department of Fisheries office.

The Royal Ordinance on Fisheries of 2015 is the broad legislative framework governing the management of aquatic resources in Thailand, inclusive of shrimp farming; this Ordinance repealed and replaced The Fisheries Act (2015), which was first enacted in 1947 (FAO, 2018b). Through this Ordinance, a National Fisheries Committee was established to develop fisheries and aquaculture policies, in addition to prompting the developing Provincial Fisheries Committees (PFCs); PFCs are authorized to designate aquaculture zones, as well as to issue notifications/legislation regarding aquaculture production, post-harvest, and processing activities within each province (Fishery Royal Ordinance, 2015).

The primary piece of legislation regulating shrimp farm discharges is the Enhancement and Conservation of Environmental Quality Act of 1992[9], by which the MoNRE is granted the authority to determine water quality standards for sea, ground, and underground waters (FAO, 2018b). The MoNRE also has the authority to regulate wastewater discharges from point sources in all sectors, inclusive of aquaculture; water quality standards for discharges from multiple sectors were developed and adopted in 2004[10] (FAO, 2018b). Farmed *L. vannamei* are considered a coastal aquaculture species, and as such, effluent discharges from shrimp ponds are subject to the effluent quality standard for coastal aquaculture (Table 1). It is unclear how the parameter thresholds were determined, and whether there was any ecological consideration in their development. This standard is enforced by the DOF and the Pollution Control Department (PCD), housed within the MoNRE (FAO, 2018b), at the district and provincial level. Of note, these water quality standards were incorporated into the ThaiGAP standard in 2014, a country-level “best aquaculture practices” certification that is indirectly required of farms producing for export; shrimp processing facilities are required to implement Hazard Analysis and Critical Control Points (HACCP) plans, and part of this requirement is to only source shrimp from ThaiGAP certified farms (pers. comm. Dr. Putth Songsanjinda, DOF, 2018).

Farms equal to or over 10 rai (1.6 ha) (the average intensive *L. vannamei* farm in Thailand in 2018 was 11.4 rai, see DOF, 2020) are required to inform the district and/or provincial DOF office of intent to discharge water, and must supply a water sample to the DOF for testing (pers. comm. Dr. Adisorn Promthep, DOF, 2018). Approval for discharge is not granted unless the sample test meets the aforementioned water quality standards (shown in Table 1) (pers. comm. Dr. Adisorn Promthep, DOF, 2018). It is unclear, though, how this process varies at the district and/or provincial level; various personal communications with industry experts and

[8] https://www4.fisheries.go.th/index.php/dof_en/view_role/1
[9] http://portal.mrcmekong.org/assets/documents/Thai-Law/Enhancement-and-Conservation-of-National-Environmental-Quality-Act-(1992).pdf
[10] http://www.wepa-db.net/policies/law/thailand/std_coastal_aqua.htm

farmers highlighted a diversity of practice and regulation regarding reporting and testing, though the requirement for discharge water to meet water quality standards was constant (pers. comm. Dr. Rawee Viriyatum, 2018; Seafood Watch field research, March 2018). Farms under 10 rai are not covered by these regulations, and it is unclear whether there are any controls regarding effluent discharges for farms of this size.

Table 1. Effluent water quality standard for coastal aquaculture[11]

Parameter	Range or Maximum Permitted Values
pH	6.5 – 9.0
Biochemical oxygen demand (BOD)	20.0 mg L^{-1}
Suspended solids (SS)	70.0 mg L^{-1}
Ammonia nitrogen (NH_3-N)	1.10 mg L^{-1}
Total phosphorus (TP)	0.40 mg L^{-1}
Hydrogen sulphide (H_2S)	0.01 mg L^{-1}
Total nitrogen (TN)	4.00 mg L^{-1}

In addition to water quality standards for effluent discharges, Thailand has also developed quality standards for surface water (established in 1994), groundwater (established in 2000), and seawater (established in 2006), as mentioned above. There are six coastal water quality and five surface water quality classes, with specific quality standards for each[12]. It is unclear if these standards were developed with ecological considerations, such as carrying capacity. Further, while waterbodies are required to meet specific water quality standards based on their intended use, there is no indication that pollution allocations have been developed for the industries discharging into these waterbodies. Shrimp farms are sited in areas defined as aquaculture zones, as legislated by the Royal Ordinances on Fisheries (2015), yet these zones may feature waterbodies of various classifications. Therefore, it is possible for shrimp farm discharges to enter waterbodies of higher water quality standards, with no indication of any limits to the cumulative discharges of multiple shrimp farms and other contributing industries, like agriculture or manufacturing.

Additionally, while the MoNRE is also granted authority to determine which types of projects/activities require an Environmental Impact Assessment (EIA), aquaculture is not currently included as a designated activity requiring an EIA to be conducted[13] (FAO, 2018b). This is discussed further in Criterion 3 – Habitat.

Broadly, discharges from shrimp ponds are regulated under an area-based, cumulative management system in conjunction with other industries in Thailand; receiving waterbodies are managed to meet specific water quality standards based on their intended use and defined

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[11] http://seaisi.org/thumbnail/a2d48bd75c37da42970ca2b30b0bd69a.pdf

[12] https://docplayer.net/62421493-Water-quality-standards.html; **Source :** Notification of the National Environment Board No.8, B.E.2537 (1994), which was issued under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1994) dated January 20, B.E.2537 (1994), and published in the Royal Government Gazette, Vol.111, Part 16 D, dated February 24, B.E.2537 (1994).

[13] https://www.boi.go.th/upload/content/ENVIRONMENTAL%20.EGULATIONS_28083.pdf

class, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). However, there is uncertainty regarding the extent to which ecological considerations, such as carrying capacity of the receiving waterbody, is considered in the development of water quality standards. It is also unclear how small farms (<10 rai) are managed, and while the number of these farms is unknown, the reported average farm size (11.5 rai) yields the potential that farms not required to comply with effluent standards may be common. Therefore, the effluent management system in Thailand is considered moderate and the final score for Factor 2.2a – Content of effluent management measures is 3 out of 5.

Factor 2.2b – Enforcement of effluent management measures

As described in Factor 2.2a, the Department of Fisheries (DOF) is the primary authority in enforcing regulations regarding shrimp farm operation in Thailand. The DOF has a main office in Bangkok, with a provincial office in each of the 76 provinces, 22 of which are coastal[14]. Each province has a Provincial Fishery Officer, as well as multiple District Fishery Offices (527 total in Thailand) and officers; the District Office and its officers report to the Provincial Officer, which in turn reports to the central Department of Fisheries office.

The Pollution Control Department (PCD), in conjunction with DOF, are tasked with enforcing the aforementioned water quality standards. Coastal water quality samples are taken twice per year at 202 sample collection points nearshore along the coast of Thailand, whereas surface water quality samples are taken quarterly at 366 monitoring stations throughout canals, rivers, and lakes in the country (PCD, 2018). The PCD uses a Water Quality Index (WQI) to evaluate water quality based on the sampling results of the parameters found in the coastal and surface water quality standards (PCD, 2018), creating classifications based on their WQI score: excellent, good, fair, poor, and very poor. The collected water quality data are published online monthly[15] and in real time[16], as well as annually at both the provincial and national level in "Thailand State of Pollution" reports[17].

The records show widespread degraded, though fluctuating, coastal and surface water quality throughout Thailand (Figures 4 and 5). Of note, there appears to be a recent trend of declining fractions of "poor" and "very poor" classifications (an 88% reduction over five years for coastal water, a 39% reduction for surface water), and increasing "fair" and "good" classifications (an 82% increase over five years for coastal water, an 18% increase for surface water), with limited "excellent" classifications varying from year to year. Over a longer period, however, improvements are not as apparent.

[14] https://www4.fisheries.go.th/index.php/dof_en/view_role/1

[15] http://iwis.pcd.go.th/index.php

[16] http://iwis.pcd.go.th/index.php?method=auto_station&etc=1541703496631

[17] http://www.pcd.go.th/public/Publications/defaultThai.cfm

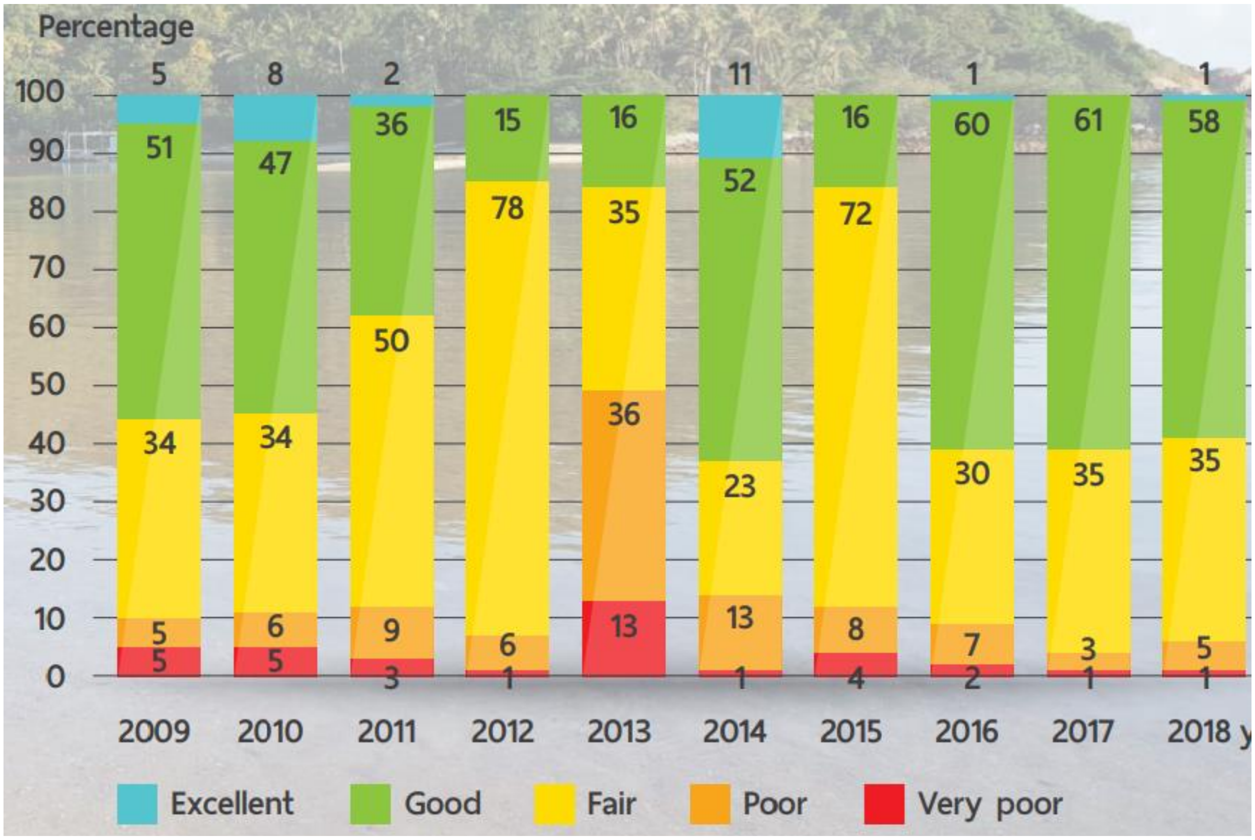

Figure 4. State of coastal water quality in Thailand, 2009 – 2018; image sourced from Thailand State of Pollution Report 2018.

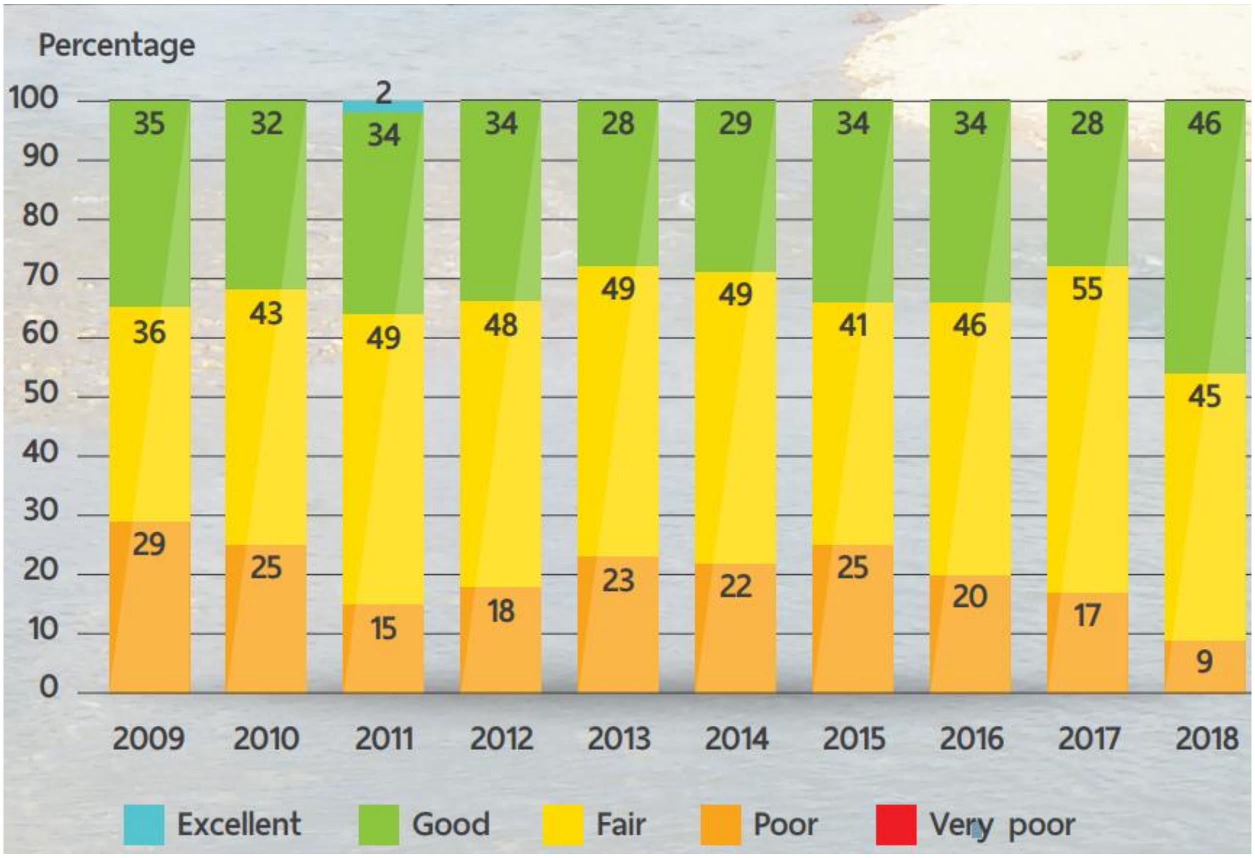

Figure 5. State of surface water quality in Thailand, 2009 – 2018; image sourced from Thailand State of Pollution Report 2018.

Marine shrimp aquaculture has occasionally been listed as a contributor to pollution leading to various parameters failing to meet water quality standards, despite the regulations intended to prevent discharge of effluent water that does not meet the coastal aquaculture effluent standard. Communications with industry experts, farmers, and representatives of the DOF indicated that farms (>10 rai in area) are not allowed to discharge without first having effluent water tested by DOF/PCD officers, but this process – how samples are taken and tested, how long it takes, how results are communicated, etc. – is fairly ambiguous, with somewhat inconsistent information communicated by different stakeholders. If the farm is ThaiGAP certified and found to have not complied with the standards requirements (which feature identical discharge standards and testing requirements to the aforementioned effluent coastal aquaculture Standard), ThaiGAP certification is lost, the farmer cannot reapply for a period of 180 days, and is subject to being placed on a watch list and follow up audits (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). General penalties for noncompliance amongst non-ThaiGAP certified farms are unknown.

The effectiveness of the DOF and PCD to enforce shrimp farm effluent standards is considered high, despite some concerns regarding human capacity limitations and a lack of sufficient resources (Pornpinatepong et al., 2016). This is supported by frequent interactions between farmers and officers and literature indicating that the DOF and PCD are effectively enforcing shrimp farm discharges (Seafood Watch field research, March 2018; Bottema et al., 2018; Bueno, 2018; Uppanunchai et al., 2016; Pornpinatepong et al., 2016), alongside the recent trend of moderately improving water quality.

Overall, enforcement of effluent discharge regulation appears to be moderately effective. Enforcement organizations are identifiable and contactable, with activity at the area-based scale and coverage of the entire production cycle. Evidence of monitoring is clear, though evidence of penalties for infringements and compliance violations are absent. There are also some questions as to the enforcement capacity of the DOF and PCD relative to the scale of the industry, given some concerns regarding a lack of sufficient resources and human capital. Despite this, water quality in Thailand appears to be improving to some degree over the last five years due to the declining fractions of poor and very poor water classifications. As such, the enforcement of effluent discharges from shrimp farms is considered moderately effective. The final score for Factor 3.2b – Enforcement of effluent management measures is 3 out of 5.

The final score for Factor 2.2 is a combination of Factor 2.2a (3 out of 5) and Factor 2.2b (3 out of 5), and results in a final score of 3.6 out of 10.

Conclusions and Final Score

Shrimp farm effluent discharges in Thailand are regulated under an area-based, cumulative management system in conjunction with other industries; receiving waterbodies are managed to meet specific water quality standards based on their intended use and defined class, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). However, there is uncertainty regarding the extent to which ecological considerations, such as carrying capacity of the receiving waterbody, is considered in the development of water quality standards. It is also unclear how small farms (<10 rai) are managed, though it is known that compliance with the coastal aquaculture effluent standard is not required; the number of these farms is unknown, yet they may be common. Enforcement of these regulations is considered moderately effective, as the DOF and PCD actively monitor farm discharges and water quality for compliance, though there are some questions regarding the capacity of these organizations, given some concerns regarding a lack of sufficient resources and human capital. Overall, coastal and surface water quality in Thailand appears to be improving to some degree over the past five years.

The scores for Factors 2.1 (8 out of 10) and 2.2 (3.6 out of 10) are combined using the Risk-Based Assessment matrix, resulting in a final score of 6 out of 10 for Criterion 2 – Effluent.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

C3 Habitat parameters	**Value**	**Score**
F3.1 Habitat conversion and function (0-10)		4
F3.2a Content of habitat regulations (0-5)	4	
F3.2b Enforcement of habitat regulations (0-5)	3	
F3.2 Regulatory or management effectiveness score (0-10)		4.80
C3 Habitat Final Score (0-10)		**4.27**
Critical?	No	Yellow

Brief Summary

Shrimp farm siting in Thailand is controlled and restricted to shrimp aquaculture zones, though it is unclear to what degree ecological considerations were factored into the zoning process. All farms are required to register with the DOF and obtain a license prior to operation, and mangrove deforestation for the construction of aquaculture ponds is illegal. The government also is actively working to reclaim land and restore mangroves in affected areas, and has restored over 100,000 hectares since the lowest point in 1996. Enforcement of siting and mangrove conservation laws is somewhat limited due to a lack of capacity. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (4 out of 10) and Factor 3.2 – Farm siting regulation and management (4.8 out of 10), and the final score is 4.27 out of 10.

Justification of Rating

Factor 3.1 – Habitat conversion and function

Shrimp aquaculture in Thailand takes place in the coastal zones of central, southern, and eastern Thailand, all areas originally consisting of dense mangrove forests, totaling nearly 375,000 hectares (ha) in size in the 1960s (Iwasaki and Teerakul, 2017; Pumijumnong, 2014; MFF, 2011). The multiple ecosystem services that mangroves provide cannot be overstated: their submerged roots provide a nursery and breeding ground to many marine species; they provide protection against storm surges in the face of floods and cyclones; they stabilize shorelines; they sequester carbon; and provide fuel, medicine, and construction materials to local communities (Giri et al., 2011). As such, they are a high value habitat.

Today, mangrove area in Thailand is estimated at 244,800 ha and has been relatively stable since 2007, up from a low of 160,000 ha in the mid-nineties (Thompson, 2018; Pumijumnong, 2014; Win, 2018). Shrimp farming has historically been a primary driver of deforestation in Thailand; it has been estimated that roughly 75,000 ha of virgin mangrove forest were converted to shrimp ponds between 1987 and 1995, the initial shrimp 'boom' in Thailand (Szuster, 2006; Aksornkoae, 2004). During this time, the industry was farming primarily the native *Penaeus monodon*, the black/giant tiger prawn, and was expanding at a rapid pace. Over 80% of farms were abandoned after only operating for several years due to disease problems and pond failures during this time period; farmers, believing crop failures were due to 'bad' ponds rather than pond management, then built and moved into new ponds, leaving the derelict ponds to idle or be repurposed for other aquaculture species or manufacturing (Szuster, 2006). By the mid-1990s, as widespread disease issues in coastal ponds continued to challenge the industry, inland rice farmers began converting freshwater paddies to shrimp farms given the high economic returns; hypersaline water was trucked in from the coast, and inland low-salinity farming grew to represent nearly 40% of Thailand's total production by the end of the 1990s (Szuster, 2006). This carried environmental and economic risks of its own – soil salinization, water pollution, and agricultural competition – and after a series of environmental impact assessments, the Thai government banned shrimp farming in non-coastal provinces in 1998, based on a recommendation from the National Environmental Board (Szuster, 2006). Soon after, the Thai government banned aquaculture in mangrove areas by a resolution dated 22 August 2000, after recommendations by the Ministry of Science, Technology and Environment and the Ministry of Agriculture and Cooperatives (Havanond, 2004). Factor 3.2 – Farm Siting Regulation and Management further details regulatory control over shrimp farm development and its interaction with mangrove ecosystems.

It was in 2001 that whiteleg shrimp, *Litopenaeus vannamei*, was introduced to Thailand and was soon adopted by a majority of producers due to its ease of domestication and higher yields relative to *P. monodon* (Szuster, 2006); by 2006, over 95% of production was *L. vannamei* (DOF, 2020). As the industry had already expanded greatly, there was not much, if any, room for expansion by area; producers used existing ponds to begin farming *L. vannamei* and focused on intensification to continue to increase production (pers. comm. Dr. Putth Songsanjinda, DOF, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Indeed, this is supported by both farm area and mangrove area data; as shown in Figure 6, shrimp farm area peaked at 71,825 ha in 2005 and has consistently declined almost every year (slight increase 2011-2012, 2015) to reach 47,975 ha in 2015, a reduction of 32.6% (DOF, 2020). Shrimp farm area has remained relatively stable ever since.

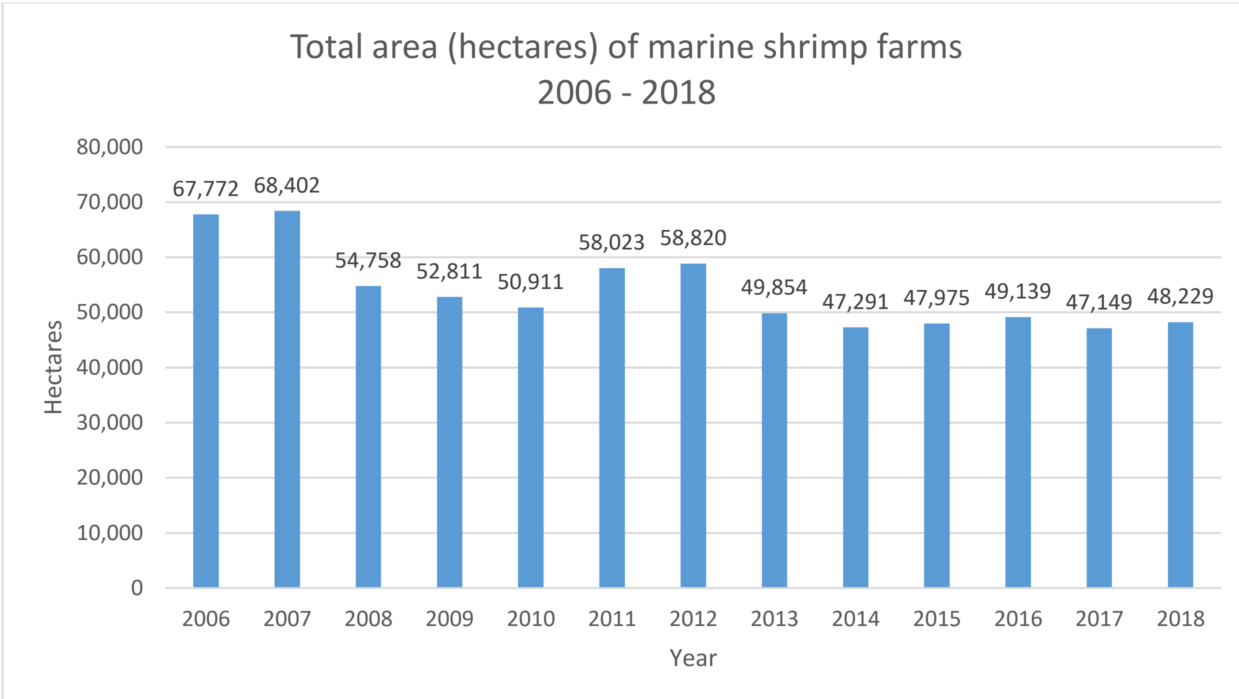

Figure 6. Total area (hectares) of marine shrimp farms in Thailand, 2004-2015. Data sourced from DOF (2020).

On the other hand, data from the Department of Marine and Coastal Resources (DMCR) show that since 1996, when mangrove area was at a low of 167,584 ha, total mangrove forest area in Thailand has nearly continuously grown to reach 245,534 ha in 2014, an increase of 46.5%, seen in Table 2 (Win, 2018). Other independent studies confirm that mangrove losses in Thailand from 2000 – 2012 are quite small, estimated at around 1.36%, and were driven by other industries, such as oil palm and urban development (Thompson, 2018; Richards and Freiss, 2016).

Table 2. Total mangrove forest area (ha) in Thailand, 1961-2014. Data from Win (2018).

	1961	**1975**	**1979**	**1986**	**1989**	**1991**	**1993**	**1996**	**2000**	**2004**	**2009**	**2014**
Central Region	66,890	36,500	31,232	1,016	596	406	5,363	5,451	12,054	7,997	12,109	10,904
Eastern region	54,845	49,000	4,414	27,981	20,709	11,084	13,048	12,658	22,741	24,360	25,848	26,344
East coast of Southern Region	56,449	35,500	33,776	19,644	17,084	13,980	16,425	16,571	32,808	27,348	29,269	32,137
West coast of Southern Region	194,172	191,700	194,156	147,796	142,218	148,352	133,847	132,904	170,727	173,604	176,783	176,148
Total (ha)	***372,356***	***312,700***	***263,578***	***196,436***	***180,607***	***173,822***	***168,683***	***167,584***	***238,330***	***233,308***	***244,010***	***245,534***

There is still some uncertainty as to whether mangroves were cut down to create additional ponds to farm *L. vannamei*, the subject of this Seafood Watch assessment, as the data regarding farm area are only available back to 2004. Literature clearly indicates that farming of *P. monodon* was the primary driver of conversions for shrimp ponds prior to this date, but there is not much information regarding any legal or illegal conversion for *L. vannamei* ponds. As such, it is not appropriate to say that *L. vannamei* were definitively not a driving factor behind the loss of high value habitat, at least in the early stages of the industry. However, considering all of the information, mangrove conversion for ponds used by *L. vannamei* farmers today and loss of ecosystem function largely, if not entirely, occurred prior to 1999 (the date of the Ramsar Convention's Resolution VII.21, *Enhancing the conservation and wise use of intertidal wetlands*; see the Seafood Watch Aquaculture Standard for more details); thus, the final score for Factor 3.1 – Habitat conversion and function is 4 out of 10.

Factor 3.2 – Farm siting regulation and management

Factor 3.2a – Content of habitat management measures
In this factor, regulations relating to the protection of habitat from impacts due to shrimp farm siting are assessed.

Marine shrimp farming in Thailand is considered a "controlled aquaculture activity" and is regulated through ministerial regulation (FAO, 2018b). As with effluents, shrimp farm siting is regulated at the national, provincial, and district level, with legislation primarily administered and enforced through the Department of Fisheries (DOF), housed within the Ministry of Agriculture and Cooperatives (MoAC) in conjunction with several other government bodies, such as the Ministry of Natural Resources and Environment (MoNRE). The DOF has a main office in Bangkok, with a provincial office in each of the 76 provinces, 22 of which are coastal[18]. Each province has a Provincial Fishery Officer, as well as multiple District Fishery Offices (527 total in Thailand) and officers; the District Office and its officers report to the Provincial Officer, which in turn reports to the central Department of Fisheries office.

Broadly, Thai law states that aquaculture cannot take place within public domain without a license granted by district DOF offices, whereby "public" is defined as any land or water area that is not privately owned (FAO, 2018b). The process of obtaining a license to farm shrimp in Thailand includes multiple steps. In order to open a new shrimp farm, a farmer must go to the district DOF office and submit an application to farm shrimp. This application is sent to the provincial office for preliminary approval, and then to DOF headquarters in Bangkok, where the application receives final approval and is returned to the district office (FAO, 2018b; pers. comm. Dr. Putth Songsanjinda, DOF, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). The farmer must include with the application proof of property rights or the lease agreement, stated farm production capacity, as well as a map of the farm layout (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). An auditor from the district office is then dispatched to survey the farm to ensure that the farm is sited within an authorized shrimp farming zone, and

[18] https://www4.fisheries.go.th/index.php/dof_en/view_role/1

provided s/he approves the siting, the farmer is registered and legally able to farm shrimp (FAO, 2018b; pers. comm. Dr. Putth Songsanjinda, DOF, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Additional terms and/or criteria required for registration process were not able to be identified.

As described in Criterion 2 – Effluent, the Royal Ordinance on Fisheries of 2015 is the overarching legislative framework governing shrimp aquaculture in Thailand, and gives authority to Provincial Fisheries Committees (PFCs) to designate the aquaculture zones mentioned above. Few details regarding the degree to which ecological considerations were incorporated into the aquaculture zoning process were able to be identified, and include "climate-related factors, such as temperatures, rainfall, sunlight, wind and water resources" alongside market and human resource considerations (Uppanunchai et al., 2016). Further, staff from the DOF indicated that "shrimp aquaculture zones" are the same areas where the Ministry of Natural Resources and Environment (MoNRE) regulates wastewater discharge from coastal aquaculture ponds and applies the effluent water quality standard for coastal aquaculture (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). The receiving waterbodies in these areas are managed under specific quality classes in conjunction with other discharging industries (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). It appears, then, that shrimp aquaculture zones are designed based on historical shrimp farming areas, and thus new farm siting is restricted to areas where ponds already exist. Aquaculture is currently not included among the designated activities that require an environmental impact assessment (EIA) (FAO, 2018b), though an EIA may be redundant when such siting is restricted to areas where the environment has historically been altered. As mentioned in Factor 3.1, shrimp farming is banned in non-coastal provinces and mangrove areas, alongside a ban on mangrove deforestation that has been in place since 2000. As such, despite the lack of a required EIA, restricting shrimp farm siting to the prescribed shrimp aquaculture zones is considered to be an area-based management system, though there is uncertainty regarding the degree to which ecological considerations were incorporated into zone formation. Unfortunately, no maps of aquaculture zones were able to be found or provided, so it is unclear where these zones are, and how aquaculture siting may affect broader ecosystems, the services they provide, or contribute to habitat fragmentation.

Further, the Thai government has taken a proactive approach in the restoration and reforestation of mangrove area. The Department of Marine and Coastal Resources (DMCR), under the authority of multiple laws (primarily the Act on the Promotion of Marine and Coastal Resource Management, B.E. 2558) has committed to reclaiming 300,000 rai (48,000 ha) of abandoned shrimp farms and "illegally occupied" mangrove areas across Thailand, with the intention of restoring mangroves to two-thirds of this area and allocating one-third to communities for economic utilization (Beresnev et al., 2016; pers. comm. Dr. Putth Songsanjinda, DOF, 2018).

To date, thousands of hectares have been reforested, though this has been and continues to be a challenging process (Thompson, 2018; Beresnev et al., 2016). A major challenge is the number of laws and government departments managing mangroves towards the stated mangrove restoration goal of two-thirds of 48,000 reclaimed hectares, many of which were developed without integration and coordination with other laws and ministries (Thompson, 2018; Beresnev et al., 2016). A non-exhaustive list of relevant laws is as follows (Beresnev et al., 2016):

- The Promotion of Marine and Coastal Resource Management Act 2015;
- Forest Act 1941 (2484 B.E.);
- National Park Act 1961 (2504 B.E.), covering national parks and mangroves located inside national parks;
- National Reserved Forest Act 1964 (2507 B.E.);
- Wildlife Reservation and Protection Act 1992 (2535 B.E.), covering wildlife sanctuaries and non-hunting areas;
- Commercial Forest Plantation Act 1992 (2535 B.E.);
- Decentralization Act 1999 (2542 B.E.); and
- Land Code 1954 (2497 B.E.)

These laws are administered by the following, non-exhaustive list of government ministries and departments (Beresnev et al., 2016):

- Department of Marine and Coastal Resources (DMCR), within the Ministry of Natural Resources and Environment (MoNRE);
- Department of National Parks, Wildlife and Plant Conservation (DNP), within MoNRE;
- Royal Forest Department (RFD), within MoNRE;
- Ministry of Interior, responsible for land management and decentralisation policies;
- Department of Fisheries;
- Ministry of Agriculture and Cooperatives;
- Tambon Administrative Organizations (sub-district level local government units consisting of elected village representatives); and
- Royal Thai Navy, which controls mangroves within naval bases

These ministries often have overlapping jurisdiction and may have objectives that conflict with other, non-mangrove related objectives from other departments; for example, while the DMCR may reclaim an illegal or abandoned shrimp farm for mangrove restoration, the Land Department may encourage the development of oil palm plantations there (Beresnev et al., 2016).

Another challenge has been that of determining land rights and ownership, with instances where there are multiple names present on a land deed, a farmer leased land from a person or entity that is illegally occupying it, or there is a discrepancy between the farmer and government's records as to who owns rights the land (Beresnev et al., 2016; pers. comm. Nick Leonard, Rubicon Resources, 2018). Mangroves are classified as "forests" and under Section 4 of the Forest Act of 1941, "forest" is any land which has not been acquired by an individual, and thus all "forest" is state-owned (Beresnev et al., 2016). Since aquaculture is banned on state-owned land or water, if the farmer is found by the government to be operating at a site s/he does not have legal access or right to, the government will consider this land public "forest", the farmer will be fined and the farm will cease to operate (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). As a result, anecdotally, this is a major concern of coastal shrimp farmers, who fear that the government will reclaim their ponds.

Broadly, however, Thailand has restored nearly 100,000 ha of mangrove area since the lowest point in 1996, and the DMCR is committed to continuing this process (Thompson, 2018; Win, 2018). It is clear that restoration of former high value habitat is a priority.

Overall, the management system governing farm siting is area-based in scope, where shrimp farms may only be sited in areas where they have historically been sited, with future expansion restricted to previous farm sites or otherwise disturbed areas within specified aquaculture zones. Despite this, the degree to which ecological considerations were incorporated into the zoning process is unknown. The government is reclaiming both abandoned and active shrimp ponds that are operating on public land and working to restore mangroves on these sites. Mangrove area in Thailand has increased by nearly 100,000 ha in the last 20 years. The final score for Factor 3.2a – Content of habitat management measures is 4 out of 5.

Factor 3.2b – Enforcement of habitat management measures

As with effluents, the Department of Fisheries (DOF) is the primary authority in enforcing regulations regarding shrimp farm operation in Thailand. The DOF has a main office in Bangkok, with a provincial office in each of the 76 provinces, 22 of which are coastal[19]. Each province has a Provincial Fishery Officer, as well as multiple District Fishery Offices (527 total in Thailand) and officers; the District Office and its officers report to the Provincial Officer, which in turn reports to the central Department of Fisheries office.

It is important to note that the DOF has no mandate on reclaiming mangrove land, and instead its role is to support the legal use of land for shrimp farming (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). The Department of Marine and Coastal Resources (DMCR) is authorized in managing mangrove area and any land reclamation associated with it.

While a comprehensive list of registered farms could not be obtained, a public database that lists farms certified to the domestic aquaculture standards (ThaiGAP or Code of Conduct, for example) was found; this database[20] lists the farm owner, the farm name, species cultivated, certification date and status, farm location, and farm registration number. Recent communications with the DOF have indicated that "about 100%" of all active farms are currently registered as of June 2019, inclusive of those practicing small-scale polyculture and farms producing for the domestic market (pers. comm. Dr. Putth Songsanjinda, DOF, 2019). Farms that are operating outside of notified "aquaculture zones" are considered illegal, and subjected to a fine of between 10,000 and 100,000 baht ($308 - $3,083 USD as of April 2020) (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). This legislation is part of the new Royal Ordinance on Fisheries (2015) and shrimp farms are currently required to re-register with DOF

[19] https://www4.fisheries.go.th/index.php/dof_en/view_role/1
[20] http://thacert.fisheries.go.th/wscert/site/certificate_list.jsp

in order to obtain new permits as the legislation becomes fully implemented (pers. comm. Dr. Putth Songsanjinda, DOF, 2019). The DOF visits farms at least once per year for a variety of audits (chemicals, effluent discharge, licensing, etc.), but there are no records available to indicate the number of fines or penalties that may have been levied; upon full implementation of the new legislation, farms that have not re-registered will be subject to this penalty (pers. comm. Dr. Putth Songsanjinda, DOF, 2019).

In addition to the DOF ensuring compliance with permit requirements, the DMCR monitors mangrove areas for encroachment and illegal development or cutting of mangroves (Beresnev et al., 2016). Monitoring takes place by car and by boat and any illegal activities identified are reported to the regional DMCR office, which responds by sending officials accompanied by police to investigate (Beresnev et al., 2016). There appear to be resource constraints limiting the effectiveness of this monitoring, however; in Samut Songkram, the DMCR mangrove management staff total seven, with four dedicated to monitoring, yet this team is responsible for monitoring mangroves in four provinces (Beresnev et al., 2016). An FAO report from 2016 stated that "illegal mangrove encroachment on 50 sites covering ~160 hectares is being investigated by DMCR in Samut Songkram province", thus giving some indication that enforcement activity is occurring (Beresnev et al., 2016). More recent surveys, however, indicate that these mangrove management programs are understaffed and underfunded, leaving the teams with relatively limited capacity with which to enforce the law (Thompson, 2018).

Overall, enforcement organizations are identifiable and active, but have limitations in resources or activities that reduce effectiveness. Transparency regarding farm siting is apparent, but compliance data are limited. The final score for Factor 3.2b – Enforcement of habitat management measures is 3 out of 5.

The final score for Factor 3.2 is a combination of Factor 3.2a (4 out of 5) and Factor 3.2b (3 out of 5), and results in a score of 4.8 out of 10.

Conclusion and Final Score

Shrimp farm siting in Thailand is controlled and restricted to shrimp aquaculture zones, though it is unclear to what degree ecological considerations were factored into the zoning process. All farms are required to register with the DOF and obtain a license prior to operation, and mangrove deforestation for the construction of aquaculture ponds is illegal. The government also is actively working to reclaim land and restore mangroves in affected areas, and have restored over 100,000 hectares since the lowest point in 1996. Enforcement of siting and mangrove conservation laws is somewhat limited due to a lack of capacity. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (4 out of 10) and Factor 3.2 – Farm siting regulation and management (4.8 out of 10), and the final score is 4.27 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- *Impact:* The use of chemical treatments can impact non-target organisms and lead to ecological and human health concerns due to the acute or chronic toxicity of chemicals and the development of chemical-resistant organisms.
- *Unit of sustainability:* Non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to treatments.
- *Principle:* Limit the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary

C4 Chemical Use parameters		Score
C4 Chemical Use Score (0-10)		4.00
Critical?	No	Yellow

Brief Summary

Overall, chemical use in Thai shrimp aquaculture is common, though most do not pose significant environmental concerns. Most chemicals used for pond preparation and disinfection pose a low risk to the environment, given the low water exchange rates and rapid degradation of these compounds and their by-products. On the other hand, the use of antibiotics in aquaculture can result in the development of antibiotic-resistant bacteria in the environment and pose significant risks to both the environment and human health.

This assessment considers the majority of shrimp farms in Thailand to discharge <1% water volume per day (see Criterion 2 – Effluent), warranting a score of 6 out of 10. While it is understood that most farmers do not use antibiotics, there is evidence that highly important antimicrobials for human medicine are being used in unknown quantities (a score of 0 out of 10) and limited evidence suggesting that critically important antimicrobials may also be used. Therefore, an intermediate score is justified. Antibiotic resistance is evident in coastal Thailand, including on shrimp farms, but is not conclusively driven by on-farm antibiotic use, resulting in some concern of resistance to chemical treatments. Other chemicals used on farms, such as disinfectants, are not believed to cause significant impacts to non-target organisms. As such, the final score for Criterion 4 – Chemicals is 4 out of 10.

Justification of Rating

In general, aquaculture throughout Asia is known to use a variety of chemicals to address issues such as water quality or disease, and the environmental impact of these chemicals is often unknown (Rico et al. 2012) (Gräslund and Bengtsson 2001). According to a review of the environmental risks of chemical and biological products in Asian aquaculture (but not Thailand specifically) by Rico et al. (2012), "chemicals, disinfectants, pesticides and antibiotics have been shown to be the most environmentally hazardous compounds owing to their high toxicity to non-target organisms and/or potential for bioaccumulation over tropic chains, and can potentially affect the biodiversity and functioning of adjacent aquatic ecosystems."

One of the most concerning issues is the use of antimicrobials that may also pose a risk to human health (Gräslund and Bengtsson 2001) because significant use of these drugs can further the development of antimicrobial-resistant pathogens, including those capable of cross-species and zoonotic transmission (Holmström et al. 2003).

Detailed information regarding chemical use on shrimp farms in Thailand is somewhat limited, given the relatively small-holder nature of the industry. Some understanding of current usage could be obtained from literature, personal communications, and regional reports from groups like the Network of Aquaculture Centers in Asia-Pacific (NACA), yet information regarding the total quantity and application frequency of chemicals was scarce. Chemicals used include pond preparation agents, such as lime, disinfectants, and veterinary medications, such as antibiotics.

Antibiotics

Antibiotic use was common in the earlier phases of the Thai shrimp farming industry, up to the early 2000s, when black tiger prawn was the primary species being farmed; field surveys indicated that roughly 75% of farmers surveyed used antibiotics, such as norfloxacin, oxytetracycline, enrofloxacin, and sulfonamides (Suzuki and Vu, 2016; Lebel et al., 2010). A series of import rejections from the US and the EU (2002 and 2003, respectively), due to antibiotic residues in shrimp, resulted in the EU temporarily banning Thai shrimp imports and the US imposing significant import duties; this spurred the industry, alongside the Thai government, to change production methods to minimize the use of antibiotics and avoid future economic disruptions (Suzuki and Vu, 2016; Lebel et al. 2008). Part of this change was the adoption of the more disease-resistant *L. vannamei* as the primary farmed species, as described in earlier sections of this assessment.

Today, ponds are managed to minimize the use of antibiotics using strategies to reduce the risk of bacterial infections, such as low water exchange and the application of probiotics, as well as disinfectants to clean incoming water (discussed later in this Criterion). The primary disease challenges facing the Thai shrimp industry are viral (more in Criterion 7 – Disease), and antibiotics are ineffective in treating these diseases. The past decade saw efforts by various stakeholders (government, international NGOs, private companies) to disseminate information to farmers regarding better pond water management practices and how to best manage disease outbreaks without antibiotics, like utilizing probiotics, lower stocking densities, and rapidly removing organic material from ponds (Suzuki and Vu, 2016). As a result, antibiotic use is said to have declined considerably in the past decade and, currently, Thai shrimp farmers rarely use antibiotics (Boyd et al., 2017; Leano, 2017; Suzuki and Vu, 2016; pers. comm. Robins McIntosh, Charoen Pokphand, 2018), despite the fact that several antibiotics are still authorized for use in shrimp farming in Thailand.

Antibiotic use is controlled by the DOF, under the Drug Act (1987)[21] and the Animal Feed Quality Control Act (2015)[22], in conjunction with the Thai Food and Drug Administration (FDA) and the Department of Livestock Development (Sommanustweechai et al., 2018). The FDA has authorized multiple antibiotics for use in aquaculture, as seen in Table 3. Of these drug classes, two are considered highly important for human medicine (tetracyclines, sulphonamides) and one is considered critically important for human medicine (fluoroquinolones), as defined by the World Health Organization (WHO)[23].

Table 3. Antibiotics authorized for use in aquaculture in Thailand. Information provided by Dr. Putth Songsanjinda, DOF, December 2017.

Drug group	Drug	Aquatic animal
Tetracycline	Oxytetracycline	Fish, shrimp
Fluoroquinolone	Oxolinic acid	Not specified
	Enrofloxacin	Fish
	Sarafloxacin	Fish, shrimp
	Flumequine	Fish (trout only)
Sulphonamide	Sulfamonomethoxine sodium	Fish, shrimp
	Sulfadiazine + trimethoprim	Fish, shrimp
	Sulfadimethoxine sodium + trimethoprim	Fish, shrimp
	Sulfadimethoxine sodium + ormethoprim	Fish, shrimp
	Sulfamonomethoxine + trimethoprim	Fish, shrimp
	Sulfadimidine + trimethoprim	Fish, shrimp
Others	Amoxicillin	Fish
	Toltrazuril	Not specified

Personal communications with farmers, industry experts, and Thai government officials indicated that oxytetracycline (OTC) is occasionally used by shrimp farmers (pers. comm. Dr. Putth Songsanjinda, DOF, 2018; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; Seafood Watch field research, March 2018). This finding is further supported by a presentation by Dr. Eduardo Leano, project leader of the FAO-NACA project, "Strengthening capacities, policies and national action plans on prudent and responsible use of antimicrobials in fisheries." (Leano, 2017). Leano and his team surveyed four hatcheries and thirty-four growout shrimp facilities in four of the major shrimp farming provinces in Thailand and found OTC was used at 100% of the hatcheries surveyed, yet only 29.2% (n=7) of the growout operations used antibiotics of any kind (Leano, 2017). Of this antibiotic usage in the growout phase, four farms used OTC, yet three used non-labeled

[21] http://thailaws.com/law/t_laws/tlaw0071_2.pdf
[22] http://extwprlegs1.fao.org/docs/pdf/tha159736.pdf
[23] World Health Organization (WHO). Critically Important Antimicrobials for Human Medicine 6th Revision 2019. Available at: https://www.who.int/foodsafety/publications/antimicrobials-sixth/en/

antibiotics, and one used enrofloxacin, unauthorized for use in shrimp farms (Leano, 2017). An additional recent survey, however, found that amongst thirty-four Thai shrimp farms sampled across six provinces, antibiotics were not used at all (Boyd et al., 2017). It is important to note that while these surveys reached the same number of farmers, sampling took place in different provinces (though both surveyed in Chantaburi and Songkhla), possibly leading to the difference in results. Additionally, farmers may have varying levels of trust towards farm suppliers, buyers, and visitors (Bottema et al., 2018; Lebel et al., 2016); the former study (Leano, 2017) was conducted by FAO/USAID staff in collaboration with the DOF, whereas the latter (Boyd et al., 2017) was conducted by staff from an international NGO. This distinction may have played a role in the disparity in responses received as well.

Farmers that may use antibiotics are said to use them in the first month of the production cycle – for prophylaxis due to high susceptibility to bacterial diseases (primarily AHPND/EMS, detailed more in Criterion 7 – Disease), and to comply with long withdrawal periods (roughly two months), ensuring an antibiotic-free product upon harvest (Leano, 2017). Indeed, as of April 2020, there have been only seven US Food and Drug Administration (USFDA) import refusals of aquacultured shrimp from Thailand for veterinary drug residues since 2003, with five of them coming from a single company in early 2017[24]. These refusals were for residues of nitrofurans, a class of antibiotics banned from animal feed in Thailand in 2002 (pers. comm. Dr. Putth Songsanjinda, DOF, 2018). It is understood that these incidents are exceptional and not the norm in Thai shrimp farming.

In addition to oversight from the US FDA, the industry's use of antibiotics is limited by Thailand's controls over antibiotic distribution, sales, and use, as briefly mentioned previously. All veterinary drugs must be registered with the Thai FDA prior to their importation or production, and veterinary drugs are, as of 2015, prohibited from use as an active ingredient in formulated shrimp feeds; rather, shrimp farmers must purchase the active ingredient from an authorized, registered supplier and incorporate it into feed themselves (Sommanustweechai et al., 2018; Suzuki and Vu, 2016; pers. comm. Dr. Putth Songsanjinda, DOF, 2018). Farmers must report and record the type and volume of antibiotic used and keep samples of the antibiotic used on hand, as the DOF conducts regular, unannounced audits of shrimp ponds where they check for, amongst other things, the aforementioned antibiotic use records and products, as well residuals in the shrimp (Suzuki and Vu, 2016; pers. comm. Dr. Putth Songsanjinda, DOF, 2018).

However, this regulatory system is not fully effective in preventing the illegal use of chemicals. Technically, drug distributors are only legally allowed to sell active ingredients to manufacturers, yet this is commonly ignored due to a lack of monitoring and tracking of these ingredients, and farmers often purchase active ingredients directly from representatives of drug companies in Thailand (Sommanustweechai et al., 2018; Leano, 2017). It is also said that sometimes salesmen illegally sell unauthorized drugs, such as enrofloxacin (as mentioned previously), and assure the farmer that they are "vitamins and/or probiotics". The DOF requires

[24] https://www.accessdata.fda.gov/scripts/importrefusals/

that farmers follow label use instructions when applying antibiotics to feed (pers. comm. Dr. Putth Songsanjinda, DOF, 2018); however, sometimes labels are not in Thai or are missing, resulting in farmers relying on the salesman for instructions (Seafood Watch field research, March 2018).

A significant concern regarding the usage of antibiotics in shrimp farming in Thailand is the potential for the development of antibiotic resistance. An abundance of literature indicates that antibiotic resistance in the Thai agriculture sector is a problem causing significant health and economic challenges (Sumpradit et al., 2017; Nhung et al., 2016); to date, however, evidence is lacking to conclusively say that the use of antibiotics on Thai shrimp farms has driven the development of this resistance. Antibiotic usage in Thailand is widespread throughout the poultry, pork, and buffalo sectors, from which runoff is considered a primary contributor to the contamination of water supplies shared by shrimp farmers (Wongsuvan et al., 2018; Pharino et al., 2016; PCD, 2017). These industries are significant users of antibiotic drugs, including those highly and critically important for human medicine, such as amoxicillin, and antibiotic resistance in livestock farms, nearby canals, and the livestock animals themselves is widespread (Wongsuvan et al., 2018; Nhung et al., 2016; Boonyasiri et al., 2014). Further, literature suggests that antibiotic resistant bacteria occur at a lower prevalence in coastal Thai fish and shrimp ponds relative to livestock farms throughout Thailand, though this finding is limited to a single study where selection bias may have affected the results (Boonyasiri et al., 2014). Regardless, there is still concern of antibiotic resistance specifically related to the shrimp industry; multidrug-resistant (tetracyclines, ampicillin, trimethoprim) strains of *E. coli*, *Salmonella*, and *Vibrio* bacteria (the causative agent of AHPND/EMS, more details in Criterion 7 – Disease), amongst others, have been found in Thai shrimp farms – in the water and pond waste – as well as in the shrimp themselves in domestic and foreign markets (De Silva et al., 2018; Nhung et al., 2016; Kongruen et al., 2016; Elmahdi et al., 2016; Yano et al., 2014; Changkaew et al., 2014). Unfortunately, it is not possible to determine whether the resistant bacteria were selected for in the environment and entered shrimp farms through water exchanges, or the excessive use of antibiotics on shrimp farms was the selective pressure driving resistance. Similarly, it is not possible to determine whether resistant bacteria found on market shrimp was a result of on-farm practice, or due to contamination along the supply chain.

<u>Pond preparation, disinfectants, and piscicides</u>
Other chemicals are used in the Thai shrimp farming industry, often for the use of pond water and bottom preparation, but sometimes for disease management. These chemicals may include disinfectants, piscicides, and sediment amendments, and may be particularly hazardous to the environment and non-target organisms (Rico et al., 2012). Thailand has banned particularly hazardous chemicals, such as malachite green, and illegal use is not considered common (pers. comm. Dr. Putth Songsanjinda, DOF, 2018).

Common pond preparation/sediment amendments used in Thailand include burnt lime (calcium oxide) and agricultural limestone (calcium carbonate), which are often used to raise the pH of pond bottoms drying between crop cycles to destroy disease-causing organisms (Boyd et al., 2017); the use of these is not considered a risk to the environment.

Disinfectants, such as calcium hypochlorite, copper sulfate, potassium permanganate, povidone iodone, and benzalkonium chloride are also used in Thailand, the purpose of which are to disinfect water and soil that may contain disease-causing organisms, as well as serving as piscicides (Boyd et al., 2017). In Thailand, disinfectants are commonly used prior to stocking ponds, though in some cases farmers will use them to disinfect the water following a disease outbreak (Boyd et al., 2017; Seafood Watch field research, March 2018); these compounds have high potential for acute toxicity, though most rapidly degrade in sediments and water (Rico and Van den Brink, 2014; Rico et al., 2012). The use of chlorine-based disinfectants, such as calcium hypochlorite, may result in the development of organic chlorine compounds as it reacts with organic matter, and these compounds may persist in the environment (Rico et al., 2012). While this disinfectant is often used prior to stocking ponds, there is anecdotal evidence that Thai shrimp farmers will use this in the event of a disease outbreak after an emergency harvest, and subsequently drain the pond (Seafood Watch field research, March 2018). There is thus some environmental risk associated with the use of disinfectants, though this risk is not considered significant given low water exchange rates and judicious use.

Saponin, the active compound found in teaseed cake, is a common piscicide used by Thai shrimp farmers to kill any fish that may be in incoming water as ponds are filled (Boyd et al., 2017; Seafood Watch field research, March 2018). This compound also rapidly degrades in the environment, and given the use of saponin prior to stocking combined with the low water exchange rates seen in Thai shrimp farming, its use does not pose an environmental risk (Rico and Van den Brink, 2014; Rico et al., 2012).

Conclusions and Final Score

Overall, chemical use in Thai shrimp aquaculture is common, though most do not pose significant environmental concerns. Most chemicals used for pond preparation and disinfection used in Thai shrimp farming pose a low risk to the environment, given the low water exchange rates and rapid degradation of these compounds and their by-products. On the other hand, the use of antibiotics in aquaculture can result in the development of antibiotic-resistant bacteria in the environment and pose significant risks to both the environment and human health.

This assessment considers the majority of shrimp farms in Thailand to discharge <1% water volume per day (see Criterion 2 – Effluent), warranting a score of 6 out of 10. While it is understood that most farmers do not use antibiotics, there is evidence that highly important antimicrobials for human medicine are being used in unknown quantities (a score of 0 out of 10) and limited evidence suggesting that critically important antimicrobials may also be used. Therefore, an intermediate score is justified. Antibiotic resistance that is evident on shrimp farms and in coastal Thailand more broadly is not conclusively driven by on-farm antibiotic use, resulting in some concern of resistance to chemical treatments. Other chemicals used on farms, such as disinfectants, are not believed to cause significant impacts to non-target organisms. As such, the final score for Criterion 4 – Chemicals is 4 out of 10.

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 the efficiency of conversion can result in net food gains or dramatic net losses of nutrients.
- *Unit of sustainability:* The amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- *Principle:* Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	0.23	
F5.1b Source fishery sustainability score (0-10)		0
F5.1: Wild fish use score (0-10)		2
F5.2a Protein INPUT (kg/100 kg fish harvested)	54.75	
F5.2b Protein OUT (kg/100 kg fish harvested)	17.80	
F5.2: Net Protein Gain or Loss (%)	-67.49	3.00
F5.3: Species-specific kg CO2-eq kg^{-1} farmed seafood protein	20.39	5.00
C5 Feed Final Score (0-10)		3.00
Critical?	No	Red

Brief Summary

Whiteleg shrimp feeds in Thailand use fishmeal and fish oil made from whole wild fish and from by-product sources. The fishmeal inclusion level is moderate (12.0%); three quarters of it (75%) is sourced from fishery and/or aquaculture by-products, and the remainder is sourced from the domestic trawl fleet. The fish oil inclusion level is low at 0.27%, and all comes from by-product sources. The Forage Fish Efficiency Ratio (FFER) is thus very low (0.23), meaning that from first principles, 0.23 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed shrimp. The small mesh trawl fishery in Thailand has a history of high concerns regarding illegal, unregulated and unreported (IUU) fishing practices, and despite encouraging recent management improvements that reduce fishing effort, the fishery remains a high conservation concern (scoring 0 out of 10 for the sustainability score). Nevertheless, the fraction of the total Thai trawl fleet catch that currently enters the shrimp feed supply chain is estimated to be no more than 11% and appears to be decreasing. Overall, despite the low levels of inclusion of these wild fish ingredients in Thai shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10). With a moderate-high net protein loss (-67.49%; score of 3 out of 10) and moderate feed footprint (20.39 kg CO_2-eq. per kg of harvested protein; score of 5 out of 10), the three factors combine to give a final score of 3.00 out of 10 for Criterion 5 – Feed.

Justification of Ranking

In Thailand, the vast majority of farmed shrimp (and those under the scope of this assessment) are fed a commercial pelleted feed. Detailed information regarding the composition of shrimp feeds utilized in Thailand was not able to be obtained; feed formulations are proprietary and may vary from batch to batch depending on the price and availability of ingredients.

Information requests were made to primary feed suppliers operating in Thailand (Charoen Pokphand, Lee Pattana, Thai Union, Grobest, Thai Royal) with limited data shared due to the proprietary nature of these formulations. The Thai Feed Mill Association (TFMA) was able to aggregate information from their associates (53 members[25], inclusive of the aforementioned companies); this information is included in this assessment alongside information from the literature and additional personal communications, and is considered broadly representative of a typical shrimp feed used in Thailand.

The Seafood Watch Aquaculture Standard assesses three feed-related factors: wild fish use (including the sustainability of the source), net protein gain or loss, and the feed "footprint" or embedded global warming potential of ingredients in feed required to produce one kg of farmed shrimp protein.

Factor 5.1 Wild Fish Use

Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed shrimp with a measure of the sustainability of the source fisheries. Table 4 shows the data used and the calculated Fish Feed Equivalency ratio (FFER) for fishmeal and fish oil.

<u>Factor 5.1a – Feed Fish Efficiency Ratio (FFER)</u>

The Feed Fish Efficiency Ratio (FFER) for aquaculture systems is driven by the feed conversion ratio (FCR), the amount of fish used in feeds, and the source of the marine ingredients (i.e., does the fishmeal and fish oil come from processing by-products or whole fish targeted by wild capture fisheries). FCR is the ratio of feed given to an animal per weight gained, measured in mass (e.g., FCR of 1.4:1 means that 1.4 kg of feed is required to produce 1 kg of fish). It can be reported as either biological FCR (bFCR), which is the straightforward comparison of feed given to weight gained, or economic FCR (eFCR), which is the amount of feed given per weight harvested (i.e., accounting for mortalities, escapes, and other losses of otherwise-gained harvestable fish). The Seafood Watch Aquaculture Standard utilizes the eFCR.

The use of a single eFCR value to represent an entire industry is challenging. The difficulty is rooted in the differences in shrimp genetics, feed formulations, farm practices, occurrence of disease, and more. Shrimp production globally has historically seen eFCRs in the range of 1.2 – 2.0, with Thailand falling just below the global average (1.7) at 1.5 (Tacon and Metian, 2008).

[25] http://www.thaifeedmill.com/AboutUs/Members/tabid/65/Default.aspx

These figures are consistent with shrimp production today, with a global average of 1.6 and reports ranging from 1.2-1.8 (Tacon, 2018; Boyd et al., 2017; Ferreira et al., 2015). The most representative data available come from recent literature, as well as personal communications with farmers, buyers, and feed suppliers (pers. comm. Nick Leonard, Rubicon Resources, 2018; pers. comm. TFMA, 2018; Seafood Watch field research, March 2018); indeed, an eFCR of 1.5 is considered representative of the Thailand shrimp industry and is the value used in the following calculations.

There is considerable variation in the ingredient composition of Thai shrimp feeds, as demonstrated by a diversity of published reports noting a number of different ingredients used in feeds, with total fishmeal (FM) and fish oil (FO) inclusions ranging from 0-44% and 0-6%, respectively (Chatvijitkul et al., 2017; Lotaka et al., 2012; Nonwachai et al., 2009; Chookird et al., 2010; Chotikachinda et al., 2008). As previously mentioned, the Thai Feed Mill Association (TFMA) aggregated information from their members and supplied it for this assessment, and they report that total fishmeal and fish oil inclusion rates in commercial Thai shrimp feeds range from 10-20% (FM) and 0-3% (FO) (pers. comm. TFMA, 2018). In addition, the DOF provided some information and reports total fishmeal inclusion rates of 2.7-31.4%, with an average inclusion 12% for the four largest feed manufacturers, and total fish oil inclusion rates of 0-0.9% with an average of 0.27% for the same manufacturers (pers. comm. Dr. Putth Songsanjinda, DOF, 2019). These average figures are considered representative of the industry and align with the aggregated data provided by TFMA as well as literature, and therefore a total fishmeal inclusion of 12.0% and total fish oil inclusion of 0.27% is used in the following calculations.

The use of by-products in shrimp feeds, as with other ingredients, varies by formulation and feed manufacturer. However, personal communications with representatives from the TFMA and DOF indicated that roughly 65-85% of fishmeal used in Thai shrimp feeds is sourced from by-products – trimmings from tuna processing, surimi manufacturing, domestic and/or international aquaculture processing (e.g. pangasius from Vietnam) – and all fish oil is sourced from by-products (pers. comm. TFMA, 2019; pers. comm. Dr. Putth Songsanjinda, DOF, 2019). These figures align with information received from private feed manufacturers, as well as public statements from manufacturers, such as Charoen Pokphand (CP)[26] and Thai Union[27], regarding the use of by-products in shrimp feed. Additional personal communications with Robins McIntosh of CP indicated that aquaculture feeds produced by CP currently contain only by-product fishmeal sourced from IFFO-RS certified plants/fisheries, and will only begin sourcing bycatch fishmeal again after an agreement from stakeholders regarding standards for certifying a sustainable fishery (pers. comm. Robins McIntosh, Charoen Pokphand, 2018). At the time of writing, CP is still only purchasing by-product fishmeal sourced from IFFO-RS certified processing facilities[28]. Additional literature indicates that by-product fishmeal inclusion is increasing and at least 65% of current fishmeal production in Thailand is sourced from by-

[26] https://www.youtube.com/watch?v=sHhA2Dl8nyg
[27] https://www.undercurrentnews.com/2014/06/13/thai-union-plans-to-cut-wild-fish-from-shrimp-feed-by-2020/
[28] https://www.cpfworldwide.com/en/media-center/list/sustainability

product raw material, up from ~50% in 2007 (Kanarat et al., 2018; Achavanuntakul et al., 2014; Leadbitter, 2019; Supongpan and Boonchuwong, 2010).

Additional information indicates that Thailand produced 350,000 – 400,000 mt of fishmeal annually from 2016 to 2018 (Preechajarn, 2019; Seafish, 2018); using an average fishmeal yield of 22.5%, the production of this volume of fishmeal requires roughly 1,550,000 – 1,750,000 mt of raw material. According to Thailand's annual Fisheries Statistics Yearbook, 21.31% of total marine catch, or approximately 280,000 mt, was reduced to fishmeal in 2017 (DOF, 2019). Thus, approximately 1,250,000 – 1,450,000 mt of raw material is additionally required in order to produce the volumes of fishmeal reported; according to the aforementioned sources, this material is likely sourced from domestic and international fishery and aquaculture processing by-products. The by-product sources contribution necessary to fill this gap (>80% by-product) appears (passably) aligned with the by-product estimates previously mentioned (65-85%), though the number of assumptions required limits the confidence in this estimate.

When considering all sources of information, fishmeal inclusions are considered to be 75% by-product and fish oil inclusions are considered to be 100% by-product for the purposes of this assessment.

Table 4. Parameters used and their calculated values to determine the use of wild fish in feeding Thai farmed shrimp.

Parameter	Data
Fishmeal inclusion level (total)	**12.0%**
Fishmeal inclusion level (whole fish)	3.00%
Fishmeal inclusion level (by-product)	9.00%
Fishmeal yield	22.5%
Fish oil inclusion level (total)	**0.27%**
Fish oil inclusion level (whole fish)	0.00%
Fish oil inclusion level (by-product)	0.27%
Fish oil yield	5.00%
Economic Feed Conversion Ratio (eFCR)	1.5
Calculated values	
Fish meal feed fish efficiency ratio (FFERfm)	0.230
Fish oil feed fish efficiency ratio (FFERfo)	0.004
Assessed FFER	**0.23**

The Feed Criterion considers the FFER from both fishmeal and fish oil and uses the higher of the two to determine the score. Fish meal and oil sourced from by-products are partially included in the FFER calculation at a rate of 5% of the inclusion level(s), in order to recognize the ecological cost of their production; please see the Seafood Watch Aquaculture Standard for additional details. As seen in Table 4, the fishmeal inclusion level drives the FFER for Thai farmed shrimp; since 75% of the fishmeal used is from by-products, based on first principles, 0.23 tons of wild fish are required to provide sufficient fishmeal to produce one ton of farmed shrimp.

Factor 5.1b – Source fishery sustainability

While 75% of fishmeal used in Thai shrimp feeds is sourced from by-products of other domestic and international processes (such as tuna processing, surimi production, pangasius farming in Vietnam, etc.), the remaining 25% is believed to be almost entirely (>90%) sourced from Thai trawlers operating in the Gulf of Thailand and Andaman Sea (pers. comm. Rawee Viriyatum, 2018; pers. comm. Dr. Putth Songsanjinda, DOF, 2018). Thailand's trawling fleet has come under considerable scrutiny for illegal, unreported, and unregulated (IUU) fishing in the past decade, with especially serious allegations of slavery and human rights abuses occurring within the fishery initially brought forward by The Guardian, a British newspaper, in 2014[29] and the Associated Press in 2015[30]. While slavery and human rights allegations are undoubtedly concerning, they fall outside the scope of this assessment of ecological impacts – rather, please refer to the Seafood Slavery Risk Tool (http://www.seafoodslaveryrisk.org/) for detailed documentation of these allegations and the risks they pose. The existence of IUU fishing however, in particular unreported catch, in the feed supply chain is of significant ecological conservation concern to Seafood Watch.

Literature indicates that prior to 2015, Thailand's trawl fishery landings were significantly (upwards of 70%) under reported (Teh and Pauly, 2018; Derrick et al., 2017; Stride and Murphy, 2016). The Thai trawl fleet uses small-mesh trawl nets and is a mixed, indiscriminate fishery, meaning there is often no target species; indeed, over 300 species of fish are caught by Thai trawling vessels, many of which are juveniles of commercially important species, often referred to as trash fish or bycatch (pers. comm. Rawee Viriyatum, 2018; Derrick et al., 2017; Panjarat et al., 2017). In general, the larger fish and/or those in suitable condition are directed for human consumption, while those too small and/or in poor condition are considered "trash fish." Historically, trash fish landings were sold directly to fishmeal processing plants and processed prior to being recorded (Stride and Murphy, 2016; pers. comm. Rawee Viriyatum, 2018).

Following the 2014 allegations mentioned above, the European Union (EU) placed Thailand on its "yellow card" list in April 2015, a warning that Thailand was not adequately addressing IUU fishing in its waters, and, if no improvements were made within six months, would eventually lead to a complete import ban of Thai marine fisheries products into the EU[31]. The same year, the United States downgraded Thailand in its Trafficking in Persons (TIP) Report to Tier 3, indicating that Thailand's government did not "fully comply with the Trafficking Victims Protection Act (TVPA) minimum standards and [is] not making significant efforts to do so",

[29] https://www.theguardian.com/global-development/2014/jun/10/supermarket-prawns-thailand-produced-slave-labour

[30] https://www.ap.org/explore/seafood-from-slaves/

[31] https://www.theguardian.com/environment/2015/apr/21/eu-threatens-thailand-with-trade-ban-over-illegal-fishing

adding that Thailand was a "source, destination, and transit country for [persons] subjected to forced labor and sex trafficking."[32]

Thailand's government thus committed to improving the seafood industry, beginning with the sweeping reformation of fishery law, the Royal Ordinance on Fisheries (2015), which replaced the Fisheries Act (1947); since then, a number of legislative actions have been enacted strengthening fisheries governance, resulting in the US upgrading Thailand to Tier 2 (indicative of significant effort to improve) and the EU lifting its "yellow card" in early 2019[33]. The reformations listed by the EU as reasons for lifting the "yellow card" are as follows:

- Comprehensive review of the fisheries legal framework in line with the International Law of the Sea, including a deterrent sanctions schemes;
- Full reform of the management of the fleet policy, with sound systems of registration and control of the fishing vessels;
- Strengthening of the Monitoring, Control and Surveillance tools, including the full coverage with Vessels Monitoring System (VMS) of the industrial fleet and a robust system of inspections at port;
- Full implementation of the United Nations Food and Agriculture Organisation (FAO) Port States Measures agreement on foreign-flagged vessels that land their catches in Thai ports to supply the processing industry;
- Comprehensive traceability system covering the whole supply chain and all modes of transportation, in line with international standards;
- Improved administrative procedures as well as training and political support, leading to proper enforcement of legislation;
- Significant reinforcement of the financial and human resources for the fight against IUU fishing.

These improvements have led to major reduction in IUU fishing, increased confidence in the capacity to enforce these laws, and increased clarity regarding the sources of raw material entering the fishmeal production chain.

Thus, the sustainability of the raw material entering the shrimp feed supply chain is the driving factor in this score. As mentioned, the Thai trawl fleet uses small-mesh trawl nets and is a mixed, indiscriminate fishery, meaning there is often no target species; indeed, over 300 species of fish are caught by Thai trawling vessels, many of which are juveniles of commercially important species, often referred to as trash fish or bycatch (pers. comm. Rawee Viriyatum, 2018; Derrick et al., 2017; Supongpan and Boonchuwong, 2010).

This trawl fleet has been operational since the 1960s and its operation has fundamentally altered the functioning of the Gulf of Thailand marine ecosystem by "fishing down the food web" (Pauly and Chuenpagdee, 2003). This resulted in both massive declines in catch per unit

[32] https://www.state.gov/j/tip/rls/tiprpt/countries/2015/243547.htm
[33] http://europa.eu/rapid/press-release_IP-19-61_en.htm

effort, from about 300 kg/hour in 1961 to about 50 kg/hour in the 1980s, and 20-30 kg/hour in the 1990s where it remained up through 2014, alongside changes on catch composition towards smaller individuals and smaller, short-lived species – "trash fish" (DOF, 2015; Pauly and Chuanpagdee, 2003; Supongpan and Boonchuwong, 2010). Over the past decade, the trash fish component of the trawl fleet has fluctuated between 35 and 50% of the trawl catch, indicative of its indiscriminate, highly efficient nature (DOF, 2019b). In 2018, the trawl catch totaled 657,765 mt, or 48% of the total marine catch recorded by Thailand (DOF 2019b).

In an effort to stem, and ideally reverse, the environmental degradation in Thai waters, the DOF also developed the Marine Fisheries Management Plan of Thailand in 2015 alongside the major reforms towards tackling IUU fishing listed above, and the two plans are closely linked (DOF, 2015). Major changes to fisheries management include the reduction of fishing capacity and effort through the removal of illegal vessels, reduction of total allowable fishing days, and capping licenses for highly efficient gears (trawls, purse seines, and anchovy nets). This reduction of effort is oriented towards maintaining fisheries resources at scientifically determined annual maximum sustainable yields (MSY) for major species groups (demersal, pelagic, anchovy), from which a total allowable catch (TAC) and allowable fishing days for highly efficient gears are determined. Additional controls have been put in place to limit effort, such as increasing mesh sizes (from 2.0 cm to 4.0 cm), limiting ground rope lengths in trawls, as well as implementing additional spatial and temporal closures intended to protect sensitive species and spawning seasons.

Since implementation in 2015, effort in the demersal fish group (driven by trawling gear) has been reduced by 46.93% in the Gulf of Thailand according to the DOF (pers. comm. Dr. Pavarot Noranarttragoon, DOF, 2019). According to the MSY assessment, at this level of effort, overfishing is no longer occurring (pers. comm. Dr. Pavarot Noranarttragoon, DOF, 2019; DOF, 2015). Catch per unit effort amongst demersal trawlers in Thai waters has recently been assessed at 37.78 kg/hr, a marked improvement relative to its lowest rates, in the 1990s and 2010s (Arnupapboon, 2019).

Despite these improvements, there are still significant concerns with regard to the ecological sustainability of this fishery. Notably, overfishing in multispecies fisheries "may not be marked by declines in total yield […], even though individual species and system-wide sustainability may be threatened" (Garcia, 2018). Indeed, "the collapse of a single species/fisheries as total production is maintained or increases, signals a biodiversity crisis more than a fisheries crisis" (Garcia, 2018). Lam and Pauly (2019) note that data suggest that 36% of fish stocks within the Gulf of Thailand are either collapsed or overexploited and that the "high degree of taxonomic aggregation in the underlying statistics" limit the confidence in interpreting the data. They further note that a "reduction in fishing pressure is often not enough for the recovery of the depleted stocks because of constraints imposed by several factors including the magnitude of the previous decline, the loss of biodiversity, species life histories, species interactions and climate change", despite previous literature suggesting that a reduction in fishing pressure may halt or reverse the ecological damage caused (Lam and Pauly, 2019; Pauly and Chuenpagdee, 2003; Heileman and Chuenpagdee, 2009). The ecological sustainability of the Thai trawl fleet is of significant concern.

This concern is balanced with the degree to which this fishery is utilized by the Thai shrimp feed industry. When considering that roughly 357,933 mt of shrimp were produced in Thailand in 2018 (DOF, 2020) with an average eFCR of 1.5, using feeds with an average fishmeal inclusion of 12.0% (comprised of 75% by-product, 25% wild whole fish raw material), an estimate regarding the total usage of wild fishmeal, and thus tonnage of wild fish caught, can be made. Using these figures, an estimated 16,107 mt of fishmeal from wild raw material was required by the Thai shrimp industry in 2018; using the aforementioned average yield rate of 22.5%, this equates to roughly 71,587 mt of wild whole fish. Considering that almost all whole fish destined for reduction are caught by the trawl fleet (>90%, DOF, 2019b, it can be estimated the Thai shrimp industry was responsible for roughly 11% of the entire Thai trawl fleet catch (657,765 mt), and roughly 21% of the marine catch for reduction (342,204 mt) in 2018 (DOF, 2019).

In summary, a minority (25%) of the fishmeal used by the Thai shrimp industry is sourced from the domestic Thai trawl fleet currently, and this percentage continues to decline with increasing utilization of processing by-products in fishmeal and feed manufacturing. The fraction of Fthe Thai trawl fleet catch that enters the shrimp feed supply chain appears to be decreasing as well, and is currently no more than 11% of the total trawl catch. Despite this, multispecies trawl fisheries present significant ecological sustainability risks and management challenges, and the functioning of the Gulf of Thailand marine ecosystem has been fundamentally altered by decades of unsustainable, indiscriminate overfishing. The Thai government is implementing measures limiting effort and access aimed at stemming and reversing the ecological damage caused by its fisheries, and recent indicators (such as catch per unit effort) suggest that overfishing is no longer occurring, and that recovery, at least to a certain degree, is possible.

The final score for Factor 5.1b – Source fishery sustainability is 0 out of 10, indicative of a fishery that is demonstrably unsustainable, given the known ecological impacts of the indiscriminate, multispecies trawl fishery and uncertainty regarding its ability to recover in light of the newly implemented management measures.

When this score is combined with an FFER of 0.23 (Factor 5.1a) according to Wild Fish Use table in the Seafood Watch Aquaculture Standard, the final Factor 5.1 score is 2.00 out of 10.

Factor 5.2 – Net protein gain or loss

In Thailand, feeds contain protein levels ranging from 30-65%, depending on the brand, function, and intended life stage of the shrimp being fed (Boyd et al. 2017; pers. comm. TFMA, 2018; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources 2018). In general, feeds intended for the growout stage of shrimp production in Thailand are around 35-38%, and as such, an average of this value – 36.5% – is considered representative of the Thai whiteleg shrimp farming industry for the purposes of this assessment (Boyd et al. 2017; pers. comm. TFMA, 2018).

Considering the eFCR of 1.5 (see Factor 5.1a for details), alongside a whole-shrimp protein content of 17.8% (Boyd et al., 2007), the net protein loss is -67.49%. This results in a score of 3 out of 10 for Factor 5.2 – Net protein gain or loss.

Table 5. The parameters used and their calculated values to determine the protein gain or loss in the production of farmed Thai whiteleg shrimp.

Parameter	Data
Protein content of feed	36.50%
Economic Feed Conversion Ratio	1.50
Total protein INPUT per ton of farmed shrimp	547.5 kg
Protein content of whole harvested shrimp	17.8%
Total protein OUTPUT per ton of farmed shrimp	178.0 kg
Net protein loss	–67.49%
Seafood Watch Score (0-10)	**3**

Factor 5.3 – Feed Footprint

Factor 5.3 – Feed Footprint is an approximation of the embedded global warming potential (kg CO_2-eq including land-use change (LUC)) of the feed ingredients required to grow one kilogram of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database[34] to estimate the GWP of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied, to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

As noted previously, information requests were made to primary feed suppliers operating in Thailand (Charoen Pokphand, Lee Pattana, Thai Union, Grobest, Thai Royal) with limited data shared due to the proprietary nature of these formulations. The Thai Feed Mill Association (TFMA) was able to aggregate information from their associates (53 members[35], inclusive of the aforementioned companies); this information is included in this assessment alongside information from the literature and additional personal communications, and is considered broadly representative of a typical shrimp feed used in Thailand.

Typical ingredients in Thai shrimp feeds include fishmeal and fish oil (see Factor 5.1), alongside soybean meal and other products (such as protein concentrate), wheat flour and wheat products, dried distillers grains, corn products, cassava products, and rice products[36] (Chatvijitkul et al., 2017; Lotaka et al., 2012; Nonwachai et al., 2009; Chookird et al., 2010; Chotikachinda et al., 2008). The degree to which inclusions of these ingredients vary depends

[34] http://globalfeedlca.org/gfli-database/gfli-database-tool/
[35] http://www.thaifeedmill.com/AboutUs/Members/tabid/65/Default.aspx
[36] https://enaca.org/?id=901

on a number of different factors such as the manufacturing company, diet type, price of ingredient, and/or availability of the ingredient. Many, if not all, of these ingredients are imported and while the origin of some ingredients are known – soybean meal originates from Brazil, Argentina, India, and the United States (Preechajarn, 2019) – it is not possible to make an approximation of origin for each ingredient given the available data. As such, for the purposes of calculating a feed footprint in Factor 5.3, all non-marine ingredients are considered to be "total vegetable meals (RER)" in the GFLI Database, and the economic allocation value for global warming potential including land-use change (GWP incl. LUC) for this line item is used.

Fishmeal from whole fish originates from multiple species caught by the Thai trawl and purse seine fleets, while fishmeal from by-products are sourced from a number of different fisheries as discussed in Factor 5.1. Fishmeal from whole fish of Thai origin is not found in the GFLI database, and the source fisheries for by-product are considered unknown; therefore, the GWP value used for both is an average value between the listed global (GLO) non-species-specific fishmeal value and worst non-species-specific fishmeal value. Fish oil originating from processing by-products are sourced from a number of fisheries, and as such the origin of these ingredients is considered unknown; therefore, therefore, the GWP value used is an average value between the listed global (GLO) non-species-specific fish oil value and worst non-species-specific fish oil value.

Table 6. Estimated embedded global warming potential of one mt of a typical Thai shrimp feed.

Feed ingredients (≥2% inclusion)	GWP (incl. LUC) Value	Ingredient inclusion%	kg CO2 eq / mt feed
Fishmeal (Thailand, mixed species)	Fish meal, from fish meal and oil production, at plant/PE Economic S Fish meal, from fish meal and oil production, at plant/GLO Economic S	3.00	35.53
Fishmeal from by-products (unknown location, unknown species)	Fish meal, from fish meal and oil production, at plant/PE Economic S Fish meal, from fish meal and oil production, at plant/GLO Economic S	9.00	106.59
Fish oil from by-products (unknown location, unknown species)	Fish oil, from fish meal and oil production, at plant/PE Economic S Fish oil, from fish meal and oil production, at plant/GLO Economic S	0.27	2.21
Total vegetable meals (unknown location)	Total vegetable meals, at plant/RER Economic S	87.73	2,275.52
	Sum of total	100%	**2,419.84**

As can be seen in Table 6, the estimated embedded GWP of one mt of a typical Thai shrimp feed is 2,419.84 kg CO_2-eq. Considering a whole harvest shrimp protein content of 17.8% and an eFCR of 1.5, it is estimated that the feed-related GWP of one kg farmed shrimp protein is 20.39 kg CO_2-eq. This results in a score of 5 out of 10 for Factor 5.3 – Feed Footprint.

Conclusions and Final Score

Whiteleg shrimp feeds in Thailand use fishmeal and fish oil made from whole wild fish and from by-product sources. The fishmeal inclusion level is moderate (12.0%); three quarters of it (75%) is sourced from fishery and/or aquaculture by-products, and the remainder is sourced from the domestic trawl fleet. The fish oil inclusion level is low at 0.27%, and all comes from by-product sources. The Forage Fish Efficiency Ratio (FFER) is thus very low (0.23), meaning that from first principles, 0.23 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed shrimp. The small mesh trawl fishery in Thailand has a history of high concerns regarding illegal, unregulated and unreported (IUU) fishing practices, and despite encouraging recent management improvements that reduce fishing effort, the fishery remains a high conservation concern (scoring 0 out of 10 for the sustainability score). Nevertheless, the fraction of the total Thai trawl fleet catch that currently enters the shrimp feed supply chain is estimated to be no more than 11% and appears to be decreasing. Overall, despite the low levels of inclusion of these wild fish ingredients in Thai shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10). With a moderate-high net protein loss (-67.49%; score of 3 out of 10) and moderate feed footprint (20.39 kg CO_2-eq. per kg of harvested protein; score of 5 out of 10), the three factors combine to give a final score of 3.00 out of 10 for Criterion 5 – Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- *Impact:* Competition, altered genetic composition, 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.
- *Unit of sustainability:* Affected ecosystems and/or associated wild populations.
- *Principle:* Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	2	
F6.1 Recapture adjustment (0-10)	0	
F6.1 Final escape risk score (0-10)		2
F6.2 Invasiveness score (0-10)		6
C6 Escape Final Score (0-10)		**4**
Critical?	No	Yellow

Brief Summary

On-farm escape prevention measures taken by Thai shrimp farmers (such as elevated dike construction, screens on outlets, harvesting prior to large storms) and the effectively closed nature of farms (<1% daily water exchange) mitigate the risk of escape from ponds. However, as the majority of the industry is sited in low-lying and/or coastal areas where flooding regularly occurs, and flooding has resulted in escape events, the escape risk of shrimp ponds in Thailand is moderate-high.

L. vannamei are non-native in Thailand and have been found in the wild during shrimp population surveys. Despite evidence indicating the ability to outcompete and even consume native shrimp, as well as the development of reproductive organs, there is no indication that *L. vannamei* have established viable populations in Thailand, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a moderate-high risk of escape (a score of 2 out of 10 for Factor 6.1) and a low-moderate risk of competitive impacts (a score of 6 out of 10 for Factor 6.2) results in a final score of 4 out of 10 for Criterion 6 – Escapes.

Justification of Ranking

Factor 6.1 – Escape risk
As described in Criterion 2 – Effluent, whiteleg shrimp pond systems in Thailand are low-exchange, and periodically discharge water throughout a cycle and harvest that results in an average exchange rate of <1% of pond water volume per day, though some systems do not discharge water over multiple production cycles (Boyd et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; pers. comm. Dr. Putth Songsanjinda, DOF, 2018). In addition, as Thai shrimp producers are required by law to meet water quality standards for discharged water, any water discharged from a culture pond will generally pass through at least one sedimentation basin prior to its release to the environment or its reuse (Boyd et al. 2017; Na nakorn et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources 2018).

The ThaiGAP standard, compliance with which is indirectly required for export, states that "appropriate measures to minimize escape of shrimp should be in place", and despite the lack of a true or specific requirement, it is in farmers' best interest to prevent escapes and thus escape prevention measures are in place throughout Thailand (MoAC, 2014). These measures generally include sluice gates that separate a farm from drainage canals, mesh netting in front of these gates and on water pump inlets to the system, and additional sluice gates with mesh netting separating drainage canals from shared water sources; it should be noted that most ponds within a farm do not have sluice gates, as water transfer between reservoir and treatment ponds to production ponds is done by pumping (pers. comm. Nick Leonard, Rubicon Resources, 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; Seafood Watch field research, March 2018). Some farms will also cover and/or surround their pond(s) with mesh netting to prevent the entry of birds, which additionally mitigates the risk of escape of shrimp (Seafood Watch field research, March 2018; Seekao and Pharino, 2016, 2016b).

Despite these measures, *L. vannamei* individuals have found their way into the environment. Though relatively dated, surveys of shrimp populations in the Bangpakong River situated in Chachoengsao province revealed the presence of *L. vannamei* in every sampling net, at rates ranging from 0.5% to 16.0% of all penaeid shrimp between 2005 and 2006 (Senanan et al., 2007). In addition, fishermen have previously reported catches of *L. vannamei*, though no quantification of these catches beyond "not large" could be obtained (Senanan et al., 2009; Briggs et al., 2004). No more recent or widespread data regarding the presence of *L. vannamei* in the wild in Thailand could be obtained, though shrimp population surveys in another area, Songkhla Lake in Songkhla province, did not reveal the presence of *L. vannamei* (Samphan et al., 2016).

Escapes can "occur during harvests, pond cleaning after disease infections or routine water exchange in ponds" according to Senanan et al. (2007); while the production system has become more closed – namely through a reduction in water exchange – since this report (Senanan et al., 2007) was written, it is still possible for escapes to occur, particularly during harvests. Additionally, there is limited evidence that farmers have intentionally released diseased individuals into neighboring waterways, though this is unlikely today given farmers' understanding of water and disease management, as well as the economic cost of releasing, rather than harvesting, shrimp (Senanan et al., 2009).

The primary pathway that *L. vannamei* escape from ponds in Thailand, however, is through flood events. Flooding frequently occurs throughout Thailand during the rainy/monsoon season (June-September), and as the majority of Thai shrimp production takes place in low-lying and coastal areas, flooding often affects the shrimp farming sector (Seekao and Pharino, 2016, 2016b). For example, flooding events occurred at least once every other year between 2005 and 2013 in Chachoengsao province, currently the fourth-largest shrimp producing province in Thailand (Seekao and Pharino, 2016). As preventative measures, it appears that at least some shrimp farmers in Chachoengsao have increased the height of pond dikes (28% of interviewed farmers), placed netting around ponds (12.6%), or harvested early prior to flooding (9.7%) (Seekao and Pharino, 2016b). It is not known how common these practices are throughout other shrimp farming provinces in Thailand, but the authors suggest that they are "regular activities, especially on shrimp farms located in areas that are highly and very highly vulnerable to floods", further adding that small-scale farmers (the majority of producers in Thailand) are particularly vulnerable, given that the majority are "located in high vulnerability areas" (Seekao and Pharino, 2016b). That said, the authors also acknowledge that these mitigation practices may not be sufficient to fully mitigate flood risk/damage, especially in the face of extreme flood events, predicted to increase in Thailand in the face of climate change (Promchote et al., 2016; World Bank, 2013; World Bank, 2012).

Indeed, catastrophic floods have occurred within the last ten years; in late 2010, heavy rains resulted in severe flooding across southern Thailand and damaged 130 shrimp farms covering roughly 20,000 rai (3,200 ha) in Surat Thani[37]. In 2011, severe flooding in southern Thailand resulting from the tropical storm Nock-ten resulted in damage to many shrimp farms and it was reported that 50,000-60,000 tons of shrimp were "washed away", though it is unclear as to whether this is in reference to shrimp escaping from ponds, mortality due to increased turbidity and decreased salinity, or future processed product that was lost[38]. The magnitude of this event, of course, is not a particularly common occurrence, and was considered to be the worst flooding event in the past 50 years (Promchote et al. 2016); however, unseasonal and more severe flooding than expected has continued to occur in recent years[39,40,41], in line with the increased climate risks mentioned above. For example, Seekao and Pharino (2016) report that flash flooding in 2013 caused the inundation of many shrimp farms across three provinces, resulting in an estimated loss of shrimp stock valued at nearly $12 million. However, again, it is not known whether these losses resulted in escaped shrimp rather than mortalities. It is, of course, in the farmers best financial interest to prevent losses due to flooding, and many

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[37] https://thefishsite.com/articles/farmers-fear-huge-shellfish-losses
[38] https://www.reuters.com/article/thailand-floods-shrimp/severe-flooding-to-reduce-thai-shrimp-output-idUSSGE73001O20110401
[39] https://www.reuters.com/article/us-thailand-floods-idUSKBN14Z049
[40] https://www.bangkokpost.com/business/news/1378899/shrimp-target-in-doubt-after-flood-trouble
[41] https://www.reuters.com/article/us-thailand-floods/thailand-braces-for-floods-residents-lay-bricks-sandbags-idUSKBN1KS0FW

farmers will harvest and sell shrimp prior to forecasted inclement weather, especially if flood warnings are issued (pers. comm. Dr. Putth Songanjinda, DOF, 2019).

Overall, the majority of Thai shrimp farms and production volume is located in flood-prone areas and are considered vulnerable to flood events. Floods commonly occur in all of the areas where shrimp are farmed and catastrophic floods have occurred in the last ten years, and the risk of extreme flooding continues to increase, which justifies a score of 0 out of 10. Despite this, on-farm escape prevention measures taken by farmers and the effectively closed nature of farms (<1% daily water exchange) mitigate the risk of escape, which justifies a score of 6 out of 10. As such, an intermediate score is warranted and the initial score for Factor 6.1 – Escape risk is 2 out of 10, given the vulnerability to flooding and uncertainty regarding the robustness of escape prevention measures in the event of large floods.

Recaptures

Though there is anecdotal evidence of escaped whiteleg shrimp being caught by fishermen (Senanan et al., 2009; Briggs et al., 2004), no such quantification of these catches could be obtained. The aforementioned anecdotal evidence reports that catches were “not reported as large.” (Briggs et al., 2004). With that said, a review of the Thai wild capture fisheries statistics for 2017 report that 7,492 mt of “other shrimp” were captured out of a total 31,105 mt of shrimp (inclusive of *Penaeus merguiensis*, *P. monodon*, *P. semisulcatus*, *P. plebejus*, and *Metapenaeus macleayi*), so theoretically it is possible that a significant number of *L. vannamei* are both present in the environment and being caught by fishermen alongside other, smaller catches of local *Metapenaeus* species (DOF, 2019b). However, without any further detail regarding the capture of *L. vannamei*, no recapture adjustment is made.

The final score for Factor 6.1 – Escape risk is 2 out of 10.

Factor 6.2 – Competitive and genetic interactions

Whiteleg shrimp are non-native to Thailand and were introduced for cultivation purposes in 1999 when *L. vannamei* fry were illegally smuggled into Surat Thani province, yet became fully authorized for culture in 2004 (Tookwinas et al., 2005a).

Since its introduction in 1999, *L. vannamei* has dominated shrimp culture in Thailand, and as mentioned in the previous section, large volumes of individuals have entered the natural environment via flooding, and historically, at harvest and water exchange. As mentioned above, surveys of shrimp populations in the Bangpakong River situated in Chachoengsao province revealed the presence of *L. vannamei* in every sampling net, at rates ranging from 0.5% to 16.0% of all penaeid shrimp between 2005 and 2006 (Senanan et al., 2007). In addition, fishermen have previously reported catches of *L. vannamei*, though no quantification of these catches beyond “not large” could be obtained (Senanan et al., 2009; Briggs et al., 2004). No more recent or widespread data regarding the presence of *L. vannamei* in the wild in Thailand could be obtained, though shrimp population surveys in another area, Songkhla Lake in Songkhla province, did not reveal the presence of *L. vannamei* (Samphan et al., 2016).

The presence of *L. vannamei* in the wild may present competitive ecological risks for Thailand's numerous native shrimp species, including the commercially relevant *P. monodon* and *P. merguiensis*, though genetic risks are considered negligible given the lack of other *Litopenaeus* species in Thailand and significant failures in interspecific hybridizations of penaeoid shrimps (Perez-Velazquez et al., 2010; Ulate and Alfaro-Montoya, 2010).

With regard to ecological impacts, the primary risks involve competition for food, predation, and acting as pathogen reservoirs (though this is discussed in Criterion 7 – Disease). The researchers who identified escaped *L. vannamei* individuals in population surveys in the Bangpakong River (described in Factor 6.1) also examined the competitive risks these escaped shrimp posed to native shrimp populations, with special regard to diet and aggression. These researchers found that gut content data "indicated that *L. vannamei* ingested the same diet types (phytoplankton, appendages of crustacean zooplankton and detritus materials) […] in similar proportions to several local shrimp species" (Senanan et al., 2010; Panutrakul et al., 2010). In addition to this, the researchers found in laboratory aquaria that *L. vannamei* exhibited more aggressive feeding behavior – approaching and capturing foods faster – than all other native shrimp species collected, even *P. monodon* (Panutrakul et al., 2010). Further laboratory research on *L. vannamei* feeding behavior relative to native Thai shrimps have confirmed this previous result, with the species appearing to be non-selective in its prey choice and faster in identifying and consuming food, despite size class differences (Chanavich et al., 2016). In this same study, however, the competitive advantage of *L. vannamei* compared to *P. monodon* was mostly lost when the ratio of *L. vannamei* to *P. monodon* was 1:2 or 1:3, indicating that the competitive risks of *L. vannamei* escapes may be density-dependent (Chanavich et al., 2016). In addition, when paired with a common and widespread native crab, *Charybdis affinis*, in food competition contests, the crab won every time, indicating that the crab may potentially control escapes and possible established populations of *L. vannamei* by preying on them (Chanavich et al., 2016).

Analyzed together, however, this research is inconclusive insofar as the true impact of escapees in the wild, but it is clear that *L. vannamei* is able to survive in Thai waterways given its wide range of tolerance to environmental conditions (salinity, pH, temperature, etc.) and its ability to find and consume food in the wild (Chanavich et al., 2016; Panutrakul et al., 2010; Senanan et al., 2010).

Senanan et al. stated in 2010 that it is "premature to conclude that the persistence of *L. vannamei* is because of natural reproduction", although they found evidence of gonadal development in captured escapees and suggested that further study regarding body size and stages of gonad development are required in order to estimate the reproductive capacity of these individuals (Senanan et al., 2010). Unfortunately, no follow up research could be identified, and though the FAO still lists *L. vannamei* in Thailand as "probably not established", the data feeding into this are sparse and outdated[42]. No other information regarding the establishment status of *L. vannamei* in Thailand could be found.

[42] http://www.fao.org/fishery/introsp/6416/en

A review of literature surrounding this topic revealed that there is no evidence of non-native *L. vannamei* establishing viable populations anywhere in the world (except for anecdotal evidence from Venezuela), despite its massive global spread as the predominant farmed shrimp species and recorded presence in the wild in the Gulf of Mexico, Caribbean (Belize[43]), and the western Atlantic (Brazil and Venezuela) (Fernandez et al., 2017; Barbieri et al., 2016; Lira and Vera-Caripe, 2016; Wakida-Kusunoki et al., 2011).

Overall, given the available data, it is concluded that *L. vannamei* are indeed present in the wild though not established, and highly unlikely to establish viable populations in Thailand. As such, the final score for Factor 6.2 – Competitive and genetic interactions is 6 out of 10.

Conclusions and Final Score

On-farm escape prevention measures taken by Thai shrimp farmers (such as elevated dike construction, screens on outlets, harvesting prior to large storms) and the effectively closed nature of farms (<1% daily water exchange) mitigate the risk of escape from ponds. However, as the majority of the industry is sited in low-lying and/or coastal areas where flooding regularly occurs, and flooding has resulted in escape events, the escape risk of shrimp ponds in Thailand is moderate-high.

L. vannamei are non-native in Thailand and have been found in the wild during shrimp population surveys. Despite evidence indicating the ability to outcompete and even consume native shrimp, as well as the development of reproductive organs, there is no indication that *L. vannamei* have established viable populations in Thailand, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a moderate-high risk of escape (a score of 2 out of 10 for Factor 6.1) and a low-moderate risk of competitive impacts (a score of 6 out of 10 for Factor 6.2) results in a final score of 4 out of 10 for Criterion 6 – Escapes.

[43] https://www.cbd.int/doc/world/bz/bz-nr-04-en.pdf

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 transmission or retransmission to local wild species that share the same water body.
- *Unit of sustainability:* Wild populations susceptible to elevated levels of pathogens and parasites.
- *Principle:* Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Disease Risk-Based Assessment

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**4**
Critical	No	Yellow

Brief Summary

As disease data quality and availability regarding the disease impact on the ecosystem is moderate/low (i.e. Criterion 1 scored 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment method was utilized. Despite the lack of information regarding the transfer of pathogens from farmed to wild species and the health status of wild species, the risk of such transmission can be estimated by the disease challenges faced by the industry, the biosecurity measures implemented, and the rate and characteristics of water discharged from farms. Farmers employ techniques to limit on-farm pathogen load, such as vector exclusion and water treatment prior to stocking. Water exchange during the production cycle is, on average, less than 1% of pond volume per day, and many farms do not discharge water to the environment over the course of a production cycle except at harvest. Despite these efforts, farms can clearly be considered to suffer from high disease or pathogen related infection and/or mortality. Further, their siting in flood-prone areas and the likelihood that some farms do not adequately treat water after an unplanned, disease-related harvest means that pathogens may be discharged to the environment. Ultimately, the biosecurity protocols in place on farms range in comprehensiveness and efficacy, and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

Justification of Rating

As disease data quality and availability regarding the disease impact on the environment is moderate/low (i.e. Criterion 1 scored 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment methodology was utilized.

Shrimp farms in Thailand are challenged by a multitude of viral, bacterial, and parasitic pathogens; given high stocking densities, close proximity of farms, shared water supplies, and a variety of different vectors for these pathogens to enter farms, disease outbreaks throughout Thailand are common. In this Criterion, the primary pathogens affecting farms are described, followed by their control measures, and then the impact (or lack thereof) that on-farm disease occurrences have on the ecosystem.

Pathogens and Conditions

Viral pathogens

The primary viral pathogen affecting *L. vannamei* culture in Thailand is white spot syndrome virus (WSSV), the causative agent of white spot disease (WSD); indeed, this is considered the most significant viral pathogen affecting shrimp culture in all of Asia (Thitamadee et al., 2016). First reported in Thailand on *P. monodon* farms in 1995, WSSV is considered endemic in the environment today (Flegel, 2006).

Symptoms of WSD include the gathering of shrimp near the pond edge and the display of common clinical signs, including carapace loss, reddish discoloration, and the hallmark presence of small (0.5-3.0 mm) circular white spots or patches on the cephalothorax and/or tail (OIE, 2018; Bir et al., 2017). A WSD outbreak can cause up to 100% mortality within 3-10 days of the appearance of symptoms, and juvenile shrimp of all sizes and age classes are susceptible to WSD, though mortality most often occurs 1-2 months post stocking (OIE, 2018; Bir et al., 2017).

Hosts for WSSV include a wide range of marine, brackish, and freshwater aquatic crustaceans, and the virus can be transferred horizontally through water or by consumption of infected tissue (OIE, 2018). WSSV can enter culture ponds by a number of different vectors including shrimp post-larvae (PL), birds, crabs, water exchange, farm visitors, and vehicles, though the primary means by which WSSV enters farms appears to be water exchange, PLs, and farm visitors (Worranut et al., 2018; Yaemkasem et al., 2017; Piamsomboon et al., 2015). Outside of the host, WSSV is viable in ponds for at least 3-4 days and, under laboratory conditions, for at least 30 days in 30°C seawater (OIE, 2018). Low ambient atmospheric temperature and high daily atmospheric temperature variation have been found to be factors that increase WSD occurrence in Chanthaburi province, though it has been stressed that drivers of WSD prevalence may differ between geographic locations and culture systems (Piamsomboon et al., 2016).

Accurate disease rates for WSSV in Thailand are difficult to establish. The World Organisation for Animal Health (OIE) publishes Quarterly Aquatic Animal Disease (QAAD) reports[44] in conjunction with the Network of Aquaculture Centres in Asia-Pacific (NACA), in which the results from uniformly collected samples of shrimp tested for major pathogens known to be present in Asian countries are published. In Thailand, data going back to 2012 within the QAAD reports indicate the presence of WSSV genes in shrimp samples range from 0.35% (Q2 2016) to

[44] http://www.rr-asia.oie.int/activities/regional-programme/aquatic-animal-health/qaad-reports/

4.56% (Q2 2013). Aligned with these figures, a recent study analyzing disease prevalence (primarily acute hepatopancreatic necrosis disease (AHPND), but also inclusive of WSD and yellow head virus (YHV)) in seven major shrimp cultivating provinces (Rayong, Chanthaburi, Trat, Phuket, Surat Thani, Nakorn Si Thammarat, and Songkhla) sampled shrimp from 200 shrimp ponds (ten shrimp from each pond) from August 2013 to April 2014, and found the presence of WSSV genes at 4.1% of ponds, though this study did not conduct histological examination to determine the presence of WSSV (Sanguanrut et al., 2018). As is expected given the various factors at play, WSD incidence varies widely. For example, annual prevalence of WSD in Chantaburi province ranged from 12.09% of farms in 2014 to 61.79% of farms in 2011 (Piamsomboon et al., 2016). Yaemkasem et al. (2017) surveyed all active shrimp ponds in Rayong province between October 2014 and March 2015, and found WSD prevalence at 38 of 165 farms (23%). More recent publications have characterized WSD prevalence as "high" in Thailand, and its presence has been recorded in all major shrimp farming provinces simultaneously as recently as 2014 (Piamsomboon et al., 2018; Sanguanrut et al., 2018).

Another viral disease that causes significant losses in Thailand is yellow head disease (YHD), caused by yellow head virus (YHV) (Thitamadee et al., 2016). Eight types of YHV have been described, with the primary type affecting shrimp ponds in Thailand being YHV-type1a/b (OIE, 2018; Thitamadee et al., 2016; Senapin et al., 2010). Clinical signs include an overall bleached appearance and yellowish discoloration of the cephalothorax ("yellow head"), caused by yellowing of the hepatopancreas; these signs are not distinct to YHD, making preliminary diagnosis challenging (OIE, 2018). Feeding activity may increase then abruptly stop shortly after the appearance of clinical signs, and similar to WSD, diseased shrimp may gather near the surface at the pond edge (OIE, 2018). As with WSD, infection can result in rapid mass mortality (total loss of a crop within days of symptoms) and often in the early to late juvenile stages (OIE, 2018).

Hosts for YHV appear limited to a number of shrimp species, including the commercially-relevant black/giant tiger prawn *Penaeus monodon* and the Jinga shrimp *Metapenaeus affinis*, both native to the Indo-Pacific region, as well as the daggerblade grass shrimp *Palaemonetes pugio* (found in the western Atlantic Ocean and Gulf of Mexico) and the blue shrimp *P. stylirostris*, native to the Eastern Pacific (OIE, 2018). A broader range of shrimp species appear to be carriers of the virus, though are not considered to be fully susceptible (OIE, 2018).

As with WSSV, YHV is transmitted horizontally via water (cohabitation with infected shrimp) and ingestion of infected tissue, and remains viable in aerated seawater for up to 72 hours (OIE, 2018). Beyond this, transmission vectors are to this date unknown; there is some information to suggest that transmission is airborne, yet studies have tested a variety of potential carriers (crustaceans, mollusks, aquatic and terrestrial insects and their larvae, and more) and all have been found to be negative (Thitamadee et al., 2016; Senapin et al., 2010). It is thought that dead shrimp transported from an infected pond by birds and dropped in a naïve pond may be a potential mode of transmission (Thitamadee et al., 2016).

The prevalence of YHD in Thailand appears to be less than that of WSD, with recent research characterizing YHD outbreaks as "periodic" at Thai shrimp farms (Thitamadee et al., 2016). Aforementioned QAAD reports show that the presence of YHV genes amongst sampled shrimp from 2013-2018 range from 0.06% (Q1 2016) to 4.27% (Q2 2017). In the same recent study mentioned previously (Sanguanrut et al., 2018), all samples from over 200 shrimp ponds amongst seven major shrimp farming provinces tested negative for YHV genes, though did not conduct histological examination to determine the presence of YHV.

Bacterial pathogens

The primary bacterial pathogen affecting *L. vannamei* culture in Thailand is *Vibrio parahaemolyticus*, a particular isolate of which is the causative agent of acute hepatopancreatic necrosis disease (AHPND) and commonly referred to as Early Mortality Syndrome (EMS) (Flegel and Sritunyaluucksana, 2018). For the purposes of this assessment, this disease will be referred to as AHPND, given that there are a number of pathogens that can cause disease resulting in early mortality, as evident from the viral section above.

AHPND outbreaks began in *P. monodon* and *L. vannamei* farms in China in 2009, spreading through Vietnam and Malaysia before reaching Thailand in 2012, and the causative agent was not discovered until 2013 (Thitamadee et al., 2016). This particular *V. parahaemolyticus* isolate (VP_{AHPND}) contains a plasmid that causes the bacteria to produce a toxin, which causes tissue destruction and organ failure of the shrimp hepatopancreas (Tran et al., 2013). Mass mortality (up to 100%) of shrimp occurs, generally within 30-35 days of stocking (though shrimp of all ages are susceptible), and as the disease spread through Thailand in 2012/2013, it caused massive economic losses and debilitated the Thai shrimp industry (OIE, 2018; Thitamadee et al., 2016). As a result of shrimp mortality from AHPND, alongside declines in pond stocking due to uncertainty in crop success, Thai shrimp production fell to less than 200,000 mt in 2014 from a peak of 600,000 mt in 2011 (Thitamadee et al., 2016).

Clinical signs of AHPND include a pale, atrophied hepatopancreas that may have black spots or streaks within it, an empty gut, and a soft shell, and become apparent as early as 10 days post-stocking (OIE, 2018).

Primary hosts susceptible to AHPND are *P. monodon* and *L. vannamei*, though *Vibrio* spp. are ubiquitous in the marine and estuarine environment and VP_{AHPND} has been shown to survive up to 9 and 18 days in estuarine and seawater, respectively (OIE, 2018); as such, vectors carrying VP_{AHPND} into shrimp ponds are nearly innumerable, and strategies to mitigate this disease focus primarily on minimizing organic content in ponds to limit bacterial growth, rather than exclusion (OIE, 2018; Thitamadee et al., 2016; pers. comm. Robins McIntosh, Charoen Pokphand, 2018). VP_{AHPND} is transmitted horizontally through oral routes and co-habitation, as with the previously described diseases in this Criterion (OIE, 2018). Certain environmental factors, such as salinity and temperature, seem to partly mediate AHPND pressure, with higher salinity and temperature appearing to increase disease incidence, as is often the case with *Vibrio* bacteria (OIE, 2018).

AHPND in Thailand is widespread, though better pond management (described later in this Criterion) and a better understanding of the pathology has resulted in lower recorded prevalence (Sanguanrut et al., 2018; Boonyawiwat et al., 2017). NACA QAAD reports indicate that the presence of VP_{AHPND} amongst sampled shrimp from 2013-2018 range from 0.6% (Q4 2016) to 20% (Q4 2013). Sanguanrut et al. (2018) found AHPND positive pond results in 41 of 196 tested ponds, or 20.9%, after testing samples from seven major shrimp farming provinces. As mentioned, despite the massive economic losses from AHPND from 2012-2014, it appears that prevalence may have been overstated and a major contributing factor to the drop in production was a result of pond fallowing due to uncertainty of crop success (Sanguanrut et al., 2018).

<u>Other conditions/diseases of note</u>
Another condition of note is hepatopancreatic microsporidiosis (HPM), caused by the microsporidian *Enterocytozoon hepatopenaei* (EHP). First reported in Thailand in *P. monodon* stocks in 2004, it has been found in *L. vannamei* since at least 2012 (Tangprasittipap et al., 2013). EHP infects the epithelial cells of the shrimp hepatopancreas, damaging the shrimp's ability to obtain nutrition from feed, and results in tissue necrosis and sloughing (Kmmari et al., 2018).

Some literature indicates that hosts for EHP are limited to crustaceans, if not solely *Penaeid* shrimp (Flegel et al., 2015), though EHP sampling of polychaetes and mollusks have returned positive PCR results; it is not known, however, if those organisms are infected or passive hosts (Thitamadee et al., 2016). Ultimately, though, EHP spores can persist in the environment for years (Kmmari et al., 2018; Tang et al., 2016), and EHP can be transmitted horizontally through oral-routes and cohabitation, and it has been suggested that poor biosecurity at hatcheries (using live, wild polychaetes and mollusks as feed, for example) is facilitating its spread (Thitamadee et al., 2016).

Clinical signs include reduced growth, and at advanced stages may result in soft shells, an empty gut, and lethargy (Aranguren et al., 2017). This disease does not appear to cause mortality, though is associated with significant reductions in growth rates and appears to increase susceptibility to the fatal VP_{AHPND} (Aranguren et al., 2017; Thitamadee et al., 2016). Its link to other diseases, such as AHPND and white feces syndrome (WFS), has been debated, however. For example, Aranguren et al. (2017) indicated that EHP is a risk factor for the development of AHPND, yet Sanguanrut et al. (2018) obtained results that indicated no statistical association between the two. Similarly, initial research indicated that EHP is not causative of WFS (Tangprasittipap et al., 2013), while more recent research suggests that the two are indeed associated, though it may simply be that EHP favors the establishment of other diseases (Aranguren et al., 2017; Rajendran et al., 2016; Tang et al., 2016). The interaction between EHP and other diseases and conditions is an area of ongoing study.

Economic losses due to EHP and the limited understanding of the pathogen and its control have led to its characterization as the third-most serious problem for shrimp farmers in Thailand following WSD and AHPND (Jaroenlak et al., 2018). Reports suggest that EHP infections are common, and have reached "epidemic proportions" in *L. vannamei* in Asia (Tang et al., 2016; Thitamadee et al., 2016), and NACA QAAD reports indicate prevalence ranging from 0.67% (Q4 2017) to 30.26% (Q3 2017). Recent research indicates the prevalence of EHP throughout Thailand to be at roughly 61% of ponds assessed (Sanguanrut et al., 2018).

White feces syndrome (WFS) is also a condition of note in Thai shrimp production. This condition is characterized by the aggregation or accumulation of white fecal strands floating on the surface of production ponds (Sanguanrut et al., 2018; Sriurairatana et al., 2014). Similar to EHP, WFS causes economic losses to shrimp farmers not through direct mortality, but rather growth retardation and elevated feed conversion ratios (Tang et al., 2016). Earlier research found high levels of multiple *Vibrio* species and gregarines (parasitic protozoa) in fecal analyses (Limsuwan, 2010). More recent research has indicated that WFS is not associated with gregarines, but rather associated with aggregated, transformed microvilli (ATM) resembling gregarines, whereby formation of massive amounts of ATM in the shrimp hepatopancreas results in severe cases of WFS (Tang et al., 2016; Sriurairatana et al., 2014). While the causative agent is still not known, it is understood that ATM arise from the transformation and sloughing of tissue in the hepatopancreas which then accumulates and is excreted within the feces; when present in sufficient quantities, the excretion of ATM results in WFS (Sanguanrut et al., 2018). It is postulated that the development of ATM is either caused by some new agent, or is an alternative manifestation of a known pathogen, such as VP_{AHPND} or EHP (Sriurairatana et al., 2014). The link between WFS and these pathogens, however, appears uncertain. Tang et al. (2016) found dense concentrations of EHP spores within white feces, and found EHP infection in all sampled ponds exhibiting white feces, while finding no EHP in healthy ponds (no white feces). More recent work has resulted in a puzzling negative association between AHPND and the ATM associated with WFS, where shrimp with a healthy hepatopancreas had significantly higher levels of ATM relative to those shrimp with AHPND, suggesting that ATM are protective to some degree against AHPND (Sanguanrut et al., 2018). Some posit that they may result from relatively low doses of the toxin produced by VP_{AHPND}, though not a dose high enough to result in the manifestation of clinical AHPND, though this is an area of continued study (Sriurairatana et al., 2014).

The presence of ATM is highly prevalent in Thailand (79.7% of ponds in the Sanguanrut et al. (2018) study), though the severity of infection is often low; indeed, no ponds in the study reported WFS outbreaks (Sanguanrut et al., 2018). Anecdotal reports suggest that WFS is common, but no such formal reporting of disease rates or affected areas could be obtained (Seafood Watch field research, March 2018).

Control Measures

A variety of control measures intended to mitigate the occurrence and minimize the impact of disease are utilized in Thailand. In general, strategies fall into three categories: (1) exclusion of the pathogen from the culture system by way of exclusion in PLs as well as carrier vectors, such as fish, and water, by minimizing water exchange, (2) water quality management strategies to limit organic content and minimize bacterial growth, and (3) immune support via probiotic and/or chemotherapeutant use and vaccination (Flegel, 2019; Thitamadee et al., 2016; pers.

comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Rawee Viriyatum, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; Seafood Watch field research, March 2018).

The first step to exclude pathogens from farms involves the use of specific pathogen-free (SPF) post-larvae (PL) produced in domestic hatcheries. In Thailand, broodstock are either domestically produced or imported, often from the United States (Munkungwongsiri et al., 2017); the Department of Fisheries (DOF) regulates domestic hatchery biosecurity with the "Good Aquaculture Practices for Hatchery of Disease Free Pacific White Shrimp" standard (MoAC, 2015) and mandates that all broodstock must be SPF (imported or domestic). To date, however, there are questions insofar as the enforcement of this regulation, as well as the practices of these hatcheries. Sometimes hatcheries will import SPF broodstock, then raise their offspring to broodstock size in less biosecure systems (such as outdoor ponds or using live, wild feeds) and sell PLs from those stocks (Munkungwongsiri et al., 2017; Thitamadee et al., 2016). These broodstock and the PLs they produce have lost their SPF status and may lose any genetic gains or disease resistance conferred by the genetics of the initial stock, and increase biosecurity risks to unwitting farmers, who believe they are purchasing SPF PLs in an attempt to exclude pathogens from their farms (Thitamadee et al., 2016).

On-farm exclusion strategies include netting over and/or surrounding ponds to exclude birds and other animals that may interact with ponds, such as dogs, cats, rats, and lizards; similarly, screens and/or mesh are sometimes placed over water pipe inlets, in an attempt to exclude aquatic disease vectors like fish and crabs (Worranut et al., 2018; Boonyawiwat et al., 2017; Thitamadee et al., 2016). The adoption of these exclusion measures is not close to 100%, however, and adoption varies by region (Worranut et al., 2018; Seekao and Pharino, 2016). Additional methods include the use of disinfectant systems to sterilize visitors on foot and in vehicles (or even ban visitors entirely), though these methods are not commonplace, given that they are relatively costly to implement (Worranut et al., 2018). The Thai GAP for Marine Shrimp Farms states "preventive measures for predators and disease carriers to enter the ponds during pond, water preparation and shrimp culturing shall be in place", but no such methodology is specified in the GAP (MoAC, 2014). Overall, the ability of the Thai shrimp farming sector to exclude pathogens from farms is only as strong as its weakest link, and the variability found within on-farm and hatchery biosecurity management practices continues to facilitate the spread and persistence of pathogens and disease in the sector.

Farmers also manage their water quality in such a way to minimize the intake of pathogens from the environment, as well as minimize the growth of those pathogens in the system. Today, the majority of Thai shrimp pond systems are low-exchange and periodically discharge water throughout a cycle and harvest that results in an average exchange rate of <1% of pond water volume per day, and some systems do not discharge water over multiple production cycles (Boyd et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018; pers. comm. Dr. Putth Songsanjinda, DOF, 2018). Water is frequently treated by farmers in reservoirs prior to entering the production ponds, using chemical compounds such as chlorine, potassium permanganate, and iodine to disinfect by killing disease organisms (or their wild hosts that may have entered upon reservoir filling) before allowing the water to fill production ponds; teaseed cake (the active ingredient, saponin, is a piscicide) is also commonly applied to recently filled production ponds to ensure that any fish, crabs, or other potential disease-carrying hosts are killed (Boyd et al., 2017; Na nakorn et al., 2017; Boonyawiwat et al., 2017). Production ponds frequently are equipped with polyethylene liners to limit erosion (either on the banks, or the entire pond, depending on the size of the farm) along with central drains, to facilitate the removal of sediment and/or sludge (uneaten feed, feces, etc.); this helps to minimize the accumulation of organic content so as not to support the growth of bacteria, such as VP_{AHPND} (Boyd et al. 2017; Na nakorn et al. 2017; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Water is recirculated and maintained throughout a production cycle, with small additions of water from the treated reservoir(s) to replace water lost through evaporation and sludge removal; this system is sometimes referred to as "intensive 2.0" or "the toilet", with the removal of sludge referred to as "flushing" (pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Between crops, farmers will dry pond bottoms for at least two weeks and may apply burnt lime (calcium oxide) to raise the pH and kill disease organisms (Boyd et al., 2017; Seafood Watch field research, March 2018).

Despite these measures – use of SPF PLs, vector exclusion, minimization of organic load, and low rates of discharge when averaged on a per-day basis – farms are still demonstrably challenged with significant disease pressure, and when faced with an outbreak, the typical response is to harvest the pond. Harvests are often completed by seining, but pond water is drained before harvest (e.g. to lower the water level making seining and shrimp capture easier) and/or after harvest. As mentioned previously, production ponds typically empty into sedimentation basins before discharge to the environment, and retention in those basins may be as long as one week. However, retention times are known to vary and there is significant uncertainty regarding additional treatment to neutralize pathogens prior to water entering the receiving waterbody. Treatment options include chlorination (Putth and Polchana, 2016), but adoption of these measures cannot be confirmed to be uniform; Yaemkasem et al. (2017), for example, note "The authorities should consider control measures to prevent farmers from releasing un treated wastewater into the environment." Given that all the primary pathogens described above can persist in seawater without the host for an extended period of time, it appears likely that water discharged from a pond due to an 'emergency' harvest could contain active pathogens.

Area-based biosecurity management schemes are being developed in Thailand, such as the Shrimp Health Resources Improvement Project ("SHRImP") managed by the Sustainable Fisheries Partnership (SFP) and the Sustainable Trade Initiative (IDH). According to the project website[45], "[SHRImP] aims to give farmers the tools to improve their productivity and to help clubs, co-ops, and local government better understand and manage emerging disease

[45] https://www.sustainablefish.org/Blog/Working-with-farmers-to-monitor-shrimp-health-in-Thailand

outbreaks", primarily by implementing an epidemiological early warning system that notifies farmers of disease risk factors and outbreaks in their surroundings[46].

The use of probiotics is also commonplace; farmers use probiotics to improve water quality by breaking down nitrogenous wastes, and to outcompete pathogenic bacteria, such as VP_{AHPND}, though some research and experts have questioned the efficacy of probiotics (Flegel, 2019; Toledo et al., 2019; Boyd et al., 2017; Nimrat et al., 2011; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018).

As described in Criterion 4 – Chemicals, the use of antibiotics still occurs in Thailand, but is not common (Boyd et al., 2017; Leano, 2017). WSD and YHD are both viral, and while AHPND is bacterial in origin, strains found in shrimp ponds have been found to be resistant to multiple antibiotics and farmers avoiding their use given the inefficacy of the drug(s) (Kongruen et al., 2016; Elmahdi et al., 2016; Yano et al., 2014; Changkaew et al., 2014). Thus, the use of chemicals to control disease (beyond in pond preparation) is not considered a primary control method.

Lastly, commercially viable vaccines are not available to treat any of the diseases that affect shrimp culture in Thailand (OIE, 2018). The primary reason for this is that the shrimp immune system does not have "adaptive immunity", the mechanism by which vertebrates obtain protective-antibody response against a specific pathogen upon receiving a vaccine (Flegel, 2019; Johnson et al., 2008). Work is currently underway to develop what is known as "immune priming" or "trained immunity" methods, whereby "the use of killed bacteria or bacterial proteins and host or viral proteins to protect shrimp" are employed (Flegel, 2019); however, these methods are not yet developed or in use.

Impact on wild species

In stark contrast with the amount of information available regarding disease pathology, there is no research or evidence to indicate that shrimp farms in Thailand are exerting negative disease pressure on wild populations of shrimp and other crustaceans, nor is there evidence to suggest that they are not.

There is limited evidence which indicates the presence of viral pathogens – YHV, WSSV, IHHNV – amongst wild *P. monodon* in Thailand, but it is assumed that the pathogens are present and endemic in the environment, given the ban on importation of PLs and non-SPF broodstock into Thailand (Hamano et al., 2017; Kongkeo and Davy, 2010; Flegel, 2006; Tookwinas et al., 2005a; pers. comm. Rawee Viriyatum, 2018). Research that sampled wild *P. monodon* from December 2012 – November 2013 found temporal trends indicating that anecdotal disease outbreaks on farms were associated with periods of higher pathogenic rates amongst wild *P. monodon* (Hamano et al., 2017). Additionally, IHHNV was found in 47% of wild *P. monodon* sampled, while the prevalence of this disease is considerably lower (1.25 – 2.91%[47]) in sampled farmed *L.*

[46] https://thefishsite.com/articles/shrimp-farmers-flock-to-data-sharing-project

[47] http://www.rr-asia.oie.int/activities/regional-programme/aquatic-animal-health/qaad-reports/

vannamei over the same period (Hamano et al., 2017). Beyond *P. monodon*, there are fifty species of shrimp and prawn native to and found in the Gulf of Thailand and coastal Andaman Sea, and many more species of crustaceans susceptible to these viruses and bacteria, though no information could be found regarding their stock statuses, pathogen loading rates, or the impact that shrimp farms may have on them (Tangrock-Olan et al., 2007).

Conclusions and Final Score

As disease data quality and availability regarding the disease impact on the ecosystem is moderate/low (i.e. Criterion 1 scored 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment method was utilized. Despite the lack of information regarding the transfer of pathogens from farmed to wild species and the health status of wild species, the risk of such transmission can be estimated by the disease challenges faced by the industry, the biosecurity measures implemented, and the rate and characteristics of water discharged from farms. Farmers employ techniques to limit on-farm pathogen load, such as vector exclusion and water treatment prior to stocking. Water exchange during the production cycle is, on average, less than 1% of pond volume per day, and many farms do not discharge water to the environment over the course of a production cycle except at harvest. Despite these efforts, farms can clearly be considered to suffer from high disease or pathogen related infection and/or mortality. Further, their siting in flood-prone areas and the likelihood that some farms do not adequately treat water after an unplanned, disease-related harvest means that pathogens may be discharged to the environment. Ultimately, the biosecurity protocols in place on farms range in comprehensiveness and efficacy, and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

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

Impact, unit of sustainability and principle

- *Impact:* The removal of fish from wild populations
- *Unit of Sustainability:* Wild fish populations
- *Principle:* Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

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

Criterion 8X Summary

C8X Source of Stock – Independence from wild fish stocks	Value	Score
Percent of production dependent on wild sources (%)	0.0	0
Use of ETP or SFW "Red" fishery sources	No	
Lowest score if multiple species farmed (0-10)		n/a
C8X Source of Stock Final Score (0-10)		**0**
Critical?	No	Green

Brief Summary

Whiteleg shrimp farms in Thailand only use hatchery-raised seed from domesticated broodstock, the majority of which are SPF from biosecure hatcheries in Thailand operated by Charoen Pokphand. There is no reliance on wild shrimp for farm production, and as such, the final score for Criterion 8X – Source of Stock, is 0 out of -10.

Justification of Ranking

Whiteleg shrimp farms in Thailand only use hatchery-raised seed from domesticated broodstock, the majority of which are SPF from biosecure hatcheries in Thailand operated by Charoen Pokphand (Tookwinas et al., 2005a; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). The final score for Criterion 8X – Source of Stock, is 0 out of -10.

Conclusions and Final Score

With no reliance on wild-caught shrimp for farm production, the final score for Criterion 8X – Source of Stock is 0 out of -10.

Criterion 9X: Wildlife mortalities

Impact, unit of sustainability and principle

- *Impact:* Mortality of predators or other wildlife caused or contributed to by farming operations
- *Unit of Sustainability:* Wildlife or predator populations
- *Principle:* Preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

Criterion 9X Summary

Wildlife Mortalities Risk-Based Assessment

C9X Wildlife Mortality parameters		**Score**
Single species wildlife mortality score		-5
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score		**-5**
Critical?	No	Yellow

Brief Summary

Overall, it is understood that Thai shrimp farms may interact with predators and other wildlife, and farmers primarily utilize nonlethal control methods to exclude predators and limit interactions; thus, it is considered that management practices for non-harmful exclusion are in place. Despite this, there is limited information available to determine whether any mortality (accidental or intentional) occurs beyond the killing of fish as a biosecurity measure, and given the "near-threatened" population status of numerous bird species that interact with shrimp ponds, some concern is warranted. It is unlikely, though, that any mortalities that may indeed occur would significantly impact the population size of the affected species. The final score for Criterion 9X – Wildlife and Predator Mortalities is -5 out of -10.

Justification of Ranking

The confidence in the data regarding the impact that predator control at shrimp farms has on wild species is poor, and the corresponding Criterion 1 – Data score is 2.5 out of 10. As such, the Risk-Based Assessment method was used.

Shrimp farming often requires the control of pests and predators, which can affect the cultured shrimp directly through predation and indirectly through competition for resources such as food (FAO, 1986). In general, predators on shrimp farms that can feed directly on shrimp can include amphibians, birds, crustaceans, finfish, mammals, and snakes (FAO 1986).

Thailand is one of the most biodiverse areas in the world, with a wide variety of ecosystems, landscapes, and habitats, and is home to thousands of species of mammals, birds, reptiles, amphibians, and fishes[48]. Shrimp farms are, as described in Criterion 3 – Habitat, sited in coastal

[48] https://www.cbd.int/countries/profile/default.shtml?country=th

areas where large tracts of mangrove forest still remain. These mangrove forests are home to a number of species, primarily birds, reptiles, and fishes that may interact with shrimp ponds. Recent surveys indicated that 44 bird species were found in and around shrimp ponds in Samut Songkhram Province, a number of which are "near-threatened" according to the IUCN (Charoenpokaraj et al., 2017). Further reference to the specific predator species, the deterrents used to control them, or their impact on predator populations in the Thai shrimp farming industry were not available in the literature.

Legislation, such as the Wild Animal Reservation and Protection Act (1992)[49], prohibits the killing of protected species (listed within the Act) and killing of any wild animal in areas designated as "non-hunting wild animal areas", though no information was available to indicate which areas are designated as such. The Thai GAP for Marine Shrimp Farms states "preventative measures for predators and disease carriers to enter the ponds during pond water preparation and shrimp culturing shall be in place", though there are no restrictions on or details regarding what those preventative measures may be. The Thai Code of Conduct, a voluntary standard to which adherence is limited (Samerwong et al., 2018), states that "predator control methods that do not require destruction of ecologically important species in receiving water should be used" (Tookwinas et al., 2005b). However, there is no description or detail given regarding what an ecologically important species is, nor does it appear that any control methods, lethal or non-lethal, are restricted (Tookwinas et al., 2005b). Likewise, it does not appear that there are any regulatory or prescriptive voluntary standard requirements to report any mortalities, nor were any databases containing these data identified.

As mentioned in Criterion 7 – Disease, it appears that the primary method of controlling potential predators and disease carriers in influent water (fish and crabs, for the most part) is through the use of screens and gates, with saponin (a piscicide) applied to eliminate any fish or fish larvae that were able to enter the pond (Worranut et al., 2018; Boonyawiwat et al., 2017; Boyd et al., 2017). Other common predators at shrimp ponds include birds and monitor lizards; the primary method of controlling these is the installation of nets over and/or surrounding ponds to prevent entry, though the adoption of these measures is variable across Thailand (Worranut et al., 2018; Boonyawiwat et al., 2017; Seekao and Pharino, 2016; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). There is no evidence to suggest that lethal control methods are in use to limit bird and lizard interactions at Thai shrimp ponds.

Conclusions and Final Score

The data regarding the impact that predator control at shrimp farms has on wild species is poor, and the Risk-Based Assessment method was used. Overall, it is understood that Thai shrimp farms may interact with predators and other wildlife, and farmers primarily utilize nonlethal control methods to exclude predators and limit interactions; thus, it is considered that management practices for non-harmful exclusion are in place. Despite this, there is limited

[49] http://thailaws.com/law/t_laws/tlaw0317.pdf

information available to determine whether any mortality (accidental or intentional) occurs beyond the killing of fish as a biosecurity measure, and given the “near-threatened” population status of numerous bird species that interact with shrimp ponds, some concern is warranted. It is unlikely, though, that any mortalities that may indeed occur would significantly impact the population size of the affected species. The final score for Criterion 9X – Wildlife and Predator Mortalities is -5 out of -10.

Criterion 10X: Escape of secondary species

Impact, unit of sustainability and principle

- *Impact:* Movement of live animals resulting in introduction of unintended species
- *Unit of Sustainability:* Wild native populations
- *Principle:* Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

Criterion 10X Summary

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	40.0	5
Biosecurity score of the source of animal movements (0-10)		7
Biosecurity score of the farm destination of animal movements (0-10)		2
Species-specific score 10X Score		-1.500
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**-1.500**
Critical?	No	Green

Brief Summary

Given the available evidence, it is determined that 40% of the Thai whiteleg shrimp farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 5 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments. The source of animal movements is mostly from fully biosecure broodstock and/or hatchery facilities, while the destination of animal movements – production ponds – have some uncertainty regarding the implementation and effectiveness of biosecurity measures in place, resulting in an overall score of 7 out of 10 for Factor 10Xb. The final score for Criterion 10x – Escape of Secondary Species is -1.5 out of -10.

Justification of Ranking

Factor 10Xa – International or trans-waterbody live animal shipments

Whiteleg shrimp farms in Thailand only use hatchery-raised seed from domesticated broodstock, the majority of which are SPF from biosecure hatcheries in Thailand operated by Charoen Pokphand (Tookwinas et al., 2005a; pers. comm. Robins McIntosh, Charoen Pokphand, 2018; pers. comm. Nick Leonard, Rubicon Resources, 2018). Robins McIntosh of Charoen Pokphand (CP) indicated that roughly 60% of post-larvae (PLs) in Thailand originate from CP hatcheries, and that while CP initially sourced SPF broodstock from the United States, all CP broodstock are now sourced from a nucleus breeding center in Thailand. It is understood, though, that other companies in Thailand are currently sourcing international SPF broodstock –

from the United States, Singapore[50], and possibly other sources – alongside domestically-sourced broodstock (Munkungwongsiri et al., 2017; Seafood Watch field research, March 2018). There is limited information to inform the estimation of the percentage of the non-CP broodstock in use that come from international sources, rather than domestic sources, and in the absence of additional data, it is assumed that no more than 40% of broodstock in Thailand are internationally sourced.

Once in country, these broodstock are kept in commercial and "backyard" nurseries/hatcheries with varying degrees of biosecurity, described further in Factor 10Xb (Worranut et al., 2018; Munkungwongsiri et al., 2017; Thitamadee et al., 2016). Data indicate that there are roughly 350 commercial hatcheries and 1,000-2,000 backyard hatcheries operating in Thailand, though CP operates roughly 30 hatcheries and is responsible for roughly 60% of the PLs sold in Thailand[51]. Hatcheries are found throughout the country and inter-provincial movements of PLs is common, though farmers preferably source PLs from nearby (<300 km) given the economic considerations (Worranut et al., 2018; Piamsomboon et al., 2015). At times, movements over 1,000 km (Songkhla Province in southern Thailand to Rayong province, in eastern Thailand) may occur (Worranut et al., 2018; Yaemkasem et al., 2017; pers. comm. Rawee Viriyatum, 2018). While these provinces all share a coastline on the Gulf of Thailand, the hatcheries use a variety of distinct water sources – rivers, canals, and seawater – and these are considered to be unique waterbodies, especially when considering the furthest movements from province to province (Worranut et al., 2018; Piamsomboon et al., 2015). Again, there is limited information to inform an estimation of trans-waterbody movements of PLs.

Overall, given the available data, it is considered that 40% of the Thai shrimp industry relies on international or trans-waterbody live animal shipments (internationally sourced broodstock and/or domestic trans-waterbody movements of shrimp), resulting in a score of 5 for Factor 10Xa – International or trans-waterbody live animal shipments.

Factor 10Xb – Biosecurity of source and destination

Source of movements

The available information indicates that ≤40% of the broodstock are imported from international sources, such as the United States and Singapore. The majority of broodstock from the United States comes from Hawaii, and the requirements for Hawaiian SPF broodstock are stringent, including two years of disease-free testing for a wide range of pathogens (SOH 2015). Required tests include for IHHNV, WSSV, TSV, YHV, IMNV, BP, monodon baculovirus (MBV), necrotizing hepatopancreatitis (NHP), and AHPNS, with potential for testing to include Mourilyan virus (MoV), hepatopancreatic parvovirus (HPV), and *Enterocytozoon hepatopenaei* (EHP) if the company wishes (pers. comm., Yamasaki, SOH, 2016, as cited in SFW, 2017). These sources are considered to be tank-based recirculating systems with appropriate biosecurity practices. No information could be found regarding the sources of broodstock in Singapore.

[50] https://seafood-tip.com/sourcing-intelligence/countries/thailand/shrimp/
[51] https://seafood-tip.com/sourcing-intelligence/countries/thailand/shrimp/

In Thailand (either sourced from shipments or raised in Thailand), broodstock are kept in commercial and "backyard" nurseries/hatcheries with varying degrees of biosecurity management. Charoen Pokphand (CP) hatcheries operate under strict biosecurity protocols, including the disinfection of any incoming water and air, operating fully closed recirculating systems once filled, and testing every batch of PLs for the aforementioned pathogens (pers. comm. Robins McIntosh, Charoen Pokphand, 2018). Limited information is available regarding the biosecurity protocols of other commercial and backyard hatcheries. Munkungwonsiri et al. (2017) indicated that some commercial hatcheries in Chanthaburi, Rayong, and Phuket were rearing broodstock of domestic origin in "earthen ponds without proper biosecurity system (inadequate reservoir and treatment ponds, no tire bath at the farm entrance, no footbath and hand disinfection at the pond entrance, no crab fence, and no bird scaring device)", while some other hatcheries (also in Phuket, as well as Chonburi) were using imported SPF broodstock from the United States and implemented strong biosecurity protocols in recirculating tanks. Other evidence from the literature indicates that many hatcheries test all PL batches for pathogens, using either a DOF or private laboratory (Worranut et al., 2018; Yaemkasem et al. 2017). Anecdotal evidence indicates that there are hatcheries in Thailand sourcing SPF broodstock imported from the United States while operating with poor biosecurity protocols (no disinfectants, abundant visitors, recirculating raceways that are open to the environment) (Seafood Watch field research, March 2018).

Given that CP supplies 60% of the PLs in Thailand, it is considered that 60% of the "source of movements" is fully biosecure, and receives a score of 10 out of 10. It is apparent that the remaining 40% of PL supply originates from hatcheries with variable biosecurity measures in place, ranging from high risk pond systems with limited biosecurity (a score of 0) to recirculating tank systems with biosecurity protocols in place, though there is uncertainty with regard to the robustness of these measures (a score of 6); as such, an intermediate score of 3 is applied to this 40%. When these scores are combined, a score of 7out of 10 is given for Factor 10Xb – biosecurity of the source of animal movements.

<u>Destination of movements</u>
As described in Criterion 7 – Disease, whiteleg shrimp farms across Thailand apply biosecurity measures to varying degrees, but in general, farms are considered to limit water exchange to <1% per day and operate using reservoirs where water is treated and disease-carrying organisms (like fish and crabs) are often destroyed. The high flood risk and vulnerability as described in Criterion 6 – Escapes, as well as pond drainage at harvest, must be considered when assessing the biosecurity of the production system. It appears that the most accurate way to describe the production system in this context is as a moderate risk system (static ponds that drain externally at harvest) with uncertainty regarding the robustness of escape prevention and biosecurity measures; as such, a score of 2 is given for Factor 10Xb – biosecurity of the destination of animal movements.

Since the final score for Factor 10Xb is the higher of the source and destination scores, the final score for Factor 10Xb – biosecurity of source and destination is 7 out of 10.

Conclusions and Final Score

Given the available evidence, it is determined that 40% of the Thai whiteleg shrimp farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 5 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments. The source of animal movements is mostly from fully biosecure broodstock and/or hatchery facilities, while the destination of animal movements – production ponds – have some uncertainty regarding the implementation and effectiveness of biosecurity measures in place, resulting in an overall score of 7 out of 10 for Factor 10Xb. The final score for Criterion 10x – Escape of Secondary Species is -1.5 out of -10.

Overall Recommendation

The overall recommendation is as follows:

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

- **Best Choice** = Final score ≥6.6 AND no individual criteria are Red (i.e. <3.3)
- **Good Alternative** = Final score ≥3.3 AND <6.6, OR Final score ≥ 6.6 and there is one individual "Red" criterion.
- **Red** = Final score <3.3, OR there is more than one individual Red criterion, OR there is one or more Critical score.

Whiteleg shrimp

Litopenaeus vannamei

Thailand

Intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	5.45	Yellow	n/a
C2 Effluent	6.00	Yellow	No
C3 Habitat	4.27	Yellow	No
C4 Chemicals	4.00	Yellow	No
C5 Feed	3.00	Red	No
C6 Escapes	4.00	Yellow	No
C7 Disease	4.00	Yellow	No
C8X Source	0.00	Green	No
C9X Wildlife	-5.00	Yellow	No
C10X Introduction of secondary species	-1.50	Green	n/a
Total	24.22		
Final score (0-10)	3.46		

OVERALL RANKING

Final Score	3.46
Initial rank	Yellow
Red criteria	1
Interim rank	Yellow
Critical Criteria?	0

Final Rank
Yellow

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Appendix 1 - Data points and all scoring calculations

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	5.0
Effluent	5.0
Habitat	5.0
Chemical Use	5.0
Feed	5.0
Escapes	5.0
Disease	5.0
Source of stock	10.0
Wildlife mortalities	2.5
Escape of secondary species	5.0
C1 Data Final Score (0-10)	**5.455**
	Yellow

Criterion 2 - Effluent

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	36.500
eFCR	1.500
Fertilizer N input (kg N/ton fish)	0.000
Protein content of harvested fish (%)	17.800
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	87.600
N output in each ton of fish harvested (kg)	28.480
Waste N produced per ton of fish (kg)	59.120

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.420
Adjustment 1 (if applicable)	-0.140
Adjustment 2 (if applicable)	-0.080
Adjustment 3 (if applicable)	0.000
Boundary adjustment (if applicable)	0.000
Discharge (Factor 2.1b) score (0-1)	0.200
Waste discharged per ton of production (kg N ton-1)	11.824
Waste discharge score (0-10)	8.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	3
2.2b Enforcement of effluent management measures	3
2.2 Effluent management effectiveness	3.600
C2 Effluent Final Score (0-10)	**6**
Critical?	No

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	4
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	4
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	4.800
C3 Habitat Final Score (0-10)	**4.267**
Critical?	No

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	4.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**4.0**
Critical?	No

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	3.000
Fishmeal from byproducts, weighted inclusion %	9.000
Byproduct fishmeal inclusion (@ 5%)	0.450
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.000
Fish oil from byproducts, weighted inclusion %	0.270
Byproduct fish oil inclusion (@ 5%)	0.014
Fish oil yield value, weighted %	5.000
eFCR	1.500
FFER Fishmeal value	**0.230**
FFER Fish oil value	**0.004**

Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	0.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**2.000**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	36.500
Protein INPUT kg/100kg harvest	54.750
Whole body harvested fish protein content	17.800
Net protein gain or loss	-67.489
Species-specific Factor 5.2 score	**3**
Critical (Score = 0)?	No
Critical (FFER>3 and 5.2 score <2)?	No

5.3 Feed Footprint	**Data and Scores**
GWP (kg CO2-eq kg-1 farmed seafood protein)	**20.392**
Contribution (%) from fishmeal from whole fish	1.468
Contribution (%) from fish oil from whole fish	0.000
Contribution (%) from fishmeal from byproducts	4.405
Contribution (%) from fish oil from byproducts	0.091
Contribution (%) from crop ingredients	94.036
Contribution (%) from land animal ingredients	0.000
Contribution (%) from other ingredients	0.000
Factor 5.3 score	**5**
C5 Final Feed Criterion Score	**3.0**
Critical?	**No**

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	6
C6 Escape Final Score (0-10)	**4.0**
Critical?	No

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**4**
Critical?	No

Criterion 8X Source of Stock	**Data and Scores**
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0-10)	0.0
Use of ETP or SFW "Red" fishery sources	No
Lowest score if multiple species farmed (0-10)	n/a
C8X Source of stock Final Score (0-10)	**0**
Critical?	No

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	-5
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-5**
Critical?	No

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	40
Factor 10Xa score	5
Biosecurity of the source of movements (0-10)	7
Biosecurity of the farm destination of movements (0-10)	2
Species-specific score 10X score	-1.500
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-1.500**
Critical?	n/a