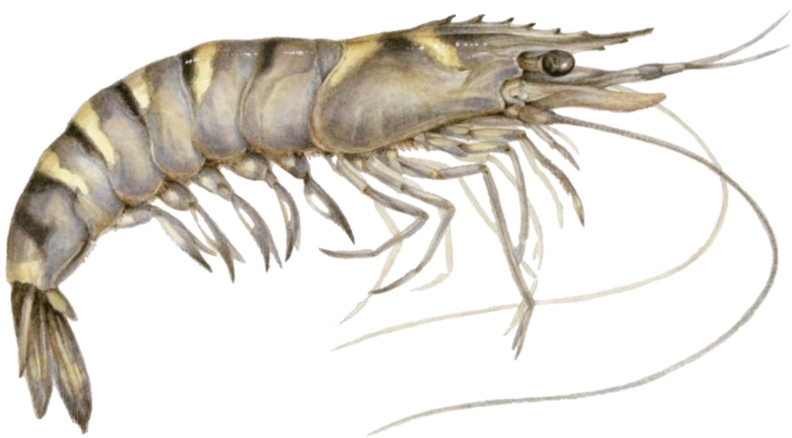
Monterey Bay Aquarium Seafood Watch®

Whiteleg Shrimp, Giant Tiger Prawn

Litopenaeus vannamei, Penaeus monodon



India

Ponds

October 4, 2021

Tyler Isaac, Senior Aquaculture Scientist

Disclaimer

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

About Seafood Watch®

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

Each sustainability recommendation on the regional pocket guides is supported by a Seafood 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
India
Semi-intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	5.00	Yellow	n/a
C2 Effluent	5.00	Yellow	No
C3 Habitat	0.67	Red	No
C4 Chemicals	0.00	Red	No
C5 Feed	3.21	Red	No
C6 Escapes	3.00	Red	No
C7 Disease	4.00	Yellow	No
C8X Source	0.00	Green	No
C9X Wildlife	-4.00	Yellow	No
C10X Introduction of secondary species	0.00	Green	n/a
Total	16.88		
Final score (0-10)	2.41		

OVERALL RANKING

Final Score	2.41
Initial rank	Red
Red criteria	4
Interim rank	Red
Critical Criteria?	0

Final Rank
Red

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 semi-intensively farmed whiteleg shrimp *(Litopenaeus vannamei)* in India is 2.41 out of 10, which is in the Red range. With four Red criteria, the final rank is Red and an “Avoid” recommendation.

Black tiger shrimp

Penaeus monodon

India

Semi-intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	4.09	Yellow	n/a
C2 Effluent	5.00	Yellow	No
C3 Habitat	0.67	Red	No
C4 Chemicals	0.00	Red	No
C5 Feed	2.78	Red	No
C6 Escapes	4.00	Yellow	No
C7 Disease	2.00	Red	No
C8X Source	-9.00	Red	No
C9X Wildlife	-4.00	Yellow	No
C10X Introduction of secondary species	-8.00	Red	n/a
Total	-2.47		
Final score (0-10)	-0.35		

OVERALL RANKING

Final Score	-0.35
Initial rank	Red
Red criteria	6
Interim rank	Red
Critical Criteria?	0

Final Rank
Red

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 semi-intensively farmed black tiger shrimp *(Penaeus monodon)* in India is -0.35 out of 10, which is in the Red range. With six Red criteria, the final rank is Red and an “Avoid” recommendation.

Executive Summary

Annual production of *L. vannamei* in India dramatically rose from 1,750 mt in 2009, the first year it was introduced, to 815,745 mt in 2020 accounting for just under 97% of all Indian shrimp production; the remaining 3% was largely accounted for by the black/giant tiger shrimp *P. monodon* (MPEDA, 2021). In 2019 (the most recent available total statistics), farmed shrimp (both species) represented roughly 10% of total aquaculture production in India, which produces large volumes of freshwater fishes, such as carp (FAO, 2020; MPEDA, 2021). Overall, India is currently the third largest producer of whiteleg shrimp globally, following China and Indonesia, and followed by Ecuador, Vietnam, and Thailand (FAO, 2020). India is currently the fifth largest producer of black tiger shrimp, following Vietnam, Indonesia, China, and Bangladesh (FAO, 2020).

Today, the majority of Indian *L. vannamei* pond systems are semi-intensive and low exchange, where water discharge during the cycle is discouraged but still occurs should pond conditions require it. Data are not available to accurately estimate the proportion of the industry that does not discharge water during the production cycle, but for the purposes of this report, an average daily exchange of <3% is considered representative of the Indian *L. vannamei* industry at large. Indian black tiger production ranges from extensive to semi-intensive, with volumes attributed to different intensities varying by account; however, only semi-intensive production is assessed in this report. The majority of *P. monodon* semi-intensive systems typically feature water exchanges of 5-25% each week throughout the production cycle, and thus an average daily exchange of >3% is considered representative of the Indian semi-intensive *P. monodon* industry.

Overall, the availability and quality of data regarding shrimp farming in India is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. There is a general lack of information available to assess the chemical usage, feed supply chain, and impacts to wild species through predator control for both species, with additional data limitations regarding production volumes and area under culture. There is also a lack of information regarding the sustainability and the movements of live *P. monodon* broodstock, whereas the impacts of *L. vannamei* escapes are not well understood. For the most part, the data were able to provide a moderate understanding of the Indian shrimp industry, though data deficiencies limited robust analysis in a number of ways. The final score for Criterion 1 – Data is 4.09 out of 10 for *P. monodon* and 5.00 out of 10 for *L. vannamei*.

Shrimp farm effluent discharges in India 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 “designated best use”, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). While EIAs are not required for the vast majority of operating farms, all farms are required to meet prescribed effluent water quality standards and most farms are required to employ effluent treatment systems (almost all *L. vannamei* farms and *P. monodon* farms >5 ha). 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. Enforcement of these regulations is considered severely limited, however. Noncompliance with the requirement to utilize effluent treatment systems is widespread, with no evidence of corrective action. The vast majority of farms operating today are not registered by the Coastal Aquaculture Authority (CAA) and are thus technically operating illegally. Despite this, as mentioned, there appears to be an effective framework and governance system for managing pollution in India via the Central and State Pollution Control Boards.

The scores for Factors 2.1 (8 out of 10 for both species) and 2.2 (1.2 out of 10 for both species) are combined using the Risk-Based Assessment matrix, resulting in a final score of 5 out of 10 for Criterion 2 – Effluent for both species.

While the majority of habitat conversion for shrimp culture took place prior to 1999, evidence indicates that pristine high-value habitat, such as mudflats and creeks, have been converted to shrimp ponds since then. Legislation requires shrimp farm siting in India to be restricted to specific areas with limitations prescribed by the Coastal Aquaculture Authority Act. These requirements include ecological considerations and are integrated with other industries; however, environmental impact assessments are not required by the vast majority of farms. All farms are required to register with the CAA and obtain a license prior to operation, yet only about 19% of currently operating farms are registered as “Active” with limited to no evidence of corrective action or penalties. Outright illegal operations are known to occur, and though there is some recent evidence of enforcement demolishing these farms, it is clear that illegal siting activities persist. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (1 out of 10) and Factor 3.2 – Farm siting regulation and management (0 out of 10), and the final score is 0.667 out of 10 for both species.

Overall, chemical use in Indian shrimp aquaculture is common. Most chemicals used for pond preparation and disinfection used in Indian 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. Recent surveys indicate on-farm usage of illegal antibiotics, such as nitrofurans and chloramphenicol, does continue to occur on farms in India and is supported by literature published throughout the past decade. Indian shrimp consignments are regularly rejected in export markets like the United States for antibiotic residues, particularly nitrofurans and chloramphenicol, and while the primary source of contamination is not clear (e.g., PLs, feed inputs, probiotics, disinfectants, etc.), it appears likely that intentional and unintentional on-farm usage is occurring. The Indian government has implemented several programs with the intention of stemming illegal use and the export of contaminated products, but it is clear that this challenge has yet to be solved.

With limited controls over antibiotic sales and distribution alongside demonstrated illegal use of these drugs beyond exceptional cases, the final score for Criterion 4 – Chemicals is 0 out of 10 for both *L. vannamei* and *P. monodon*.

Shrimp feeds for both species in India use fishmeal and fish oil made from whole wild fish and fishery by-product sources, though differ in their inclusion levels. For *L. vannamei*, the fishmeal inclusion level is moderate (15%) and nearly half of it (45%) is sourced from fishery by-products. The fish oil inclusion level is low at 1.1% and 42% of it comes from by-product sources. With an eFCR of 1.4, the Forage Fish Efficiency Ratio (FFER) is thus low (0.53), meaning that from first principles, 0.53 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed *L. vannamei*. For *P. monodon*, the fishmeal inclusion level is higher (17%) with 26% of it sourced from fishery by-products. The fish oil inclusion level is also higher at 2.0%, with 12.5% of it sourced from by-products. With an eFCR of 1.5, the FFER for *P. monodon* is moderate (0.912).

Data supplied by feed manufacturers indicated the source fisheries used for both whole fish and by-product ingredients and indicate that they are the same for *L. vannamei* and *P. monodon*. In the case of whole fish, the source fisheries indicated by the manufacturers are Indian oil sardine, “silverbelly” and “other pelagic lean fish” caught with trawls and purse seines. With respect to by-products, the source fisheries are “pelagic fish trimmings” and “mackerel/perches/ribbon fish”. There is limited information available to assess the sustainability of Indian oil sardine, and with no data on capture method or other specific identifying information, the other inclusions are considered sourced from unknown fisheries.

Overall, despite the moderately low levels of inclusion of these wild fish ingredients in Indian shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10 for *L. vannamei* and 1 out of 10 for *P. monodon*). They each have a moderate-high net protein loss (-64.10% for *L. vannamei* and -66.84% for *P. monodon*; both score of 3 out of 10) and a moderate-low feed footprint (14.71 kg CO_2-eq. per kg of harvested protein for *L. vannamei* and 14.44 kg CO_2-eq. for *P. monodon*; both score of 6 out of 10). The three factors combine to result in a final score of 3.21 out of 10 for Criterion 5 – Feed for *L. vannamei* and 2.78 for *P. monodon*.

On-farm escape prevention measures taken by Indian shrimp farmers (such as elevated dike/bund construction, screens on outlets, harvesting prior to large storms) helps to 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 India is high.

L. vannamei are non-native in India and have been found in the wild during shrimp population surveys. While limited evidence specific to India is available, research in similar environments has indicated their ability to outcompete and even consume native shrimp, as well as the development of reproductive organs. Despite this, there is no indication that *L. vannamei* have

established viable populations in India, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a moderate risk of competitive impacts (score of 6 out of 10 for Factor 6.2) results in a final score of 3 out of 10 for Criterion 6 – Escapes.

P. monodon are native to India and as farmed stock are almost entirely sourced from wild broodstock, it is unlikely that escaped farmed *P. monodon* present any significant competitive or genetic impact risk to wild populations.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a low risk of competitive impacts (score of 8 out of 10 for Factor 6.2) results in a final score of 4 out of 10 for Criterion 6 – Escapes.

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 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 typically 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 3% of pond volume per day for *L. vannamei*, and farms strive to not discharge water to the environment over the course of a production cycle except at harvest; for *P. monodon*, water exchange during the cycle is more common, and daily water exchange is, on average, between 3% and10% of pond volume.

Despite these efforts to limit pathogen risk, the shrimp farming industry 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 *L. vannamei* farms for Criterion 7 – Disease is 4 out of 10, due to limited water exchange during the production cycle; the final score for *P. monodon* farms for Criterion 7 – Disease is 2 out of 10, due to moderate daily water exchange during the production cycle.

Whiteleg shrimp farms in India only use hatchery-raised seed from domesticated broodstock, the majority of which are imported SPF largely from the United States. There is no reliance on wild shrimp for farm production, and as such, the final *L. vannamei* score for Criterion 8X – Source of Stock is 0 out of -10.

On the other hand, *P. monodon* production is nearly 100% reliant on wild captured broodstock of unknown sustainability. Despite advancements in the development of a domesticated broodstock supply in India, the current status of *P. monodon* production is estimated to be 90-99% reliant on wild captured broodstock – the fishery for which cannot be considered demonstrably sustainable – and as such, the final *P. monodon* score for Criterion 8X – Source of Stock is -9 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 Indian 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 evidence that suggests intentional mortality of animals may occur beyond the killing of fish as a biosecurity measure, though this is considered exceptional and the majority of species interacting with farms are considered "least concern" by the IUCN. It is thus unlikely that any mortalities that may indeed occur would significantly impact the population size of the affected species, but actual mortality numbers are unknown. Legislation explicitly prohibits the killing of wildlife, though exceptions may be made in the event that property, such as shrimp ponds, are threatened. The final score for Criterion 9X – Wildlife and Predator Mortalities is -4 out of -10.

Given the available evidence, it is determined that 100% of both the Indian *L. vannamei* and *P. monodon* farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 0 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments.

The source of *L. vannamei* is entirely from fully biosecure international suppliers of broodstock and/or PLs, while the source of *P. monodon* broodstock is almost exclusively from the wild. The destination of animal movements, farms across India, for both *L. vannamei* and *P. monodon* have significant uncertainty regarding the implementation and effectiveness of biosecurity measures in place and are considered moderate-high biosecurity risks. This results in an overall score of 10 out of 10 for *L. vannamei* and 2 out of 10 for *P. monodon* for Factor 10Xb.

The final score for Criterion 10x – Escape of Secondary Species is 0 out of -10 for *L. vannamei*. The final score for Criterion 10x – Escape of Secondary Species is -8 out of -10 for *P. monodon*. The final numerical score for semi-intensively farmed whiteleg shrimp *(Litopenaeus vannamei)* in India is 2.41 out of 10, which is in the Red range. With four Red criteria, the final rank is Red and an "Avoid" recommendation. The final numerical score for semi-intensively farmed black tiger shrimp *(Penaeus monodon)* in India is -0.35 out of 10, which is in the Red range. With six Red criteria, the final rank is Red and an "Avoid" recommendation.

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species: Whiteleg shrimp (*Litopenaeus vannamei*); Black/Giant tiger prawn (*P. monodon*)
Geographic coverage: India
Production Method: Semi-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 India. *Penaeus monodon* is a tropical marine shrimp that is indigenous to India; it is found naturally in the Indian Ocean and the western Pacific (Indo-West Pacific), with a distribution range that includes much of Asia and reaches as far north as Japan and North Korea and as far south as Australia.

As for all Penaeid species, adults of both species live and spawn in the open ocean, while post-larvae (PL) migrate inshore to spend their juvenile, adolescent and sub-adult stages in coastal estuaries, lagoons or mangrove areas (FAO, 2006).

Production system
Indian whiteleg shrimp production is largely semi-intensive to intensive, as all farms source post-larvae (PLs) from hatcheries, and most utilize aeration via paddlewheels, apply fertilizers, and provide manufactured feed to boost production above which natural inputs (and fertilization) can sustain. There does not appear to be any extensive whiteleg shrimp production in India. The line between semi-intensive and intensive is blurred, though the use of stocking density and/or annual yield per hectare as indicators of "intensity" is common.

Amongst semi-intensive to intensive *L. vannamei* ponds, stocking densities usually range from 10-70 PLs per m^2, as regulations limit *L. vannamei* stocking densities to 60 PLs per m^2; however, local experts report densities approaching 85 PLs per m^2 amongst farmers producing smaller shrimp counts, though caution this is quite rare due to the increased risk of disease. There are additional reports of the most intensive ponds in India utilizing a stocking density of 120-150+ PLs per m^2, which is more typical of intensive *L. vannamei* production in other countries (Ghoshal et al., 2019; STIP, 2020; Towers, 2016). Annual yield per hectare in India ranges from 2-5 mt for semi-intensive production, whereas more intensive production generally yields 7-15 mt shrimp per hectare, with 2-3 crops per year (85-175 days per crop) as the norm (Ghoshal et al., 2019; STIP, 2020; Towers, 2016). Anecdotal information indicates that the most intensive production in India results in annual yields of >50 mt per hectare (Towers, 2016). There is clearly a range of production intensity in use in Indian *L. vannamei* shrimp production, and it is not possible to determine the percentage of the industry that is semi-intensive or intensive simply by the metric of stocking density; data are not available indicating the distribution of annual yields at the farm-level, though these would provide valuable insight with regard to the varying intensities of farming practice. Overall, though, an estimate from Seafood Trade Intelligence Portal (STIP) indicates that over 80% of total shrimp production (inclusive of *P. monodon*) is semi-intensive *L. vannamei* production, defined as utilizing stocking densities of 11-69 PL/m^2, with average annual productivity of 10.6 mt per hectare (STIP, 2020).

Indian black tiger production ranges from extensive to semi-intensive, with volumes attributed to different intensities varying by account. Semi-intensive *P. monodon* culture features a similar production system as that used for semi-intensive *L. vannamei*, with aeration, fertilizer usage, and supplemental feed regularly applied, and PLs sourced from local hatcheries (Ghoshal et al., 2019; STIP, 2020). Information from STIP indicates that average semi-intensive *P. monodon* culture utilizes stocking densities of 8-20 PL/m^2 resulting in average annual productivity of 1.3 mt per hectare, with 1-2 crops per year (90-120 days per crop) as the norm.

Recent production data from MPEDA (2021)[1] align with this, indicating a five-year average productivity of 0.94 mt per hectare for *P. monodon* farming across India. With regard to extensive production – with partial reliance on wild PLs and little to no use of aeration or supplemental feeds – stocking densities are <4 PL/m^2 which results in average annual productivity of <500 kg per hectare with harvesting taking place following the lunar cycle throughout the year (STIP, 2020). The vast majority of this type of production takes place in West Bengal, with 19,190 mt in 2020 over 50,000 ha (0.38 mt/ha), with additional production in Kerala (1,129 mt over 2,814 ha, 0.40 mt/ha) and Karnataka (1,000 mt over 2,175 ha, 0.46 mt/ha). Some of these extensive farmers are beginning to supplement with manufactured feeds on a regular basis, though the feeding intervals are longer (e.g., once per week) than semi-intensive, and may be categorized as modified or improved extensive – these are not considered in the scope of this assessment, which covers semi-intensive production only. Semi-intensive production of *P. monodon* is likely the major production method in several states, such as Andhra Pradesh (5,222 mt in 2020 over 2,591 ha, 2.02 mt/ha), Orissa (878 mt in 2020 over 551 ha, 1.59 mt/ha), Gujarat (116 mt in 2021 over 35 ha, 3.31 mt/ha) and Tamil Nadu & Pondicherry (81 mt in 2020 over 30 ha, 2.7 mt/ha); this production accounts for 6,297 mt out of total production of 27,616, or 23%. Semi-intensive production of *P. monodon* in any state is covered under the scope of this assessment.

Production statistics

The Indian shrimp aquaculture industry is dominated by small-holder farmers that own or manage 1-2 ponds totaling <2 ha in area. Official statistics indicate that just over 166,000 ha were under culture in 2020 (108,526 ha *L. vannamei*; 58,196 ha *P. monodon*), giving an estimate of ~75,000 individual farmers (MPEDA, 2021).

[1] https://mpeda.gov.in/?page_id=684

Data from MPEDA indicate that roughly 74,500 ha were under shrimp culture in Andhra Pradesh in 2020, equivalent to 45% of the total farming area in India; this is followed by West Bengal, where 56,059 ha is under culture, 34% of total farming area (MPEDA, 2021).

Indeed, the majority of total shrimp production occurs in the state of Andhra Pradesh, representing 639,896 mt or 76% of production in 2020; the next largest producer state, West Bengal, totaled 54,582 mt or 6.5% of production in 2020, and is followed by Gujarat which totaled 50,526 mt or 6% of production in 2020 (MPEDA, 2021). It is noteworthy that these data indicate an average production of 8.6 mt/ha in Andhra Pradesh and 5.6 mt/ha in Gujarat, yet an average production of 0.97 mt/ha in West Bengal, driven by higher intensity of production of *L. vannamei* and *P. monodon* adopted in Andhra Pradesh and significant extensive *P. monodon* production in West Bengal.

With regard to *L. vannamei* specifically, Andhra Pradesh produced 634,672 mt or 78% of the total *L. vannamei* production in 2020, followed by Gujarat (50,410 mt, 6%) and Tamil Nadu & Pondicherry (44,735 mt, 5.5%) (MPEDA, 2021). Thus, production of *L. vannamei* in Andhra Pradesh is equivalent to three-fourths of the total shrimp production in India.

Figure 1. Farmed shrimp production in India from 2008 to 2020. (MPEDA, 2021).

Import and export sources and statistics

Today, the primary export destination for shrimp farmed in India is the United States. According to statistics obtained from both MPEDA and the United States National Marine Fisheries Service (NMFS), shrimp exports to the United States in 2020 totaled roughly 271,000 mt, equivalent to 42% of total shrimp exports (MPEDA, 2021; NMFS, 2021). In terms of value, shrimp exports to the United States in 2020 totaled $2.3 billion USD, 48% of total shrimp export value (MPEDA, 2021; NMFS, 2021). Exports to the United States in 2013 totaled 82,000 mt, indicating a 330% increase to the volumes today. It is expected that Indian shrimp exports to the United States will continue to rise, though perhaps at a slower rate than the previous five years; the rapid increase in Indian exports to the United States are partly the result of filling the gap left by the massive decline in exports from Thailand due to the EMS crisis in 2012-2013 (Rabobank, 2019).

Other major markets for Indian shrimp include China (180,000 mt in 2018), the EU (75,000 mt in 2018), Japan (30,000 mt in 2017) and the UAE (16,000 mt in 2017) (Rabobank, 2019; STIP, 2020).

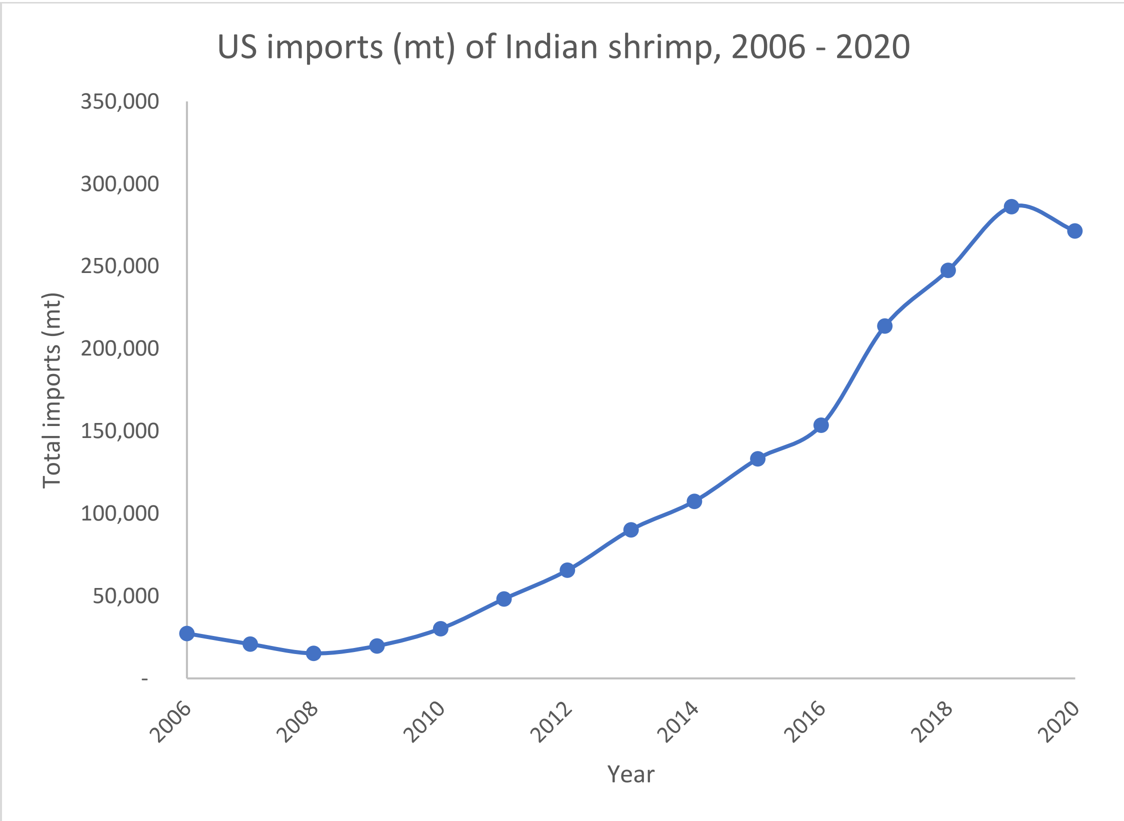


Figure 2. US imports of Indian shrimp, inclusive of all warm-water species. Data from the National Marine Fisheries Service.[2]

Common and market names

[2] https://www.fisheries.noaa.gov/foss/f?p=215:2:28194046073069::NO:::

Scientific Names	*Litopenaeus vannamei*	*Penaeus monodon*
Common Names	Pacific white shrimp, whiteleg shrimp, western white shrimp, or shrimp	Black tiger shrimp, black tiger prawn, Asian tiger shrimp, tiger shrimp, tiger prawn, giant tiger prawn
United States	Whiteleg shrimp	Tiger shrimp
Spanish	Camarón patiblanco	Langostino jumbo
French	Crevette pattes blanches	Crevette géante tigrée

Product forms

Shrimp are exported from India in a variety of product forms, though in the US, over 95% of shrimp imported from India is frozen[1]. 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.

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

Litopenaeus vannamei – Semi-intensive ponds

C1 Data Category	Data Quality
Production	5.0
Management	5.0
Effluent	5.0
Habitat	5.0
Chemical Use	2.5
Feed	2.5
Escapes	2.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	2.5
Introduction of secondary species	10.0
C1 Data Final Score (0-10)	**5.00**

Penaeus monodon – Semi-intensive ponds

C1 Data Category	Data Quality
Production	5.0
Management	5.0
Effluent	5.0
Habitat	5.0
Chemical Use	2.5
Feed	2.5
Escapes	7.5
Disease	5.0
Source of stock	2.5
Wildlife mortalities	2.5
Introduction of secondary species	2.5
C1 Data Final Score (0-10)	**4.09**

Brief Summary

Overall, the availability and quality of data regarding shrimp farming in India is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. There is a general lack of information available to assess the chemical usage, feed supply chain, and impacts to wild species through predator control for both species, with additional data limitations regarding production volumes and area under culture. There is also a lack of information regarding the sustainability and the movements of live *P. monodon* broodstock, whereas the impacts of *L. vannamei* escapes are not well understood. For the most part, the data were able to provide a moderate understanding of the Indian shrimp industry, though data deficiencies limited robust analysis in a number of ways. The final score for Criterion 1 – Data is 4.09 out of 10 for *P. monodon* and 5.00 out of 10 for *L. vannamei*.

Justification of Ranking

Industry or production statistics

Aggregated industry and production statistics are readily available from the Marine Products Exports Development Authority (MPEDA), the Coastal Aquaculture Authority (CAA), 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. However, there is significant uncertainty in the number of active operating farms and production capacity, given variance in the figures and widespread unregistered production occurring. There is also uncertainty regarding adoption rates of certain production methodologies within the "semi-intensive" label (e.g., water exchange, use of reservoirs, etc.), and therefore, data quality regarding industry and production statistics is moderate and receives a score of 5 out of 10 for both *L. vannamei* and *P. monodon*.

Management and regulations

A significant amount of information was able to be obtained regarding legislation governing the Indian shrimp industry from official Indian government websites, 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, 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 for both *L. vannamei* and *P. monodon*.

Effluent and Habitat

Information regarding farm siting and effluent discharge practices was able to be obtained through literature and personal communications, though significant gaps in the data regarding enforcement and farm registration remain. Reports from the Central Pollution Control Board (CPCB) helped inform the status of water quality, and literature analyzing satellite imagery informed both the spatial extent and habitat impact of the shrimp industry. Broadly, 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 for both *L. vannamei* and *P. monodon*.

Chemical use
Detailed data regarding chemical use in India were not able to be obtained, particularly with respect to that of antibiotics. 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. However, Indian shrimp exports are regularly rejected at their destination markets due to contamination with banned antibiotics. The data quality and ensuing confidence in understanding the nature of chemical use on Indian shrimp farms is low and scores 2.5 out of 10 for both *L. vannamei* and *P. monodon*.

Feed
Information regarding feed composition, conversation ratios, and the source of wild fish was obtained through personal communications with 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 sustainability of source fisheries of whole-fish fishmeal ingredients, as well as the origin of fishery by-product raw material. The data quality and confidence in the data is low and scores 2.5 out of 10 for both *L. vannamei* and *P. monodon*.

Escapes
Very limited information was obtained regarding the incidence or number of escaped shrimp of both species. The only source of information detailing these numbers were news reports and several studies assessing shrimp populations in the wild in India. Information regarding escape and flood mitigation measures was obtained from the literature and personal communications with government officials and industry experts, yet the adoption rates of these measures are uncertain. The body of literature assessing the competitive and genetic risks to wild species posed by escaped *L. vannamei* globally is moderately robust, though there is limited information specific to India. On the other hand, nearly all *P. monodon* are a single generation domesticated (e.g., broodstocks are sourced from the wild) and therefore the risk of competitive and genetic impacts is significantly mitigated. As such, the data score for Criterion 6 – Escapes is 2.5 out of 10 for *L. vannamei* and 7.5 out of 10 for *P. monodon*.

Disease
There is a large body of literature and study detailing the pathogens, biosecurity measures, disease control methods, and water exchange rates in the Indian 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 for both *L. vannamei* and *P. monodon*.

Source of stock

As is the case for *L. vannamei* production globally, Indian farmed whiteleg shrimp are produced from domesticated broodstocks and are therefore independent of wild shrimp populations. The vast majority of farmed *P. monodon*, however, originate from wild caught broodstock in Indian waters with only two approved international sources of domesticated broodstock at the time of writing. These conclusions were established through literature review alongside personal communications with government officials, industry representatives, and farmers. Very limited information could be obtained regarding the sustainability of wild *P. monodon* fisheries that the majority of *P. monodon* broodstock are sourced from, and the data that were obtained were often outdated. Therefore, the data score for Source of Stock is 10 out of 10 for *L. vannamei* and 2.5 out of 10 for *P. monodon*.

Wildlife mortalities

Data regarding deliberate or accidental mortalities of any animals at shrimp farms are limited to anecdotes in literature. 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 for both *L. vannamei* and *P. monodon*.

Introduction of secondary species

Data regarding the international and/or trans-waterbody movement of live animals were good for *L. vannamei*, as all original broodstock and/or PLs must be shipped through a single port-of-entry and pass-through quarantine before entering the country. While nearly all *P. monodon* broodstock are sourced from the wild, data regarding source fishing areas, landing locations, and destinations of broodstock were limited. The biosecurity of the source *L. vannamei* broodstock facilities is well-understood, though that of the destination for both species (e.g., farms throughout India) were uncertain, given the variability in production practices. Literature sources and personal communication with industry experts contributed to the understanding of biosecurity. The confidence in the data is for *L. vannamei* is high and scores 7.5 out of 10, while the confidence in the data for *P. monodon* is low and scores 2.5 out of 10.

Conclusions and Final Score

Overall, the availability and quality of data regarding shrimp farming in India is fair, despite some significant data aggregation and gaps, given the variability and small-holder nature of the industry. There is a general lack of information available to assess the chemical usage, feed supply chain, and impacts to wild species through predator control for both species, with additional data limitations regarding production volumes and area under culture. There is also a lack of information regarding the sustainability and the movements of live *P. monodon* broodstock, whereas the impacts of *L. vannamei* escapes are not well understood. For the most part, the data were able to provide a moderate understanding of the Indian shrimp industry, though data deficiencies limited robust analysis in a number of ways. The final score for Criterion 1 – Data is 4.09 out of 10 for *P. monodon* and 5.00 out of 10 for *L. vannamei*.

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

Litopenaeus vannamei – Semi-intensive ponds

C2 Effluent parameters	Value	Score
F2.1a Waste (nitrogen) production per of fish (kg N ton-1)	52.240	
F2.1b Waste discharged from farm (%)	22.000	
F2.1b Boundary adjustment (0-1)	0.000	
F2 .1 Waste discharge score (0-10)		8
F2.2a Content of regulations (0-5)	3	
F2.2b Enforcement of regulations (0-5)	1	
F2.2 Regulatory or management effectiveness score (0-10)		1.200
C2 Effluent Final Score (0-10)		**5**
Critical?	No	Yellow

Penaeus monodon – Semi-intensive ponds

C2 Effluent parameters	Value	Score
F2.1a Waste (nitrogen) production per of fish (kg N ton-1)	69.460	
F2.1b Waste discharged from farm (%)	27.000	
F2.1b Boundary adjustment (0-1)	0.000	
F2 .1 Waste discharge score (0-10)		8
F2.2a Content of regulations (0-5)	3	
F2.2b Enforcement of regulations (0-5)	1	
F2.2 Regulatory or management effectiveness score (0-10)		1.200
C2 Effluent Final Score (0-10)		**5**
Critical?	No	Yellow

Brief Summary

Shrimp farm effluent discharges in India 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 “designated best use”, and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). While

EIAs are not required for the vast majority of operating farms, all farms are required to meet prescribed effluent water quality standards and most farms are required to employ effluent treatment systems (almost all *L. vannamei* farms and *P. monodon* farms >5 ha). 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. Enforcement of these regulations is considered severely limited, however. Noncompliance with the requirement to utilize effluent treatment systems is widespread, with no evidence of corrective action. The vast majority of farms operating today are not registered by the Coastal Aquaculture Authority (CAA) and are thus technically operating illegally. Despite this, as mentioned, there appears to be an effective framework and governance system for managing pollution in India via the Central and State Pollution Control Boards.

The scores for Factors 2.1 (8 out of 10 for both species) and 2.2 (1.2 out of 10 for both species) are combined using the Risk-Based Assessment matrix, resulting in a final score of 5 out of 10 for Criterion 2 – Effluent for both species.

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.

The degree to which semi-intensive culture of whiteleg shrimp and black tiger prawn takes place in India relative to semi-extensive and intensive culture is difficult to quantify, given the evident ranges of stocking densities utilized (10-70 PLs per m^2, can range to >150 PLs per m^2) and yield per hectare – typical measures of production intensity. Regardless, higher stocking densities and increased feeding, characteristic of semi-intensive and intensive shrimp systems worldwide, may 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).

India manages and measures water quality throughout the country through collaboration between Central and State Boards for Prevention and Control of Water Pollution, as established through the Water (Prevention and Control of Pollution) Act, 1974[3]. More specifically, shrimp aquaculture effluents are largely governed by the Coastal Aquaculture Authority (CAA). While there is some information available regarding the water quality status of coastal watersheds, there appears to be a lack of robust analysis relating 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

<u>Factor 2.1a – Biological waste production</u>

[3] http://extwprlegs1.fao.org/docs/pdf/ind2085.pdf

The Risk-Based Assessment method estimates the amount of waste nitrogen produced per ton of shrimp farmed for *L. vannamei* and for *P. monodon*.

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 commonly used in semi-intensive shrimp farming of both species in India, with reported applications of inorganic fertilizers such as urea, triple superphosphate (TSP), and diammonium phosphate (DAP), as well as organic fertilizers, such as jaggery, rice bran, and groundnut oil cake (pers. comm. Aquaconnect, June 2020; pers. comm. Avanti Feeds Ltd., May 2020; Seafood Watch field research, September 2019). The quantity of applied fertilizer varies based on the fertilizer and production strategy of the farmer, though typical application rates range from 15-20 kg urea and 5-10 kg TSP per hectare, with reported average total rates of 40 kg per hectare (pers. comm. Aquaconnect, June 2020; pers. comm. Avanti Feeds Lt.d, May 2020; Seafood Watch field research, September 2019).

Seafood Watch expresses nitrogenous input from fertilizers as kg N per metric ton (mt) of shrimp production. Assuming a five-year average productivity of Indian *L. vannamei* farms of 6.9 mt/ha (MPEDA, 2021), average urea application of 17.5 kg/ha, and a nitrogen content of 46% in urea[4], it is calculated that the average nitrogenous input from applied fertilizers is 1.2 kg N per mt of *L. vannamei* production. Similarly, assuming a five-year average productivity of Indian *P. monodon* farms of 0.95 mt/ha (MPEDA, 2021), the same calculation yields an average nitrogenous input from applied fertilizers of 8.5 kg N per mt of *P. monodon* production. The significant difference in productivity is largely driven by the lower intensity of *P. monodon* production, as described in the introduction.

Manufactured feeds are additional nitrogenous inputs applied to support shrimp growth. The following feed data were provided by private feed manufacturers who represent 60% of the total feed market in India. These data were supported by personal communications with Aquaconnect, an aquaculture technology and support venture based in India, and farm societies representing over 40 farmers visited by Seafood Watch staff in September 2019. The

[4] https://extension.umn.edu/nitrogen/fertilizer-urea

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:

L. vannamei

a) Protein content of feed: 32 – 42% (Boyd et al., 2018; pers. comm. Avanti Feeds Ltd., May 2020; pers. comm. Devi Seafoods, June 2020; pers. comm. Aquaconnect, June 2020; Seafood Watch field research, September 2019)
b) Fertilizer application: 1.2 kg N per mt shrimp (see above)
c) Economic Feed Conversion Ratio (eFCR): 1.0 – 4.0 (Kumaran et al., 2020; Boyd et al., 2018; pers. comm. Avanti Feeds Ltd., September 2019; pers. comm. Devi Seafoods, September 2019, Seafood Watch field research, September 2019)
d) Protein content of harvested whole shrimp – 17.8% (Boyd et al., 2007)

P. monodon

a) Protein content of feed: 32 – 42% (Boyd et al., 2018; pers. comm. Avanti Feeds Ltd., May 2020; pers. comm. Devi Seafoods, June 2020; pers. comm. Aquaconnect, June 2020; Seafood Watch field research, September 2019)
b) Fertilizer application: 8.5 kg N per mt shrimp (see above)
c) Economic Feed Conversion Ratio (eFCR): 1.3 – 2.2 (Boyd et al., 2018; Rayv et al., 2017; Mohanty et al., 2017; Kumar et al., 2014; Sahu et al., 2013; pers. comm. Avanti Feeds Ltd., September 2019; pers. comm. Devi Seafoods, September 2019, Seafood Watch field research, September 2019)
d) Protein content of harvested whole shrimp – 18.9% (Boyd et al., 2007)

For the purposes of this assessment, a protein content of 35.5% and an eFCR value of 1.4 are considered representative of the Indian *L. vannamei* farming industry, while a protein content of 38.0% and an eFCR value of 1.5 are considered representative of the *P. monodon* – 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:

L. vannamei

N input per ton of shrimp produced = a x N content factor (0.16) x b x 10 =	80.72 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 =	52.24 kg N t^{-1}

P. monodon

N input per ton of shrimp produced = a x N content factor (0.16) x b x 10 =	99.70 kg N t^{-1}
N content of harvested shrimp = c x N content factor (0.16) x 10 =	30.24 N t^{-1}
Waste N produced per ton fish produced (2.1a) = N input – harvested N =	69.46 kg N t^{-1}

Therefore, the net excretion of nitrogen in soluble and particulate wastes is 52.24 kg N per ton of *L. vannamei* production.

The net excretion of nitrogen in soluble and particulate wastes is 69.46 kg N per ton of *P. monodon* production.

Factor 2.1b – Production system discharge

Water exchange may be employed on shrimp farms to improve pond water quality, which, as stated previously, may be reduced due to increased feeding and elevated stocking densities, given the additional nutrient inputs. Given the wide variability of shrimp farming intensity throughout India, so too do production system discharge rates (water exchanges) vary.

Recent literature indicates that a minority of *L. vannamei* farmers (33.7%, 30 out of 89 surveyed) across India exchanged water on a daily basis, while the remainder did not discharge except at harvest (Boyd et al., 2018). Amongst those *L. vannamei* farms that did conduct water exchange, daily rates were observed ranging from 0.1% to 40% of pond volume, averaging 9.8 ± 1.9% (Boyd et al., 2018). With respect to *P. monodon*, a majority of farms (81.8%, 9 out of 11 surveyed) exchanged water on a daily basis, with observed rates ranging from 4.0% to 45% of pond volume and averaging 13.0 ± 4.1% (Boyd et al., 2018).

These surveys were administered in 2017, and while the raw survey data could not be obtained to examine the distribution or ascertain any differences by state, the majority of surveyed *L. vannamei* farms were in Andhra Pradesh (73%, 65 out of 89 surveyed), while the majority of *P. monodon* farms were in West Bengal (72.7%, 8 out of 11 surveyed).

Interviewed expert stakeholders for this report indicated that at the time of writing, *L. vannamei* farmers across India, and more specifically Andhra Pradesh, do not exchange water during the culture period due to high cost of pumping water and potential for disease vectors (pers. comm. Aquaconnect, June 2020; pers. comm. Indian government agency, August 2020; Seafood Watch field research, September 2019); however, aligning with the literature, these experts indicate that water exchange is not unheard of, should pond conditions (such as salinity or temperature) require it. Additional conditions, such as soil porosity (and in turn, seepage rates) and climate, vary across India, and may drive farmers to exchange water during the culture period to maintain optimal conditions. Experts also confirmed that water exchange is more common with *P. monodon* culture, though estimated exchange to be lower than that indicated by Boyd et al. (2018) and again stressed that exchange rates are variable based on environmental and economic conditions (pers. comm. Aquaconnect, June 2020; pers. comm. Solidaridad, August 2020; Seafood Watch field research, September 2019).

Given the available information and accounting for the minority of the *L. vannamei* industry that does exchange water daily, a basic (unadjusted) production system discharge score of 0.42 (e.g., 42% of the waste produced by the shrimp is considered to be discharged from the pond), representing an average annual daily exchange of <3% of pond volume, is utilized. With respect to *P. monodon*, a basic (unadjusted) production system discharge score of 0.51, representing an average annual daily exchange of >3% of pond volume, is utilized.

As is advised by the Coastal Aquaculture Authority (CAA) Guidelines for Regulating Aquaculture (CAA, 2014) and the best management practices (BMPs) recommended by the Marine Products Exports Development Authority (MPEDA)[5], literature indicates that sludge is often removed from pond bottoms at the end of a cycle and either used to reinforce dykes/bunds or landfilled (Boyd et al., 2018; Sivaraman et al., 2018). As such, an adjustment for proper sludge disposal is warranted and applied to both *L. vannamei* (-0.2) and *P. monodon* (-0.24) farms.

Additionally, Indian shrimp producers are required by law to meet water quality standards for discharged water, and almost all *L. vannamei* farms (exception made for farms <5 ha and utilizing stocking densities <20 PLs/m^2) and relatively large *P. monodon* farms (>5 ha of water surface area) are required to implement effluent treatment systems (ETS), a pond or multiple ponds that are designed to settle suspended solids and reduce nutrient concentrations (CAA, 2014). The average shrimp farm size in India today is <2 ha and utilizes stocking densities >20 PLs/m^2 and the use of ETS is not common regardless of species cultured or stocking densities employed, despite the legal requirement (Kumaran et al., 2020; STIP, 2020; Anand et al., 2019; Valderrama et al., 2014; Seafood Watch field research, September 2019). For these farms, it is common to discharge directly into drainage canals that lead back to the waterbody where water is sourced. As such, no further adjustments to the production system discharge score are made.

Considering the adjustments detailed above (i.e., 0.42 – 0.20, meaning 0.22 or 22% of the waste produced by the shrimp is considered to be discharged from the pond), the estimated total waste discharged per ton of *L. vannamei* produced is 11.49 kg N t^{-1}. This results in a final score for Factor 2.1 – Waste discharged per ton of shrimp of 8 out of 10.

For *P. monodon*, considering the adjustments (0.51 – 0.24, meaning 0.27 or 27% of the waste produced by the shrimp is considered to be discharged from the pond), the estimated total waste discharged per ton of *P. monodon* produced is 18.75 kg N t^{-1}. This results in 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, state, and district level, with legislation primarily administered and enforced through the national Coastal Aquaculture Authority (CAA, or the 'Authority'). The CAA was established with the passing of the Coastal Aquaculture Authority Act (2005) in order to better regulate the rapidly expanding coastal shrimp aquaculture industry and ensure that "coastal aquaculture does not cause any detriment to the coastal environment and the concept of responsible aquaculture is followed"

[5] https://mpeda.gov.in/MPEDA/lv.php#

(CAA, 2014). The structure of the CAA consists of a Chairperson, Secretary, and representative Members from federal ministries, State fisheries departments, and institutes to provide expertise in various fields related to aquaculture; in the case of environmental protection and pollution control, CAA includes a member appointed from the Ministry of Environment and Forests. The CAA has a central main office in Chennai, Tamil Nadu, and is supported by state-level (SLC) and district-level committees (DLC) for all activities (CAA, 2014).

As outlined in the Coastal Aquaculture Authority Act (CAAA), the Authority has the power to develop and enforce regulations and guidelines for the construction, registration, and operation of farms, and the power to remove or demolish noncompliant operations (CAA, 2014). With respect to effluent specifically, the CAA has the power and function to "advise and extend support to the State/[Union Territory] Governments for constructing common infrastructure, common water in-take, discharge canals and common effluent treatment systems" (CAA, 2014). The scope of CAA jurisdiction is limited to the coastal area, defined as 2 km inland from the high tide line of seas, rivers, creeks, and backwaters with a clarifying note stating, "the delineating boundaries along rivers, creeks and backwaters shall be governed by the distance up to which the tidal effects are experienced and where salinity concentration is not less than 5 parts per thousand (ppt)" (CAA, 2014). It is thus assumed that any shrimp farm outside of the scope of CAA would be considered freshwater and subject to Fisheries Department freshwater aquaculture rules in their respective states. It is estimated that roughly 70% of India's shrimp farms fall under the jurisdiction of CAA, while the remaining production falls under the jurisdiction of their respective State fisheries departments (pers. comm. Indian government agency, September 2019). While the primary activity of the CAA was historically registration of shrimp farms with inspection carried out by SLCs and DLCs, since the introduction of *L. vannamei* in 2009, activities have expanded to include continuous monitoring and collection/analysis of farm effluents to ensure compliance with water quality standards, amongst other activities (CAA, 2014).

Indeed, the primary piece of legislation that governs shrimp farming effluents in India is the CAAA, acting as a broad legislative framework, while the functional details are set out in the Guidelines for Regulation Coastal Aquaculture published alongside the CAAA (Puthucherril, 2016; CAA, 2014). The primary mechanisms by which the Guidelines manage effluent are through requirements for farms to implement effluent treatment systems/ponds (ETS/ETP), and effluent discharge standards which specify the maximum levels of water quality parameters permitted in shrimp farm wastewater.

Several conditions are specified with respect to ETS/ETP requirements; notably, when written in 2005, the CAAA required the use of an ETS/ETP for farms larger than 5 ha, with a minimum coverage of 10% of the total farm area (CAA, 2014). At this time, *P. monodon* was the only cultured shrimp species and thus, when *L. vannamei* culture was approved in 2009, the Ministry of Agriculture amended the CAA (G.S.R. 740 (E)) to require that all *L. vannamei* farms, irrespective of their size, must utilize an ETS/ETP whether it is for that farm specifically or a cluster of small farms (CAA, 2014); however, the original requirements for *P. monodon* remained in place. The amendment also required that in the event of a disease outbreak, the

ETS/ETP must be designed for residence times of 48 hours in order to enable the chlorination (for disinfection) and dichlorination of water prior to release (detailed further in Criterion 7 – Disease). Further modifications have since been made, and the "Application for Registration of Coastal Aquaculture Farm"[6] states in a section titled "Note for Exotic Shrimps [*L. vannamei*] Farming" that an ETS/ETP "is not mandatory for farms of less than 5 ha WSA using stocking density below 20nos. PL/m^2". However, as noted in Factor 2.1 and further described in Factor 2.2b, these requirements are largely not met by most operating farms.

Effluent discharges from shrimp ponds are also subject to the effluent quality standard for aquaculture farms, hatcheries, feed mills, and processing units prescribed by the CAA (Table 1). Water quality parameter thresholds are specified, though it is unclear how the parameter thresholds were determined, and whether there was any ecological consideration in their development. A new tool developed by the Central Institute for Brackishwater Aquaculture (CIBA) called "CarryCap" allows the estimation of "maximum nutrient loading which can be assimilated by the waterbody based on its dilution rate and flushing time without exceeding the permissible levels of water bodies", though to date, it appears to only have been used in case studies for developing aquaculture zones in Andhra Pradesh[7] and not in the development of existing effluent quality standards.

Table 1. Standards for treatment of wastewater discharged from the aquaculture farms, hatcheries, feed mills and processing units. (CAA, 2014).

[6] http://caa.gov.in/uploaded/doc/form-Inew.pdf
[7] https://www.was.org/Meeting/Program/PaperDetail/153903

S No	Parameters	Final Discharge Point	
		Coastal Marine Waters	Creek or estuarine courses when the same inland water courses are used as water source & disposal point
1	pH	6.0 – 8.5	6.0 – 8.5
2	Suspended solids mg/1	100	100
3	Dissolved oxygen mg/1	Not less than 3	Not less than 3
4	Free Ammonia (as NH3-N) mg/1	1.0	0.5
5	Biochemical Oxygen Demand-BOD (5 days @ 20 c) Max mg/1	50	20
6	Chemical Oxygen Demand-COD mg/1 Max	100	75
7	Dissolved Phosphate (as P) mg/1 Max	0.4	0.2
8	Total Nitrogen (as N) mg/1	2.0	2.0

The CAA Guidelines also require an environmental impact assessment (EIA) for all farms >40 ha in size and require an environmental impact statement (EIS) for all farms >10 ha in size, though it was not clear what the difference between the two are (CAA, 2014). Farms >40 ha must also incorporate an Environment Monitoring Plan and Environment Management Plan (EMMP), which requires assessment of the farm's impact on surrounding waterbodies, groundwater sources, and drinking water sources amongst others (CAA, 2014). It is unclear what the threshold of "acceptable" impacts are. A list of registered farms, by district, is available on the CAA website[8]. A perusal of this database indicates that, at the time of access (December 2020, last updated in September 2020), the CAA has registered 40,088 farms across India, with 12,721 farm registrations listed as "Active" and 27,376 farm registrations listed as "Not Renewed". The water spread area (WSA) of "Active" farms totals 11,458.6 ha, at an average of 0.9 ha per farm, with only 33 farms (0.26% of "Active" farms) have a WSA of >10 ha, and one farm with a WSA >40 ha. It is apparent that the vast majority of farms are not required to conduct an EIA or an EIS.

As noted earlier, roughly 30% of the shrimp farming industry is estimated to fall outside of CAA jurisdiction and is thus managed by the respective State Departments of Fisheries (pers. comm.

[8] http://www.caa.gov.in/farms.html

Indian government agency, September 2019). The state of Andhra Pradesh published "Regulation of Fresh Water Aquaculture in the State" on March 16th, 2013, which states:

> *The farm shall ensure that the effluent quality at discharge point conforms to the specific standards prescribed by the Andhra Pradesh Pollution Control Board. The discharge of affluent shall meet the Surface Irrigation Standards as there is every possibility of using the same waste water let out into the drain for irrigation purpose in the downstream. 7.20 All laws to protect the environment and ecology such as the Andhra Pradesh Water, Land and Trees Act, 2002, The Water (Prevention & Control of Pollution) Act, the Environment (Protection) Act, 1986, Wetlands Conservation Rules, etc. shall be followed.*

Unfortunately, the specific discharge standards referenced could not be found, and no further information with respect to the governance of shrimp farm effluent discharges by various State Department of Fisheries could be found.

Water quality in India is also governed more broadly by the Central and State Pollution Control Boards (CPCB for Central), as established through the Water (Prevention and Control of Pollution) Act, 1974[9]. Amongst numerous other activities, the CPCB has established standards for water quality criteria of different sources[10], as well as standards for the emission or discharge of environmental pollutants from various industries[11], including coastal water marine outfalls[12]. The water quality parameter thresholds in each Standard vary based on the receiving water body's "designated best use", as determined by the Environment (Protection) Rules, 1986[13].

Though the relationship between these various governing bodies is not clear, it is apparent that effluents from shrimp farms are regulated under an area-based, cumulative management system in conjunction with other industries in India; receiving waterbodies are managed to meet specific water quality standards based on their "designated best use", and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). However, the established effluent discharge standards for aquaculture are universal and do not vary by area or receiving waterbody. While EIAs are not required for the vast majority of operating farms, all farms are required to meet prescribed effluent water quality standards and most farms are required to employ effluent treatment systems (almost all *L. vannamei* farms and *P. monodon* farms >5 ha). 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 or in their application. Therefore, the effluent

[9] http://extwprlegs1.fao.org/docs/pdf/ind2085.pdf
[10] https://cpcb.nic.in/wqstandards/
[11] https://cpcb.nic.in/effluent-emission/
[12] https://cpcb.nic.in/displaypdf.php?id=SW5kdXN0cnktU3BlY2lmaWMtU3RhbmRhcmRzL0VmZmx1ZW50LzQ4NC0xLnBkZg==
[13] http://www.fao.org/faolex/results/details/en/c/LEX-FAOC008236/#:~:text=Environment%20(Protection)%20Rules%2C%201986,factors%20specified%20in%20Rule%205.

management system in India 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 Coastal Aquaculture Authority (CAA) is the primary authority in enforcing regulations regarding shrimp farm operation in India. The CAA has a central main office in Chennai, Tamil Nadu, and is supported by state-level (SLC) and district-level committees (DLC) for all activities (CAA, 2014).

The Central and State Pollution Control Boards (CPCB and SPCB), in conjunction with CAA, are tasked with enforcing the aforementioned water quality standards. The most recent CPCB Annual Report[14] (2018-2019) describes the National Water Quality Monitoring Programme (NWMP) which passively and actively monitors 3,500 stations across 29 states and 6 union territories, including rivers, lakes, creeks, and seawater. Surface water is monitored monthly, whereas most groundwater is monitored twice a year. While the reports do not broadly summarize the results of monitoring, they identify areas where the implementation of pollution control measures and other interventions to improve water quality are needed. Most shrimp aquaculture occurs in Andhra Pradesh, and a review of the most recent Andhra Pradesh Pollution Control Board (APPCB) Annual Report[15] (2015-2016) indicates that water quality varies amongst most categories (e.g., some lakes are fully compliant, some lakes are not) with elevated total dissolved solids (TDS) and biological oxygen demand (BOD), and reduced dissolved oxygen (DO), as primary concerns in non-compliant areas.

More specific to shrimp aquaculture, the CAA is tasked with enforcing the requirements set forth in the CAA Guidelines as described in Factor 2.2a. As outlined in the Guidelines and Rules, representatives of the CAA are authorized to enter farms and:

- take samples of water, soil and the farmed animal for the purpose of detection of banned antibiotics, chemicals and other pharmacologically active compounds and to adopt appropriate procedures for collection, analysis, reporting and follow up action;
- subject to the provision of rule 7, remove or demolish any coastal aquaculture farm which is causing pollution and which was not removed or demolished after an order to that effect, passed under clause (d) of sub-section (1) of section 11 of the Act.
- drain the water from the coastal aquaculture farm or destroy the crop which is causing pollution in respect of which an appropriate order passed under clause (e) of sub-section (1) of section 11 of the Act has not been complied with.

[14] https://cpcb.nic.in/annual-report.php
[15] https://pcb.ap.gov.in/APPCBDOCS/Tenders_Noti/Pdf's//Annual%20Report%202015-16.pdf

Further, the CAA is authorized to suspend or cancel the registration of any farm that has either furnished false information in order to receive registration or has "contravened any of the provisions of these rules or of the conditions mentioned."

However, it is clear that enforcement of the requirements is lacking. A review of CAA registrations indicates that <20% of all farms estimated in India have been registered by the CAA, a significant sustainability concern detailed further in Criterion 3 – Habitat. Literature and personal communications with industry stakeholder experts indicate that the use of effluent treatment systems (ETS), required by almost all *L. vannamei* farms (exception made for farms <5 ha and utilizing stocking densities <20 PLs/m^2) and *P. monodon* farms >5 ha in size, are rarely in use (Joint Committee Report, 2020; pers. comm. Aquaconnect, June 2020; pers. comm. Devi Seafoods, June 2020; Seafood Watch field research, September 2019).

In response to allegations of illegal farming activity in East Godavari, a primary shrimp farming district in Andhra Pradesh, a joint committee comprised of representatives from the Ministry of Environment, Forest, and Climate Change, Indian Administrative Service, Central Pollution Control Board, and Andhra Pradesh Pollution Control Board was empaneled in 2020 and confirmed that hundreds of farms in the district were operating without ETS (Joint Committee, 2020). The committee concluded that ETS are mandatory for these farms and "submits that CAA, Fisheries department, APPCB, Revenue and District Collector in the state of AP shall permit the operation of these cluster of farms only if common effluent treatment systems are constructed and are put in operation." The committee also concluded that "farms that are not registered with CAA or Fisheries department or which have not renewed the registration are considered as illegal."

Literature has also noted that enforcement bodies in India, namely, State Fisheries Departments and the CAA, are poorly staffed with limited capacity (Sivaraman et al., 2018). During Seafood Watch field research visiting farms of varying sizes in September 2019, it was apparent that many of the small farms (<2 ha) were not measuring water quality in their effluent discharges, as it had been tested previously numerous times and found to be compliant and additional testing imposed onerous cost (Seafood Watch field research, September 2019). It is unclear how frequently, if at all, CAA representatives visit farms and conduct water quality testing to ensure compliance.

Overall, enforcement of effluent regulations specific to the shrimp industry is limited. Noncompliance with the requirement to utilize effluent treatment systems is widespread, with no evidence of corrective action. The vast majority of farms operating today are not registered by CAA and are thus technically operating illegally, as defined by a joint committee investigating allegations of illegal farming comprised of representatives from the Ministry of Environment, Forest, and Climate Change, Indian Administrative Service, Central Pollution Control Board, and Andhra Pradesh Pollution Control Board. Despite this, as mentioned, there appears to be an effective framework and governance system for managing pollution in India via the Central and State Pollution Control Boards. As such, the overall enforcement of effluent regulations is considered minimal and a final score of 1 out of 5 is given for Factor 2.2b – Enforcement of effluent management measures.

The final score for Factor 2.2 is a combination of Factor 2.2a (3 out of 5) and Factor 2.2b (1 out of 5) and results in a final score of 1.2 out of 10 for both species.

Conclusions and Final Score

Shrimp farm effluent discharges in India 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 "designated best use", and standards for discharge quality are defined for each contributing industry (inclusive of aquaculture). While EIAs are not required for the vast majority of operating farms, all farms are required to meet prescribed effluent water quality standards and most farms are required to employ effluent treatment systems (almost all *L. vannamei* farms and *P. monodon* farms >5 ha). 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. Enforcement of these regulations is considered severely limited, however. Noncompliance with the requirement to utilize effluent treatment systems is widespread, with no evidence of corrective action. The vast majority of farms operating today are not registered by CAA and are thus technically operating illegally. Despite this, as mentioned, there appears to be an effective framework and governance system for managing pollution in India via the Central and State Pollution Control Boards.

The scores for Factors 2.1 (8 out of 10 for both species) and 2.2 (1.2 out of 10 for both species) are combined using the Risk-Based Assessment matrix, resulting in a final score of 5 out of 10 for Criterion 2 – Effluent for both species.

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

Litopenaeus vannamei and *Penaeus monodon* – Semi-intensive ponds

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0-10)		1
F3.2a Content of habitat regulations (0-5)	3	
F3.2b Enforcement of habitat regulations (0-5)	0	
F3.2 Regulatory or management effectiveness score (0-10)		0.000
C3 Habitat Final Score (0-10)		**0.667**
Critical?	No	Red

Brief Summary

While the majority of habitat conversion for shrimp culture took place prior to 1999, evidence indicates that pristine high-value habitat, such as mudflats and creeks, have been converted to shrimp ponds since then. Legislation requires shrimp farm siting in India to be restricted to specific areas with limitations prescribed by the Coastal Aquaculture Authority Act. These requirements include ecological considerations and are integrated with other industries; however, environmental impact assessments are not required by the vast majority of farms. All farms are required to register with the CAA and obtain a license prior to operation, yet only about 19% of currently operating farms are registered as "Active" with limited to no evidence of corrective action or penalties. Outright illegal operations are known to occur, and though there is some recent evidence of enforcement demolishing these farms, it is clear that illegal siting activities persist. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (1 out of 10) and Factor 3.2 – Farm siting regulation and management (0 out of 10), and the final score is 0.667 out of 10 for both species.

Justification of Rating

Factor 3.1 – Habitat conversion and function

Shrimp aquaculture in India predominantly takes place in the coastal zones of the country, largely in the southeastern and eastern states of Andhra Pradesh, West Bengal, Tamil Nadu, and Odisha (collectively 93% of total shrimp production by tonnage and 90% by area under culture; MPEDA, 2021). Additional culture occurs in the western states of Gujarat, Maharashtra, Karnataka, Kerala, and Goa (MPEDA, 2021).

While the coastal zones of India are quite diverse and differ in their ecology significantly between the east and west coasts, shrimp farms are located in ecosystems characterized by mangroves, estuaries, river deltas, and backwaters found on both coasts due to abundant water supply and suitable climatic conditions for farming shrimp. The multiple ecosystem services that mangroves and associated wetlands and mudflats 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 they provide fuel, medicine, and construction materials to local communities (Dissanayake et al., 2018; Giri et al., 2011). As such, shrimp farms are considered to be located in areas of high value habitat.

Historic and extensive mangrove loss occurred in India since the beginning of the 1900s. An FAO analysis in 2000 noted that these losses were initially due to collection of wood for fuel and timber, land conversion, grazing, and natural damage from cyclones (Hein, 2000). However, shrimp farming expanded rapidly in India during the 1990s, adding almost 100,000 ha of shrimp farms by going from roughly 65,000 ha under culture to 161,570 ha over the course of the decade (Hein, 2000). This analysis noted that only 5% of total shrimp farms were sited in former mangrove land, while an additional 14% were sited in intertidal wetlands; the remaining 81% of farms were sited in rice farms or “other”, which included fallowed land. The study additionally observed that “the rate of conversion of mangroves into shrimp ponds increased in the period 1997 to 1999, suggesting that shrimp pond construction started in fallow and crop lands but then encroached on mangroves in the absence of suitable fallow land.” (Hein, 2000).

Today, there are at least 166,722 ha under shrimp culture collectively (inclusive of *L. vannamei* and *P. monodon*), suggesting that there has been limited conversion of additional undisturbed habitat for shrimp ponds. Official species- and state-specific production data are available on the MPEDA website and are shown in Figure 3 and Figure 4.

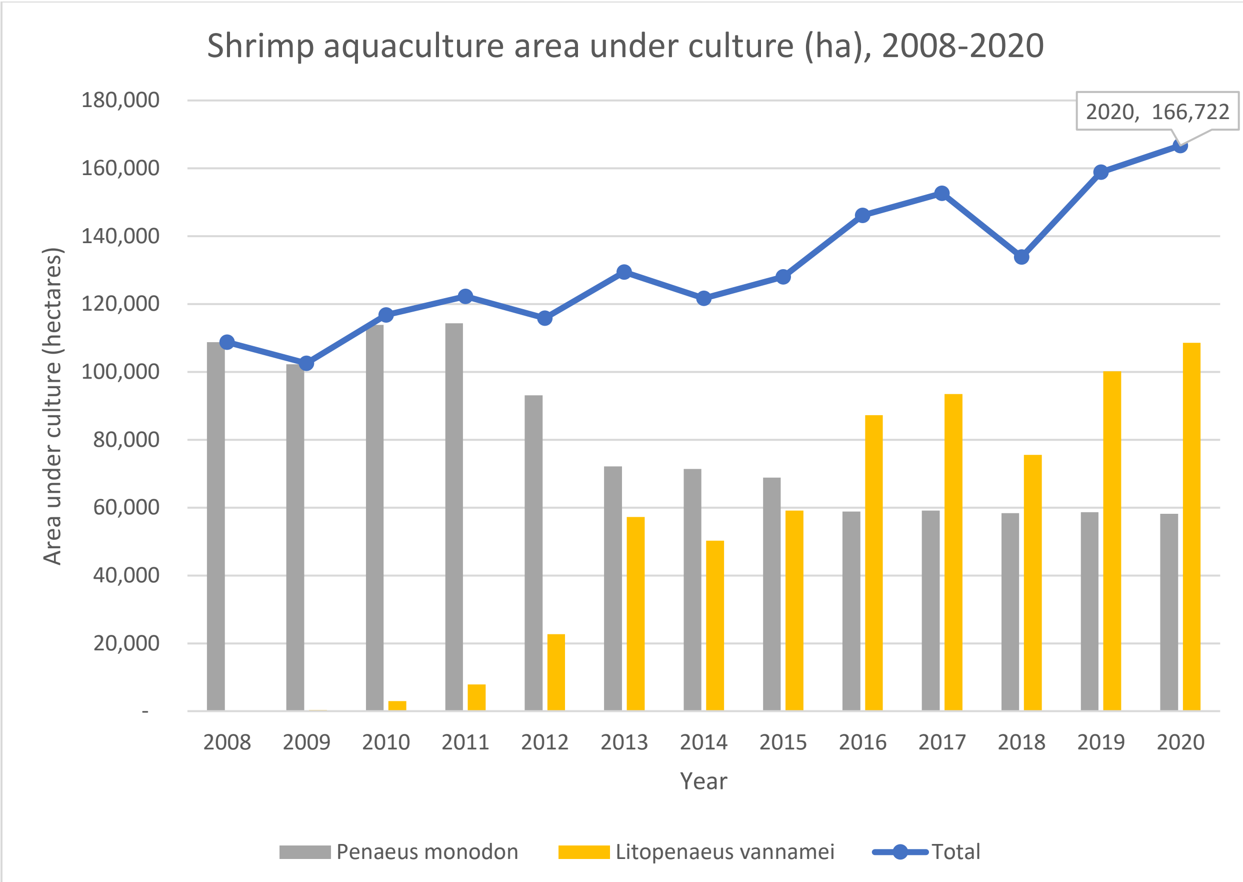


Figure 3. Shrimp aquaculture area under culture (hectares) by species, 2008-2020. MPEDA, 2021.

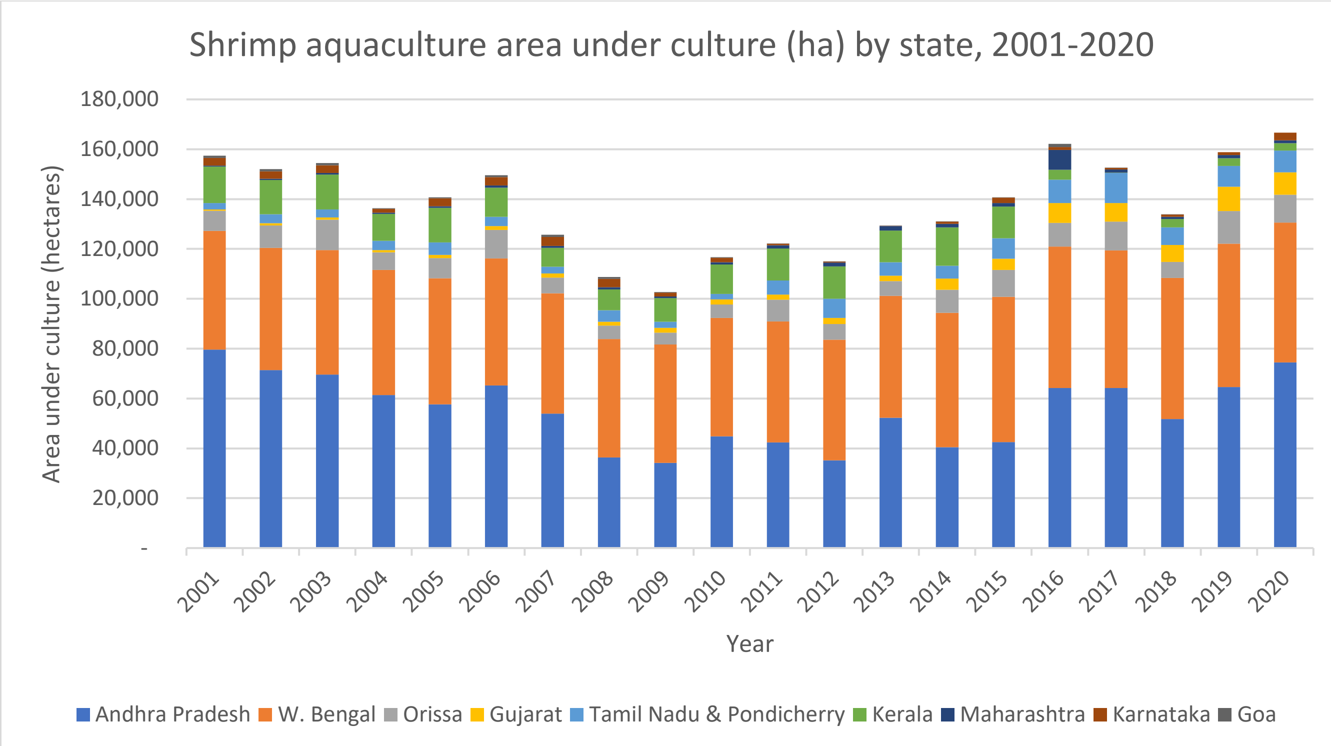


Figure 4. Shrimp aquaculture area under culture (hectares) by state, 2001-2020. MPEDA, 2021.

A number of recent studies have utilized series of satellite imagery to estimate land-use conversion through time. One recent study demonstrated that the majority of brackishwater ponds currently operating in the Krishna District of Andhra Pradesh, dominated by *L. vannamei* culture and the primary producing state in the country, were converted from agricultural fields (6,988 ha; 30.6% of surveyed ponds) followed by revived abandoned shrimp ponds (3,676 ha; 16.1% of surveyed ponds) over the period from 2000 to 2015 (Jayanthi et al., 2019). Over the same time period, 97 ha of mangrove forest and 1,265 ha of mudflats were converted to shrimp ponds, 0.4% and 5.5% of current ponds respectively (Jayanthi et al., 2019). The total area of shrimp ponds in the study area was 22,861 ha in 2015, down from 39,049 ha in 2000, a reduction of 16,188 ha or 41.5%; though there was considerable flux between uses (e.g., agriculture to brackishwater pond back to agriculture), these ponds were largely left as abandoned (11,968 ha) (Jayanthi et al., 2019). It is possible that these ponds have been revived today, as shrimp aquaculture area in Andhra Pradesh has nearly doubled (+30,000 ha) since 2009 (MPEDA, 2021).

However, similar satellite analysis by the same authors showed the majority of shrimp ponds across India, at the time of analysis in 2013, were converted from mud flats (51.7%), followed by agriculture (28.1%) and aquaculture ponds (9.3%) when compared to land-use imagery from 1988 (Jayanthi et al., 2018). Mud flats are considered high-value habitat given their significant provision of ecosystem services and integrated nature in coastal wetland ecology, and ponds sited in or near mud flats in India have been shown to have negative impacts on remaining neighboring pristine habitat, particularly with respect to birds (Dissanayake et al., 2018;

Sandilyan et al., 2010). The data show wide variability in land-use conversion between states; for example, “mud flat to aquaculture” represented 27.4% of conversion in West Bengal, whereas it represented 84.1% of conversion in Gujarat (Jayanthi et al., 2018). While it is not clear when this conversion took place (e.g., pre-1999 or post-1999), it appears likely that conversion of habitat occurred post-1999 when viewing production area statistics provided by MPEDA. Active area under culture has grown dramatically in several major production states throughout India since 2000, such as Gujarat (2001: 540 ha; 2019: 9,709 ha; 1,798% increase) and Tamil Nadu (2001: 2,480 ha; 2019: 8,393 ha; 338% increase), with contemporary literature noting pond construction in pristine habitat in Tamil Nadu after 1999 as well (MPEDA, 2021; Sandilyan et al., 2010).

More recent information specific to West Bengal, where the vast majority of *P. monodon* culture takes place, was found. Roy et al. (2021) analyzed satellite imagery over the period of 1988-2018 in a study area within the Purba Medinipur district where, according to CAA[16], 1,115 registered farms are currently located (60% of 1,860 registered farms in West Bengal) and cover roughly 524 ha of water surface area. The study area itself is 45,232 ha and while the study does not cover the entirety of West Bengal, in the absence of other information, the results of the analysis in addition to previously mentioned literature are thus considered representative of West Bengal for the purposes of this assessment.

Since 1998, roughly 1,770 ha of new shrimp ponds were constructed (532.36 ha from 1998-2008; 1238.08 ha from 2008-2018), an expansion of 34.5% by area. Previous literature surveying ponds within the Purba Medinipur district indicated that 100% of surveyed ponds had been created between 2004 and 2012, bolstering the notion that conversion of habitat has occurred since 1999 in West Bengal (Sahu et al., 2013). The majority of new ponds were converted from cropland (1,068 ha, or 60% of converted land), followed by 260 ha of “bare earth and sandy beach” (15% of converted land), 251 ha of “other vegetation” (14% of converted land), and 186 ha of “rivers and coastal water” (11% of converted land) (Roy et al., 2021). Notably, zero hectares of mangroves were converted to ponds over this time period and mangrove area grew from 1.47 ha to 205 ha, a nearly 14,000% increase in area.

Taking a look at the broader context initially suggests that the overall study area was largely degraded by the end of the 1980s, with roughly 45% of the area already under cropland (20,453 ha) by 1988. However, the study notes that while agriculture was the dominant land-use and the primary source of livelihood in this region “since time immemorial”, it is described as traditional subsistence farming as opposed to commercialized production. Assessing the impacts of the industry expansion inland along creeks from 1998 through 2018, the authors found significant alterations to perennial creek flows occurred and, in some areas, farm development completely replaced creek networks with shrimp ponds (Roy et al., 2021). The study further notes that salinization of topsoil appears to be occurring due to the storage of brackish water in ponds, with a number of salt-tolerant floral and faunal species colonizing around farms in inland (>2.5 km from the high tide line) areas (Roy et al., 2021).

[16] http://www.caa.gov.in/farms.html

In addition, there are numerous allegations of ongoing illegal pond construction and operation as noted by literature and recent news reports[17],[18],[19],[20] (Salunke et al. 2020; Jayanthi et al. 2018); these allegedly illegal ponds appear largely constructed in mangrove areas and unnamed officials have estimated the total area to be 100,000 ha in Andhra Pradesh alone[15]. As noted in Criterion 2 – Effluent, a joint committee determined that ongoing illegal farm siting activity was occurring in East Godavari district, Andhra Pradesh, stating that many farms were not registered while also noting that many farms, regardless of registration status, are constructed in violation of mandatory siting requirements within the CAA Act (such as proximity to high tide line, human habitation and/or drinking water sources, lack of proper farm design, etc.; further details in Factor 3.2) (Joint Committee, 2020). Citing the requirement for farms under CAA jurisdiction to register with CAA and the publishing of registered, active farms on the CAA website, the committee found "As per the list, it was observed that very few coastal farms have registered and renewed their registration and are indicated as Active ponds in the list." The committee concluded that "farms that are not registered with CAA or Fisheries department or which have not renewed the registration are considered as illegal."

Overall, the extent of shrimp aquaculture area has fluctuated over time due to various factors, resulting in both the abandonment and revival of ponds. The available evidence, however, indicates that new ponds have been constructed from various land-uses since 1999, both low-value or modified habitat (e.g., agriculture and/or abandoned ponds), and high-value habitat such as mud flats and other coastal wetlands. Furthermore, there is evidence of ongoing illegal conversion of high-value habitat. Given the wide variability of habitat conversion timelines across India yet the high potential impact risk, a precautionary score of 1 out of 10 is given for Factor 3.1 – Habitat conversion and function, representing a loss of functionality in high-value habitat that has occurred since 1999. This score applies to both *L. vannamei* and *P. monodon*, given the evidence in both Andhra Pradesh and West Bengal.

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.

As with Criterion 2 – Effluent, the siting and construction of shrimp farms is regulated at the national, state, and district level, with legislation primarily administered and enforced through the national Coastal Aquaculture Authority (CAA, or the 'Authority'). As outlined in the Coastal

[17] https://www.downtoearth.org.in/news/agriculture/under-salty-waters-58968
[18] https://www.newindianexpress.com/states/odisha/2015/may/18/Twin-Threats-to-Bhitarkanika-Park-Illegal-Tree-Felling-Prawn-Farming-761970.html
[19] https://www.newindianexpress.com/states/odisha/2020/sep/30/illegal-shrimp-farms-demolished-in-odishas-kendrapara-2203860.html
[20] https://timesofindia.indiatimes.com/city/surat/survey-ordered-to-identify-illegal-shrimp-farms-in-olpad/articleshow/78210008.cms

Aquaculture Authority Act (CAAA), the Authority has the power to develop and enforce regulations and guidelines for the construction, registration, and operation of farms, and the power the remove or demolish noncompliant operations (CAA, 2014).

The scope of CAA jurisdiction is limited to the coastal area, defined as 2 km inland from the high tide line of seas, rivers, creeks, and backwaters with a clarifying note stating, “the delineating boundaries along rivers, creeks and backwaters shall be governed by the distance up to which the tidal effects are experienced and where salinity concentration is not less than 5 parts per thousand (ppt)” (CAA, 2014). It is thus assumed that any shrimp farm outside of the scope of CAA would be considered freshwater and subject to freshwater aquaculture rules. It is estimated that roughly 70% of India’s shrimp farms fall under the jurisdiction of CAA, while the remaining production falls under the jurisdiction of their respective State fisheries departments (pers. comm. Indian government agency, September 2019).

Registration of all shrimp farms under the jurisdiction of CAA, regardless of species cultivated and size of operation, is required under the CAAA. Farmers must complete the “Application for Registration of Coastal Aquaculture Farm”, which requires the farmer to list such details as the address and ownership rights of the land, total farm area, water spread area, any additional land categories found on the land (e.g., agricultural land, wetlands, mangroves, salt pans), distance of the aquaculture unit from such categories, and the water source for the aquaculture units. A representative of CAA must inspect all applying *L. vannamei* farms prior to approval, whereas this is only required for *P. monodon* farms >2 ha in size. Registration is submitted to a District Level Committee (DLC), which is tasked with examining the application, inspecting the site (following the same caveats noted for each species previously), and passing the application through to the State Level Committee (SLC), tasked with reviewing the application and passing it through to the CAA. The DLC is comprised of representatives from several State departments, notably Revenue, Agriculture, Environment, Zilaparishad (effectively a District Council), and Fisheries Departments; the SLC is comprised of representatives from Secretaries of Fisheries, Revenue, and Environment Departments, alongside a representative from MPEDA and the Director of Fisheries for that particular State.

The CAA Guidelines for Regulating Coastal Aquaculture are mandatory to implement in order to receive registration (despite numerous “should” statements) and require an environmental impact assessment (EIA) for all farms >40 ha in size as well as require an environmental impact statement (EIS) for all farms >10 ha in size (CAA, 2014). Farms >40 ha must also incorporate an Environment Monitoring Plan and Environment Management Plan (EMMP), which requires assessment of the farm’s impact on surrounding waterbodies, groundwater and drinking water sources, as well as agriculture activities and nearby soil amongst others (CAA, 2014). These are required to be included with the farm’s registration application.

The CAAA also describes where shrimp farms are explicitly disallowed, stating:

- No coastal aquaculture may be carried out within two hundred meters from High Tide Lines; and

- No coastal aquaculture shall be carried on in creeks, rivers and backwaters within the Coastal Regulation Zone declared for the time being under the Environment (Protection) Act, 1986

Siting restrictions are further detailed in the Guidelines (not all listed below):

- Mangroves, agricultural lands, saltpan lands, ecologically sensitive areas like sanctuaries, marine parks, etc., should not be used for shrimp farming.
- Shrimp farms should be located at least 100 m away from any human settlement in a village / hamlet of less than 500 population and beyond 300 m from any village / hamlet of over 500 population. For major towns and heritage areas it should be around 2 km.
- All shrimp farms should maintain 100 m distance from the nearest drinking water sources.
- The shrimp farms should not be located across natural drainage canals / flood drain.
- While using common property resources like creeks, canals, sea, etc., care should be taken that the farming activity does not interfere with any other traditional activity such as fishing, etc.
- A minimum distance of 50-100 m shall be maintained between the nearest agricultural land (depending on the soil condition), canal or any other water discharge / drainage source and the shrimp farm.
- Water spread area of a farm shall not exceed 60 per cent of the total area of the land. The rest 40 per cent could be used appropriately for other purposes. Plantation could be done wherever possible.
- Areas where already a large number of shrimp farms are located should be avoided. Fresh farms in such areas can be permitted only after studying the carrying / assimilation capacity of the receiving water body.

In practice, however, very few operating farms are at or above the size that would require an EIS or EIA. A list of registered farms, by district, is available on the CAA website[21]. A perusal of this database indicates that, at the time of access (August 2021, last updated in June 2021), the CAA has registered 41,140 farms across India, with 13,773 farm registrations listed as "Active" and 27,376 farm registrations listed as "Not Renewed". The water spread area (WSA) of "Active" farms totals 12,346.6 ha, at an average of 0.9 ha per farm, with only 33 farms (0.24% of "Active" farms) having a WSA of >10 ha, and one farm with a WSA >40 ha. As noted previously, a joint committee comprised of Ministers empaneled to investigate allegations of illegal farming activity has declared "farms that are not registered with CAA or Fisheries department or which have not renewed the registration are considered as illegal." (Joint Committee, 2020).

As noted earlier, roughly 30% of the shrimp farming industry is estimated to fall outside of CAA jurisdiction and is thus managed by the respective State Departments of Fisheries (pers. comm. Indian government agency, September 2019). The state of Andhra Pradesh published "Regulation of Fresh Water Aquaculture in the State" on March 16th, 2013, which includes some siting requirements (not all listed below):

> 7.1 The applicant shall have a clear title of land in his name or shall be a lease holder of the land for a minimum period of five years.

[21] http://www.caa.gov.in/farms.html

> 7.2 Fertile agriculture lands shall not be permitted for conversion into fresh water aquaculture ponds except in cases where agriculture lands are less productive, fallow, low lying, prone to water logging, etc.
>
> 7.3 Salt pan lands, mangroves, wet lands, forest lands, casuarina plantations, grazing grounds for cattle, lands meant for village common purposes, lands meant for public purposes, ecologically sensitive areas like national parks, sanctuaries, marine parks, etc. shall not be used or converted for fresh water aquaculture.

Additional restrictions are listed, such as distances required between farms and other land uses, discharge requirements, and water use requirements. It is important to remember that these requirements are applicable to freshwater aquaculture farms that fall outside of the scope of the CAA, the jurisdiction of which is limited to the coastal area. The coastal area is defined as 2 km inland from the high tide line of seas, rivers, creeks, and backwaters with a clarifying note stating, “the delineating boundaries along rivers, creeks and backwaters shall be governed by the distance up to which the tidal effects are experienced and where salinity concentration is not less than 5 parts per thousand (ppt)” (CAA, 2014). It is thus assumed that any shrimp farm outside of the scope of CAA would be considered freshwater and subject to freshwater aquaculture rules.

Unfortunately, no further information with respect to the governance of shrimp farm siting and construction by various State Department of Fisheries could be found.

In addition to CAA and State Fisheries Departments, MPEDA operates an enrollment program[22] for farms producing shrimp for export; this process involves confirming the name and address of the owner of the farm, reviewing the “farm land document OR lease agreement for the farm land in the name of the farmer” and a photograph of the farmer. An MPEDA officer will visit the farm to verify these documents and geolocate the farm, and return an enrollment card to the farmer which, in turn, can furnish to processors, alongside a pre-harvest test (PHT) certificate confirming no antibiotic residues, in order to export their product. It is clear that having an active registration with CAA is not a requirement of MPEDA enrollment, as nearly 70,000 farms have been enrolled by MPEDA, roughly six times the number actively registered by CAA.

Overall, the management system governing shrimp farm siting is area-based in scope, where shrimp farms present and future may only be sited in locations according to requirements prescribed by the CAAA. These requirements consider the impact of shrimp farm development in the context of broad ecosystem functionality protection and are integrated with other industries. However, environmental impact assessments are not required by the vast majority of farms, and there are no requirements of the shrimp industry to implement habitat restoration programs (e.g., mangrove reforestation). The final score for Factor 3.2a – Content of habitat management measures is 3 out of 5.

<u>Factor 3.2b – Enforcement of habitat management measures</u>

[22] https://mpeda.gov.in/?page_id=989

As with effluents, the Coastal Aquaculture Authority (CAA) is the primary authority in enforcing regulations regarding shrimp farm construction operation in India. The CAA has a central main office in Chennai, Tamil Nadu, and is supported by state-level (SLC) and district-level committees (DLC) for all activities (CAA, 2014).

All shrimp farms under the jurisdiction of CAA are required to register with CAA in order to legally operate in India. A list of registered farms, by district, is available on the CAA website[23]. A perusal of this database indicates that, at the time of access (August 2021, last updated in June 2021), the CAA has registered 41,140 farms across India, with 13,773 farm registrations listed as "Active" and 27,376 farm registrations listed as "Not Renewed". The water spread area (WSA) of "Active" farms totals 12,346.6 ha, at an average of 0.9 ha per farm, with only 501 farms (3.6% of "Active" farms) having a WSA of >2 ha.

It is not readily apparent whether some areas have not been updated or simply have no registered farms, but large areas known for shrimp culture such as West Godavari district in Andhra Pradesh have zero listed "Active" farms.

There are major discrepancies with these data as compared to other sources of information, such as MPEDAs annual production volume and production area statistics. For example, MPEDA statistics indicated that in 2020, there were 166,722 ha of WSA under culture across India, roughly 14 times the total WSA of "Active" CAA registered farms (MPEDA, 2021). In addition, MPEDA statistics indicated that there are 72,275 shrimp farmers currently operating in India, which means that only 19.1% of these farmers are currently registered as "Active" with CAA (MPEDA, 2021). Further, official total shrimp production in 2020 was 843,633 mt from an area under culture (AUC) of 166,722 ha, for an average productivity of 5.1 mt/ha. If this productivity parameter is applied to the total WSA of "Active" CAA registered farms, estimated production volume would reach roughly 62,968 mt, less than 10% of reported export production.

It is clear that the vast majority of Indian shrimp farms are operating without CAA registration, yet are able to not only continue operating, but also able to export their products. This notion has been echoed by the literature, where estimated production did not match with both farm capacity and hatchery PL production (Salunke et al., 2020; Jayanthi et al., 2018).

The penalty for farming without registration is steep; the CAAA states that the Authority may imprison the violating farmer for up to three years or levy a fine of up to 100,000 Rupees (~$1,350 USD), or both. There is no evidence available to assess whether or not fines or imprisonment have occurred but it appears that operation without registration is commonplace, and these penalties are rarely, if ever, applied. Personal communications with anonymous expert stakeholders have indicated that the lack of registrations is not necessarily due to widespread illegal activity, but rather bureaucracy; many farmers have allegedly submitted the necessary registration application to the District Level Committees, where they remain in limbo awaiting transfer to the State Level Committee and final approval by the CAA.

[23] http://www.caa.gov.in/farms.html

Indeed, literature has also noted that enforcement bodies in India, namely State Fisheries Departments and the CAA, are poorly staffed with limited capacity, lending credence to this notion (Sivaraman et al., 2018). In addition, there are also allegations of outright illegal culture occurring throughout India as noted in Factor 3.1; some of the news reports[24],[25] indicate enforcement activity, where illegal farms were destroyed by District Fisheries and District Forest officers. While this is evidence of the enforcement system working as intended, it is also evidence that illegal shrimp culture does indeed occur.

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. According to data published by the CAA and MPEDA, only about 19% of all shrimp farms in India are currently registered, a mandatory requirement, yet there is limited to no evidence of corrective action or penalties. Outright illegal operations are known to occur, and though there is some recent evidence of enforcement demolishing these farms, it is clear that illegal siting activities persist. The final score for Factor 3.2b – Enforcement of habitat management measures is 0 out of 5.

The final score for Factor 3.2 is a combination of Factor 3.2a (3 out of 5) and Factor 3.2b (0 out of 5), and results in a score of 0 out of 10.

Conclusion and Final Score

While the majority of habitat conversion for shrimp culture took place prior to 1999, evidence indicates that pristine high-value habitat, such as mudflats and creeks, have been converted to shrimp ponds since then. Legislation requires shrimp farm siting in India to be restricted to specific areas with limitations prescribed by the Coastal Aquaculture Authority Act. These requirements include ecological considerations and are integrated with other industries; however, environmental impact assessments are not required by the vast majority of farms. All farms are required to register with the CAA and obtain a license prior to operation, yet only about 19% of currently operating farms are registered as “Active” with limited to no evidence of corrective action or penalties. Outright illegal operations are known to occur, and though there is some recent evidence of enforcement demolishing these farms, it is clear that illegal siting activities persist. The score for Criterion 3 – Habitat is a combination of the scores for Factor 3.1 – Habitat conversion and function (1 out of 10) and Factor 3.2 – Farm siting regulation and management (0 out of 10), and the final score is 0.667 out of 10.

[24] https://www.newindianexpress.com/states/odisha/2015/may/18/Twin-Threats-to-Bhitarkanika-Park-Illegal-Tree-Felling-Prawn-Farming-761970.html

[25] https://www.newindianexpress.com/states/odisha/2020/sep/30/illegal-shrimp-farms-demolished-in-odishas-kendrapara-2203860.html

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

Litopenaeus vannamei and *Penaeus monodon* – Semi-intensive ponds

C4 Chemical Use parameters		Score
C4 Chemical Use Score (0-10)		0.00
Critical?	No	Red

Brief Summary

Overall, chemical use in Indian shrimp aquaculture is common. Most chemicals used for pond preparation and disinfection used in Indian 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. Recent surveys indicate on-farm usage of illegal antibiotics, such as nitrofurans and chloramphenicol, does continue to occur on farms in India and is supported by literature published throughout the past decade. Indian shrimp consignments are regularly rejected in export markets like the United States for antibiotic residues, particularly nitrofurans and chloramphenicol, and while the primary source of contamination is not clear (e.g., PLs, feed inputs, probiotics, disinfectants, etc.), it appears likely that intentional and unintentional on-farm usage is occurring. The Indian government has implemented several programs with the intention of stemming illegal use and the export of contaminated products, but it is clear that this challenge has yet to be solved.

With limited controls over antibiotic sales and distribution alongside demonstrated illegal use of these drugs beyond exceptional cases, the final score for Criterion 4 – Chemicals is 0 out of 10 for both *L. vannamei* and *P. monodon*.

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 India 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 or improper 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 India is 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 in Indian shrimp farms has been evident in the literature since at least the early 2000s, with farm surveys noting the indiscriminate use of oxytetracycline, chloramphenicol, and other antibiotics alongside other antimicrobials (such as malachite green and nitrofurans) (Surendran, 2003; Pathak et al., 2000). The improper application of these drugs resulted in frequent residue detection and rejection of shipments to the US and EU; in turn, the Government of India, Ministry of Agriculture banned the use of 20 antibiotics/antimicrobials in 2002, which remain illegal to this day and are listed in Table 2 (Surendran, 2003; pers. comm. Indian government agency, August 2020). Notably, tetracyclines, oxolinic acid, and trimethoprim remain approved for use, all of which are considered highly important for human medicine by the World Health Organization[26] (CAA, 2014; pers. comm. Indian government agency, August 2020). Beyond this ban, there appear to be very few controls over the sale and distribution of antibiotics in Indian shrimp farming.

Table 2. Banned antibiotics and other pharmacologically active substances for shrimp aquaculture. (CAA, 2014).

[26] https://www.who.int/foodsafety/publications/antimicrobials-sixth/en/

Sl. No.	Antibiotics and other Pharmacologically Active Substances
1	Chloramphenicol
2	Nitrofurans including : Furaltadone, Furazolidone, Furylfuramide, Nifuratel, Nifuroxime, Nifurprazine, Nitrofurantoin, Nitrofurazone
3	Neomycin
4	Nalidixic acid
5	Sulphamethoxazole
6	Aristolochia spp and preparations thereof
7	Chloroform
8	Chlorpromazine
9	Colchicine
10	Dapsone
11	Dimetridazole
12	Metronidazole
13	Ronidazole
14	Ipronidazole
15	Other nitroimidazoles
16	Clenbuterol
17	Diethylstilbestrol (DES)
18	Sulfonamide drugs (except approved Sulfadimethoxine, Sulfabromomethazine and Sulfaethoxypyridazine)
19	Fluroquinolones
20	Glycopeptides

Despite most being outlawed, antibiotic use in shrimp aquaculture appears to have continued to present day; literature published as recently as 2020 (surveying *L. vannamei* farms throughout Andhra Pradesh in 2018 and 2019) indicated roughly 25% of farmers used antibiotics, either for prophylaxis (84.6%) or as therapeutic treatments (15.4%) (Parvez and Vijaya, 2020). As was the case in the earlier days of the industry, the drugs reported were oxytetracycline, chloramphenicol, and nitrofurans (Parvez and Vijaya, 2020). Anecdotal information suggests that antibiotic use has declined to a small fraction of the industry, yet there are no official data or other publicly available information to quantify this (pers. comm. Indian government agency, 2019; pers. comm. Aquaconnect, 2020; Seafood Watch field research, September 2019). Although there is a lack of data regarding usage rates, studies continue to demonstrate the presence of residues in harvested *L. vannamei* and *P. monodon*, alongside regular import rejections due to contamination with veterinary drugs (MPEDA, 2018; Rao and Prasad, 2014; Venkatesh et al., 2013; Swampna et al., 2012; Palaniyappan et al., 2013).

Indeed, between 2014 and 2021 (to date, August 2021), there have been 226 rejections of Indian aquacultured shrimp by the USFDA with 12 occurring in 2020 and seven in 2021 as of the time of writing (August 2021) (Table 3). Indian shrimp was rejected more than the next five major suppliers of shrimp to the United States combined for the same refusal charges over the same time period (e.g., Indonesia (8), Ecuador (0), Viet Nam (135), Thailand (10), and China (62)).

Table 3. US FDA import refusals of Indian shrimp, 2014-2020 (through July 2021).

	Refusal Charge				Total Rejections
	Chloramphenicol	Nitrofurans	Veterinary Drugs	Combination	
2014	-	5	4	10	19
2015	-	14	9	10	33
2016	-	4	69	22	95
2017	-	-	11	1	12
2018	1	5	8	1	15
2019	-	24	9	-	33
2020	1	2	3	6	12
2021*	0	4	0	3	7
Total	**2**	**58**	**113**	**53**	**226**

This has not gone unnoticed by Indian authorities, who have implemented various programs to identify where in the value chain contamination with antibiotics are occurring. The National Residue Control Plan (NRCP) has been implemented by MPEDA to monitor for the presence of residues in aquaculture products, and MPEDA field offices conduct monitoring at each stage of the production chain – hatcheries, feed mills, farms, and processing plants – so as to identify and rectify problems prior to export (pers. comm. Indian government agency, August 2020). Thousands of samples are taken each year, and roughly 2-4% of samples have tested positive for residues each year according to the MPEDA Annual Reports[27] 2016-2018, down from 8-10% in 2011-2015. Similarly, MPEDA developed a program of pre-harvest testing (PHT) to ensure antibiotic-free product prior to export; this is carried out in 11 labs established throughout the country and certificates are given to the farms to certify their status. Additionally, the CAA registers "antibiotic-free aquaculture inputs" such as feed additives, probiotics, chemicals, disinfectants, immune stimulants, and drugs through a testing and registration process which can be viewed on the website[28]; farmers are encouraged to only use registered antibiotic-free inputs so as to avoid potential contamination. However, despite these programs, it is clear that products containing antibiotic residue continue to be produced and exported. More basically, these programs do not guarantee that antibiotics are not actually used on farms – in reality, their existence is only necessary due to the continued use of antibiotics at some point in the supply chain.

Antibiotic resistance is also widespread in India, in shrimp farms and beyond[29]. Samples taken from *L. vannamei* and *P. monodon* hatcheries and farms, as well as source and receiving waters, have indicated multiple-drug resistance among *Vibrio* spp., *Salmonella* spp., and others (Thornber et al. 2020; Patel et al. 2020; Silvester et al. 2019; Silvester et al. 2017; Ramasamy et al. 2018; Sanathkumar et al. 2014). To date, however, evidence is lacking to conclusively say that the use of antibiotics on Indian shrimp farms has driven the development of this resistance. Antibiotic usage in India is widespread throughout the poultry and livestock sectors

[27] https://www.mpeda.gov.in/MPEDA/annual_reports.php#
[28] http://www.caa.gov.in/Antibiotic.html
[29] https://www.cdc.gov/ncezid/stories-features/global-stories/ar-india.html

in India, as well as hospitals, from which runoff is considered a primary contributor to the contamination of water supplies shared by shrimp farmers (Girijan et al. 2020; Sarkar et al. 2019; Sivagami et al. 2018). 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 (Girijan et al., 2020; Sarkar et al., 2019; Sivagami et al., 2018). As such, it cannot be ascertained as to whether antibiotic use that may occur on shrimp farms is contributing to selective pressure driving the development of antibiotic resistance.

Pond preparation, disinfectants, and piscicides

Other chemicals are used in the Indian shrimp farming industry, often for 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). India has banned particularly hazardous chemicals, such as malachite green, crystal violet, and nitrofurans (CAA, 2014); however, as described previously, it is clear that nitrofuran use is continuing to occur.

Common pond preparation/sediment amendments used in India 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., 2018; pers. comm. Aquaconnect, June 2020); 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 India, 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., 2018). In India, 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., 2018; Seafood Watch field research, September 2019); 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 (also known as bleaching powder), 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, it is recommended that shrimp farmers use this to sterilize water in the event of a disease outbreak after an emergency harvest, and subsequently drain the pond[30]. There is thus some environmental risk associated with the use of disinfectants, though this risk is not considered significant given low water exchange rates.

Conclusions and Final Score

Overall, chemical use in Indian shrimp aquaculture is common. Most chemicals used for pond preparation and disinfection used in Indian shrimp farming pose a low risk to the environment,

[30] https://mpeda.gov.in/MPEDA/lv.php#

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. Recent surveys indicate on-farm usage of illegal antibiotics, such as nitrofurans and chloramphenicol, does continue to occur on farms and is supported by literature published throughout the past decade. Indian shrimp consignments are regularly rejected in export markets like the United States for antibiotic residues, particularly nitrofurans and chloramphenicol, and while the primary source of contamination is not clear (e.g., PLs, feed inputs, probiotics, disinfectants, etc.), it appears likely that intentional and unintentional on-farm usage is occurring. The Indian government has implemented several programs with the intention of stemming illegal use and the export of contaminated products, but it is clear that this challenge has yet to be solved.

With limited controls over antibiotic sales and distribution alongside demonstrated illegal use of these drugs beyond exceptional cases, the final score for Criterion 4 – Chemicals is 0 out of 10 for both *L. vannamei* and *P. monodon*.

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

Litopenaeus vannamei – Semi-intensive ponds

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	0.534	
F5.1b Source fishery sustainability score (0-10)		**1**
F5.1: Wild fish use score (0-10)		**2**
F5.2a Protein INPUT (kg/100kg fish harvested)	49.700	
F5.2b Protein OUT (kg/100kg fish harvested)	17.800	
F5.2: Net Protein Gain or Loss (%)	-64.185	**3.00**
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	14.714	**6.00**
C5 Feed Final Score (0-10)		**3.21**
Critical?	**No**	Red

Criterion 5 Summary

Penaeus monodon – Semi-intensive ponds

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	0.912	
F5.1b Source fishery sustainability score (0-10)		**1**
F5.1: Wild fish use score (0-10)		**1**
F5.2a Protein INPUT (kg/100kg fish harvested)	57.000	
F5.2b Protein OUT (kg/100kg fish harvested)	18.900	
F5.2: Net Protein Gain or Loss (%)	-66.842	**3.00**
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	14.444	**6.00**
C5 Feed Final Score (0-10)		**2.77**
Critical?	**No**	Red

Brief Summary

Shrimp feeds for both species in India use fishmeal and fish oil made from whole wild fish and fishery by-product sources, though differ in their inclusion levels. For *L. vannamei*, the fishmeal inclusion level is moderate (15%) and nearly half of it (45%) is sourced from fishery by-products. The fish oil inclusion level is low at 1.1% and 42% of it comes from by-product sources. With an eFCR of 1.4, the Forage Fish Efficiency Ratio (FFER) is thus low (0.53), meaning that from first principles, 0.53 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed *L. vannamei*. For *P. monodon*, the fishmeal inclusion level is higher (17%) with 26% of it sourced from fishery by-products. The fish oil inclusion level is also higher at 2.00%, with 12.5% of it sourced from by-products. With an eFCR of 1.5, the FFER for *P. monodon* is moderate (0.912).

Data supplied by feed manufacturers indicated the source fisheries used for both whole fish and by-product ingredients and indicate that they are the same for *L. vannamei* and *P. monodon*. In the case of whole fish, the source fisheries indicated by the manufacturers are Indian oil sardine, "silverbelly" and "other pelagic lean fish" caught with trawls and purse seines. With respect to by-products, the source fisheries are "pelagic fish trimmings" and "mackerel/perches/ribbon fish". There is limited information available to assess the sustainability of Indian oil sardine, and with no data on capture method or other specific identifying information, the other inclusions are considered sourced from unknown fisheries.

Overall, despite the moderately low levels of inclusion of these wild fish ingredients in Indian shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10 for *L. vannamei* and 1 out of 10 for *P. monodon*). They each have a moderate-high net protein loss (-64.10% for *L. vannamei* and -66.84% for *P. monodon*; both score of 3 out of 10) and a moderate-low feed footprint (14.71 kg CO_2-eq. per kg of harvested protein for *L. vannamei* and 14.44 kg CO_2-eq. for *P. monodon*; both score of 6 out of 10). The three factors combine to result in a final score of 3.21 out of 10 for Criterion 5 – Feed for *L. vannamei* and 2.78 for *P. monodon*.

Justification of Ranking

In India, 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 India was not able to be fully 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 India with somewhat limited data shared due to the proprietary nature of these formulations. This information is aggregated and 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 India.

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 (inclusive of land-use change) 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.

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

The Feed Fish Efficiency Ratio (FFER) for aquaculture systems is driven by the feed conversion ratio (FCR), the amount of aquatic (typically marine) animals 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 data from the mid-2000s demonstrating India's alignment with the global average of 1.7 (inclusive of *L. vannamei* and *P. monodon*) at the time (Tacon and Metian, 2008). These figures are consistent with shrimp production today, with a global average of 1.6 and reports of Indian shrimp production ranging from 1.0 – 4.0, depending on the species and intensity (Boyd et al., 2018; CIBA, 2019; Kumar et al., 2014; Kumaran et al., 2020; Sahu et al., 2013; Tacon, 2018). The most representative data available come from recent literature, as well as personal communications with farmers, buyers, and feed suppliers (pers. comm. Avanti Feeds Ltd., September 2019; pers. comm. Devi Seafoods, September 2019; Seafood Watch field research, September 2019); indeed, an eFCR of 1.4 is considered representative of the Indian semi-intensive *L. vannamei* industry and an eFCR of 1.5 is considered representative of the semi-intensive *P. monodon* industry. Both values are used in the following species-specific calculations.

As noted previously, feed formulations may vary from batch to batch depending on the price and availability of ingredients, and this is compounded by variation between manufacturers and even regions. Feed manufacturers representing roughly 60% of the total Indian shrimp feed market supplied ingredient composition information for their *L. vannamei* and *P. monodon* feeds for this assessment; these data indicate an average fishmeal (FM) inclusion of 15% and fish oil (FO) inclusion of 1.1% for *L. vannamei*, and an average FM inclusion of 17% and FO inclusion of 2% for *P. monodon* (Table 4). While there is limited literature available to compare these numbers to, they align with control diet compositions found in several Indian studies investigating various ingredient replacements (Janathulla et al., 2018; 2018b; 2018c), as well as typical shrimp feeds in other countries. As such, these average figures are considered representative of the industry and are used in the following calculations.

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

Parameter	Data	
	L. vannamei	***P. monodon***
Fishmeal inclusion level (total)	**15.0%**	**17.0%**
Fishmeal inclusion level (whole fish)	8.25%	13.50%
Fishmeal inclusion level (by-product)	6.75%	3.50%
Fishmeal yield	22.5%	22.5%
Fish oil inclusion level (total)	**1.09%**	**2.00%**
Fish oil inclusion level (whole fish)	0.63%	1.75%
Fish oil inclusion level (by-product)	0.46%	0.25%
Fish oil yield	5.00%	5.00%
Economic Feed Conversion Ratio (eFCR)	1.4	1.5
Calculated values		
Fishmeal feed fish efficiency ratio (FFERfm)	0.534	0.912
Fish oil feed fish efficiency ratio (FFERfo)	0.183	0.529
Assessed FFER	**0.534**	**0.912**

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 both Indian farmed *L. vannamei* and *P. monodon*; based on first principles, 0.534 tons of wild fish are required to provide sufficient fishmeal to produce one ton of farmed *L. vannamei* and 0.912 tons of wild fish are required to produce one ton of farmed *P. monodon*.

<u>Factor 5.1b – Source fishery sustainability</u>
As shown in Factor 5.1a, the majority of fishmeal and fish oil in both *L. vannamei* and *P. monodon* feeds are sourced from whole fish, with relatively minor fractions from by-products, particularly for fish oil. The feed manufacturers also supplied information with respect to the source fisheries used for both whole fish and by-product ingredients and indicate that they are the same for *L. vannamei* and *P. monodon*.

In the case of whole fish, the source fisheries indicated by the manufacturers are Indian oil sardine, "silverbelly" and "other pelagic lean fish". Only about 17% of the source whole fish volume are indicated as being IFFO/MarinTrust certified (Indian oil sardine caught with trawls and purse seines in FAO Fishing Area 51), though this could not be confirmed, as no certificates were provided by the feed manufacturers. The remaining 83% of source fisheries (Indian oil sardine, silverbelly, other pelagic lean fish) have no accompanying information beyond country of origin (India) and gear type (purse seines).

With respect to by-products, the source fisheries indicated by the manufacturers are "pelagic fish trimmings" and "mackerel/perches/ribbon fish". Only about 17% of the source by-product volume are indicated as being IFFO/MarinTrust certified (caught with trawls and purse seines in FAO Fishing Area 51), though again this could not be confirmed without certificates. The remaining 83% of by-product volume is sourced from "mackerel/perches/ribbon fish" have no accompanying information beyond country of origin (India).

The IFFO/MarinTrust certification for Indian oil sardines caught in FAO Fishing Area 51 is listed as an "approved by-product" in Thailand[31], and the most recent report (a 2019 reassessment[32]) notes that this raw material is imported into Thailand from Yemen and Oman registered vessels. It is likely that this material was reimported to India and processed into feed at an Indian feed mill, though there are no IFFO/MarinTrust approved sites or chain-of-custody (CoC) approved sites in India listed on the webpage. It is unclear why Indian oil sardine is considered by-product as opposed to whole fish by IFFO/MarinTrust. Regardless, the most recent report notes several sustainability concerns associated with the fishery, referencing existing FishSource profiles:

- "There is no evidence of any species-specific management measures for Indian oil sardine in FAO 51"
- "No catch limits or TACs are advised for oil sardine in India"

Indian oil sardines, like other species of forage fish, experience significant natural fluctuations in population and catches are highly variable given spatiotemporal variation (Hamza et al., 2020). Indeed, documented catch volumes of the Indian oil sardine from 1961 to 2017 range from 1,500 mt in 1994 to over 400,000 mt in 2012 (Hamza et al., 2020). Given this variability, the management of forage fish resources is particularly challenging but necessary in ensuring the sustainable harvest of these species, especially as climate change advances (Hamza et al., 2020).

FishSource has initial profiles of Indian oil sardines caught with trawls, gillnets, and or purse seines in six Indian states (Andhra Pradesh, Goa, Karnataka, Kerala, Maharashtra, and Tamil Nadu). In every state, the Management Strategy is scored <6 and Managers Compliance is scored ≥6, while the categories of Fishers Compliance, Current Stock Health and Future Stock Health are all data deficient. While the analysis notes management strengths, such as seasonal closures, fishing area and gear restrictions, and regular rapid stock assessments conducted by each state by the Central Marine Fisheries Research Institute of India (CMFRI), there are a number of management weaknesses. Notably, the analysis states that the rapid stock

[31] https://www.marin-trust.com/marintrust-approved-products
[32] https://www.marin-trust.com/sites/marintrust/files/approved-raw-materials/Indian%20oil%20sardine%20S.longiceps%2051%2057%20BP%20Initial%20v%202.0%202019_%20Final.pdf

assessments are not conducted at the entire stock level (the stock distribution in India is not well understood) and due to limited information provided by the CMFRI, the quality of these stock assessments cannot be evaluated. The analysis further states in addition to the concerns cited by IFFO/MarinTrust, while there is no recent information indicating that illegal, unreported, and unregulated (IUU) fishing is occurring in the Indian oil sardine fishery, "IUU fishing was flagged as a major issue in the past including a range of illicit activities: fishing without permission or out of season; using outlawed types of fishing gear; non-reporting or underreporting of catch." FishSource lastly notes that "there is very little information on the environmental impact of the oil sardine fishery in India in terms of bycatch and ecosystem effects". It is important to note that IFFO/MarinTrust began working with some stakeholders to develop a fishery improvement program ("FIP") for the Indian oil sardine fishery in Goa and Maharashtra states and produced a draft action plan in early 2019[33], which outlined considerable gaps between the current performance of the fishery and the FIPs goals – notable gaps are related to stock assessments, harvest strategies, and ecosystem impacts. The original website for this FIP (http://indiasardinefip.co.in/) was no longer active as of July 2021, and no information regarding the status of the FIP beyond January 2020[34] could be found publicly. Broadly, it is clear that information regarding the sustainability of Indian oil sardine fisheries is limited yet sustainability concerns are high, given the apparent lack of management. While a portion of the source fisheries are said to be IFFO/MarinTrust certified, this could not be confirmed. Therefore, fishmeal and fish oil sourced from Indian oil sardine warrants a Factor 5.1b score of 2 out of 10 for unknown sustainability and more than one FishSource score <6. The remaining source fisheries for both whole fish and by-product fishmeal ingredients could not be ascertained by the data provided, and therefore warrant a Factor 5.1b score of 0 out of 10 for unknown source fishery. Therefore, the final score for Factor 5.1b – Source fishery sustainability is 1 out of 10, an intermediate score reflecting the balance between unknown sustainability of Indian oil sardine and unknown fisheries supplying the remainder of fishmeal and fish oil raw material. This score is applied to both *L. vannamei* and *P. monodon* feeds.

When this score is combined with an FFER of 0.534 for *L. vannamei* (Factor 5.1a), according to the Wild Fish Use table in the Seafood Watch Aquaculture Standard, the final Factor 5.1 score is 1.92 out of 10.

When this score is combined with an FFER of 0.912 for *P. monodon* (Factor 5.1a), according to the Wild Fish Use table in the Seafood Watch Aquaculture Standard, the final Factor 5.1 score is 1.05 out of 10.

Factor 5.2 – Net protein gain or loss

In India, feeds contain protein levels ranging from 32-42%, depending on the brand, species, function, and intended life stage of the shrimp being fed (Boyd et al., 2018; pers. comm. Avanti

[33] https://www.marin-trust.com/sites/marintrust/files/2021-04/IOS%20DRAFT%20FIP%20Action%20PlanJuly2019%20-%20no%20budget%20info.pdf

[34] https://www.marin-trust.com/sites/marintrust/files/2021-04/Attahcment%201-%20Marin%20Trust%20yearly%20report.pdf

Feeds Ltd., May 2020; pers. comm. Devi Seafoods, June 2020; pers. comm. Aquaconnect, June 2020; Seafood Watch field research, September 2019). In general, feeds intended for the growout stage of shrimp production in India are around 35-38% (Boyd et al., 2018), and data provided by Indian feed manufacturers align with this, with an average value of 35.5% indicated for *L. vannamei* and 38.0% indicated for *P. monodon*. These values are thus considered representative of the respective industries and used in the following calculations.

Considering an eFCR of 1.4 for *L. vannamei* and 1.5 for *P. monodon* (see Factor 5.1a for details), alongside a whole-shrimp protein content of 17.8% (*L. vannamei*) and 18.9% (*P. monodon*) (Boyd et al., 2007), the net protein loss is -64.19% and -66.84% respectively (Table 5). This results in a score of 3 out of 10 for Factor 5.2 – Net protein gain or loss for both species.

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

Parameter	Data	
	L. vannamei	***P. monodon***
Protein content of feed	35.5%	38.0%
Economic Feed Conversion Ratio	1.4	1.5
Total protein INPUT per ton of farmed shrimp	497.0 kg	570.0 kg
Protein content of whole harvested shrimp	17.8%	18.9%
Total protein OUTPUT per ton of farmed shrimp	178.0 kg	189.0 kg
Net protein loss	-64.19%	-66.84%
Seafood Watch Score (0-10)	**3**	**3**

Factor 5.3 – Feed Footprint

Factor 5.3 – Feed Footprint approximates 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[35] 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; this approach is intended 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 India with somewhat limited data shared due to the proprietary nature of these formulations. This information is aggregated and 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 India.

[35] http://globalfeedlca.org/gfli-database/gfli-database-tool/

Typical ingredients in Indian shrimp feeds include fishmeal and fish oil (see Factor 5.1), alongside soybean meal, wheat flour and wheat products, corn products, rice products, and other crop ingredients, like sesame cake (Jannathulla et al., 2018; 2018b; 2018c). The degree to which inclusions of these ingredients vary depends 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 reported by the aforementioned feed companies to be Indian in origin (particularly fishmeal, fish oil, and soybean and wheat products), while the origins of other crop ingredients are not known – thus, it is not possible to make an approximation of origin for each ingredient given the available data.

Fishmeal and fish oil from whole fish originates from multiple species caught by the Indian trawl and purse seine fleets, while fishmeal from by-products is sourced from a number of different fisheries as discussed in Factor 5.1. Fishmeal and fish oil from whole fish of Indian 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.

Soybean meal and wheat products (flour, gluten, bran) are known to be of Indian origin, given the data provided by feed manufacturers. The closest approximations that could be found in the GFLI database are "Soybean, at farm" and "Wheat grain, dried, at farm", both of Indian origin, and the economic allocation value for global warming potential including land-use change (GWP incl. LUC) for these line items is used.

For all remaining crop-based ingredients (such as corn and rice products), country of origin could not be ascertained from the available data, and inclusion rates are approximated from the literature. 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.

Table 6. Estimated embedded global warming potential of one mt of a typical Indian *L. vannamei* feed.

Feed ingredients (≥2% inclusion)	GWP (incl. LUC) Value	Ingredient inclusion%	kg CO_2 eq / mt feed
Fishmeal from whole fish (India, 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	8.25	76.85
Fishmeal from by-products (India, 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	6.75	62.88
Fish oil from whole fish (India, mixed species)	Fish oil, from fish meal and oil production, at plant/PE Economic S	0.63	4.11

	Fish oil, from fish meal and oil production, at plant/GLO Economic S		
Fish oil from by-products (India, 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	0.46	3.00
Soybean meal (India)	Soybean, at farm/IN Economic S	30.00	814.32
Wheat products (India)	Wheat grain, dried, at farm/IN Economic S	24.00	185.33
Total vegetable meals (unknown location)	Total vegetable meals, at plant/RER Economic S	27.90	723.66
Vitamins and minerals (unknown location)	Total minerals, additives, vitamins, at plant/RER Economic S	2.00	0.47
	Sum of total	99.99%	**1,870.63**

Table 7. Estimated embedded global warming potential of one mt of a typical Indian *P. monodon* feed.

Feed ingredients (≥2% inclusion)	GWP (incl. LUC) Value	Ingredient inclusion%	kg CO_2 eq / mt feed
Fishmeal from whole fish (India, 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	13.50	125.76
Fishmeal from by-products (India, 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	3.50	32.60
Fish oil from whole fish (India, mixed 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	1.75	11.42
Fish oil from by-products (India, 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	0.25	1.62
Soybean meal (India)	Soybean, at farm/IN Economic S	30.00	814.32
Wheat products (India)	Wheat grain, dried, at farm/IN Economic S	24.00	185.33
Total vegetable meals (unknown location)	Total vegetable meals, at plant/RER Economic S	25.00	648.44
Vitamins and minerals	Total minerals, additives, vitamins, at plant/RER Economic S	2.00	0.47
	Sum of total	100.00%	**1,819.98**

As can be seen in Table 6, the estimated embedded GWP of one mt of a typical Indian *L. vannamei* feed is 1,870.63 kg CO_2-eq. Considering a whole harvest shrimp protein content of

17.8% and an eFCR of 1.4, it is estimated that the feed-related GWP of one kg farmed *L. vannamei* protein is 14.71 kg CO_2-eq. This results in a score of 6 out of 10 for Factor 5.3 – Feed Footprint.

As can be seen in Table 7, the estimated embedded GWP of one mt of a typical Indian *P. monodon* feed is 1,819.98 kg CO_2-eq. Considering a whole harvest shrimp protein content of 18.9% and an eFCR of 1.5, it is estimated that the feed-related GWP of one kg farmed *L. vannamei* protein is 14.44 kg CO_2-eq. This results in a score of 6 out of 10 for Factor 5.3 – Feed Footprint.

Conclusions and Final Score

Shrimp feeds for both species in India use fishmeal and fish oil made from whole wild fish and fishery by-product sources, though differ in their inclusion levels. For *L. vannamei*, the fishmeal inclusion level is moderate (15%) and nearly half of it (45%) is sourced from fishery by-products. The fish oil inclusion level is low at 1.1% and 42% of it comes from by-product sources. With an eFCR of 1.4, the Forage Fish Efficiency Ratio (FFER) is thus low (0.53), meaning that from first principles, 0.53 mt of wild fish are needed to produce the fishmeal required to produce one mt of farmed *L. vannamei*. For *P. monodon*, the fishmeal inclusion level is higher (17%) with 26% of it sourced from the fishery by-products. The fish oil inclusion level is also higher at 1.75%, with 12.5% of it sourced from by-products. With an eFCR of 1.5, the FFER for *P. monodon* is moderate (0.912).

Data supplied by feed manufacturers indicated the source fisheries used for both whole fish and by-product ingredients and indicate that they are the same for *L. vannamei* and *P. monodon*. In the case of whole fish, the source fisheries indicated by the manufacturers are Indian oil sardine, "silverbelly" and "other pelagic lean fish" caught with trawls and purse seines. With respect to by-products, the source fisheries are "pelagic fish trimmings" and "mackerel/perches/ribbon fish". There is limited information available to assess the sustainability of Indian oil sardine, and the other inclusions are considered sourced from unknown fisheries.

Overall, despite the moderately low levels of inclusion of these wild fish ingredients in Indian shrimp feeds, the poor sustainability of raw material drives the wild fish use score (2 out of 10 for *L. vannamei* and 1 out of 10 for *P. monodon*). They each have a moderate-high net protein loss (-64.10% for *L. vannamei* and -66.84% for *P. monodon*; both score of 3 out of 10) and a moderate-low feed footprint (14.71 kg CO_2-eq. per kg of harvested protein for *L. vannamei* and 14.44 kg CO_2-eq. for *P. monodon*; both score of 6 out of 10). The three factors combine to result in a final score of 3.21 out of 10 for Criterion 5 – Feed for *L. vannamei* and 2.78 out of 10 for *P. monodon*.

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

Litopenaeus vannamei – Semi-intensive ponds

C6 Escape parameters		Value	Score
F6.1 System escape risk (0-10)		1	
F6.1 Recapture adjustment (0-10)		0	
F6.1 Final escape risk score (0-10)			1
F6.2 Invasiveness score (0-10)			6
C6 Escape Final Score (0-10)			**3**
	Critical?	No	Red

Penaeus monodon – Semi-intensive ponds

C6 Escape parameters		Value	Score
F6.1 System escape risk (0-10)		1	
F6.1 Recapture adjustment (0-10)		0	
F6.1 Final escape risk score (0-10)			1
F6.2 Invasiveness score (0-10)			8
C6 Escape Final Score (0-10)			**4**
	Critical?	No	Yellow

Brief Summary

On-farm escape prevention measures taken by Indian shrimp farmers (such as elevated dike/bund construction, screens on outlets, harvesting prior to large storms) helps to 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 India is high.

L. vannamei are non-native in India and have been found in the wild during shrimp population surveys. While limited evidence specific to India is available, research in similar environments has indicated their ability to outcompete and even consume native shrimp, as well as the development of reproductive organs. Despite this, there is no indication that *L. vannamei* have

established viable populations in India, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a moderate risk of competitive impacts (score of 6 out of 10 for Factor 6.2) results in a final score of 3 out of 10 for Criterion 6 – Escapes.

P. monodon are native to India and as farmed stock are almost entirely sourced from wild broodstock, it is unlikely that escaped farmed *P. monodon* present any significant competitive or genetic impact risk to wild populations.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a low risk of competitive impacts (score of 8 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, pond systems used to cultivate *L. vannamei* and *P. monodon* in India differ in their water management. Typically, *L. vannamei* pond systems in India are managed with no water exchange during the production cycle, though some farmers still do exchange water on a daily basis at an average rate of 10% of pond volume daily (observed range of 0.1% to 40%); for the purposes of this assessment, *L. vannamei* farms are considered to exchange <3% water daily.

Water exchange is more frequent in *P. monodon* systems, with expert review and literature indicating daily or weekly water exchange throughout the production cycle (Boyd et al., 2018; STIP, 2020; pers. comm. Aquaconnect, August 2020). While the volume of water exchanged varies based on stocking densities, pond conditions, and environmental conditions, the most recent information indicates roughly 20-25% of water volume is exchanged weekly (pers. comm. Aquaconnect, August 2020; STIP, 2020) with older information indicating average daily exchange of 13% (observed range of 4-45%) (Boyd et al., 2018); for the purposes of this assessment, *P. monodon* farms are considered to exchange >3% water daily.

In both cases, water is typically discharged from production ponds directly into a drainage canal that leads back to the waterbody where water is sourced (Boyd et al., 2018; pers. comm. Aquaconnect, August 2020; Seafood Watch field research, September 2019).

The Coastal Aquaculture Authority (CAA) Guidelines for Regulating Coastal Aquaculture (2005) include guidance for farm design and construction, with specific advice to ensure sluice gates are watertight and fitted with net screens/filters to prevent escapes (CAA, 2014). Information requests made to experts and Seafood Watch field research in India in 2019 indicate that this simple escape prevention measure is commonplace, though few others are implemented. There do not appear to be any other escape prevention or reporting requirements in the regulations, and accordingly, there are no official escape data by which to assess the frequency or magnitude of escape events.

Evidence that farmed *L. vannamei* individuals have found their way into the environment can be found, however, in the literature. The most recent Central Institute for Brackishwater Aquaculture (CIBA) annual report revealed the presence of *L. vannamei* in Pulicat Lake, the second largest lagoon in India on the border of Andhra Pradesh and Tamil Nadu (CIBA, 2019). The report states that *L. vannamei* are regularly caught by fishermen, though daily catches are small (3-5 individuals), and indicated that the apparent population is able to survive and grow with average catch weights in November of 11.5 grams and the following February of 27.7 grams (CIBA, 2019). A more recent, unpublished report from CIBA bolstered these findings, with sampling finding *L. vannamei* in Pulicat Lake in seven months during a yearlong sampling program (December 2019 – December 2020) (pers. comm. Indian government agency, July 2021). The report states:

> *No continuous growth pattern was observed during this seven month survey period. From July to September a progressive growth pattern could be observed. Although some of the female shrimps had reached minimum size of the maturity, none of the animals showed any indication of gonadal maturation. On the contrary, a small percentage of males, showed maturation.*

Additional sampling surveys in Chilika Lake, the largest lagoon in India found in the state of Odisha, have also found the presence of *L. vannamei* with genetic analysis indicating that the individuals are more closely related to previously sampled individuals of commercial origin throughout the world (Germany and China) than they are to previously sampled individuals from the East and West Coast of India (Kundu et al., 2018). The authors indicate that their results may depict multiple populations of *L. vannamei* (sampled by the authors and those previously found in East/West coast India). This suggests that, at the very least, escapes of *L. vannamei* have occurred throughout India multiple times. The study sampled *P. monodon* as well and found genetic similarity with previous samples from Germany (commercial product), Brazil, Sri Lanka, China, and the West Coast of India (Kundu et al., 2018); less can be inferred from this result, as broodstock for farmed *P. monodon* in India (and other areas) are regularly captured from the wild in the Indian Ocean, and thus it would be expected to see genetic similarity across these groups.

Escapes from shrimp ponds can “occur during harvests, pond cleaning after disease infections or routine water exchange in ponds” according to Senanan et al. (2007) profiling Thai shrimp farms; while the Indian 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. The primary pathway that shrimp can escape from ponds in India, however, appears to be through flood events.

Flooding frequently occurs throughout coastal India during the rainy/monsoon season (June-September), and as the majority of Indian shrimp production takes place in low-lying and coastal areas, flooding often affects the shrimp farming sector (Jayanthi et al., 2018b; Jayanthi et al., 2017; Muralidhar et al., 2017; CIBA, 2017). While ponds are advised to be built outside of flood-prone areas and with sufficiently high embankments (often called *bunds*) to prevent inundation, catastrophic flooding events have occurred affecting both the *L. vannamei* and *P. monodon* sectors over the years. Recent flooding events (2019) have affected *L. vannamei* culture on the west coast in Gujarat[36] and the east coast in Andhra Pradesh[37], as well as West Bengal[38] where the majority of *P. monodon* culture takes place (2020). Flooding does not necessitate escapes, as it is, of course, in the farmers best financial interest to prevent losses due to flooding, and many farmers will time their stocking and harvest so as to avoid the monsoon season (pers. comm. Indian government agency, 2020). In the event of inclement weather, farmers may arrange to harvest and sell shrimp, especially if flood warnings are issued (pers. comm. Aquaconnect, August 2020). With this in mind, however, there is evidence that floods have resulted in shrimp escapes, at times including the contents of entire farms[39]. The unpublished CIBA report mentioned previously notes that during flooding in Chennai in early 2016, nearly 10 kg of *L. vannamei* were captured per day at one landing center for several months before catches declined “substantially”, indicating that flooding can indeed result in the escape of farmed shrimp (pers. comm. Indian government agency, July 2021).

It is also important to note that some shrimp farms are said to be outside of flood zones, as the industry has continued expanding inland along creeks, and government guidance advises against siting in flood prone areas (pers. comm. Aquaconnect, August 2020; pers. comm. Indian government agency, August 2020); this could not be quantified, however, and it is clear that many thousands of shrimp farms are indeed vulnerable to flooding.

Overall, on-farm escape prevention measures are implemented by both *L. vannamei* and *P. monodon* farmers to mitigate the risk of escape, and guidance advises proper farm siting and embankment construction to avoid flooding. However, both systems are known to exchange water at harvest, and some *L. vannamei* and most, if not all, *P. monodon* farms exchange water during the production cycle. Farmed *L. vannamei* have been found in the wild in multiple locations in recent years, and fishermen are said to regularly catch them in these areas. Additionally, it appears that the majority of Indian shrimp farms and production tonnage 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 and resulted in shrimp escapes in the last ten years, and the risk of extreme flooding continues to increase, which justifies a score of 0 out of 10. However, in addition to the previously mentioned escape prevention measures, it is also understood that stocking and harvesting is

[36] https://timesofindia.indiatimes.com/city/surat/shrimp-farmers-stare-at-massive-losses/articleshow/70564849.cms?from=mdr
[37] https://www.undercurrentnews.com/2019/08/12/indias-shrimp-industry-may-have-lost-another-5-of-output-after-monsoon-floods/
[38] https://thefishsite.com/articles/cyclone-and-pandemic-prove-doubly-destructive-for-shrimp-farming-in-west-bengal
[39] https://timesofindia.indiatimes.com/city/surat/shrimp-farmers-stare-at-massive-losses/articleshow/70564849.cms?from=mdr

typically timed around monsoon season so as to avoid the productive and flooding risks. As such, an intermediate score is warranted and the initial score for Factor 6.1 – Escape risk is 1 out of 10 for both *L. vannamei* and *P. monodon*, given the vulnerability to flooding and uncertainty regarding the robustness of escape prevention measures in the event of large floods.

Recaptures
Though there is evidence of escaped whiteleg shrimp being caught by fishermen (CIBA 2019; pers. comm. Aquaconnect 2020), no such quantification of these catches could be obtained beyond the aforementioned reports indicating that daily catches were "below three to five" (CIBA, 2019) and catches of nearly 10 kg per day at one landing center for several months following large flooding events (pers. comm. Indian government agency, July 2021). With respect to *P. monodon*, there is no evidence of escaped farmed *P. monodon* being recaptured. For either species, there is no apparent regulatory or other best-practices requirement or guidance for the recapture of escaped shrimp. Thus, no recapture adjustment is made for either species.

The final score for Factor 6.1 – Escape risk is 1 out of 10.

Factor 6.2 – Competitive and genetic interactions
Whiteleg shrimp are non-native to India and were introduced for cultivation purposes in 2009.

Since its introduction in 2009, *L. vannamei* grew to dominate shrimp culture in India, and as mentioned in the previous section, individuals have entered the natural environment via potential pathways of flooding, regular water exchange, and harvest. As mentioned above, recent surveys of shrimp populations in two major estuaries in India revealed the presence of *L. vannamei*, with reported small daily catches by fishermen (CIBA, 2019; Kundu et al., 2018). No more recent or widespread data regarding the presence of *L. vannamei* in the wild in India could be obtained, though recent shrimp catch data in Andhra Pradesh – and nationally, through the Central Marine Fisheries Research Institute – did not reveal major catches of *L. vannamei* or "other species" where they may be categorized (Naik et al., 2020; CMFRI, 2019).

The presence of *L. vannamei* in the wild may present competitive ecological risks for India'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 India 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). While no research specific to India could be found, literature has examined the competitive risks that escaped *L. vannamei* pose to native shrimp populations with special regard to diet and aggression in other countries, notably Thailand. 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). These species included *P. monodon*, *P. semisucatus*, *P. merguiensis*, *Metapenaeus affinis*, *M. brevicornis*, and *Macrobrachium rosenbergii*, all species found in India. 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 Thai 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 in both Thailand and India, *Charybdis affinis*, in food competition contests, not only did the crab win every time, but it also occasionally caught and consumed the shrimp. This suggests 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 Indian waterways given the documentation of its growth (CIBA, 2019), its wide range of tolerance to environmental conditions (salinity, pH, temperature, etc.) and its ability to find and consume food in the wild in environments similar to India (Chanavich et al., 2016; Panutrakul et al., 2010; Senanan et al., 2010).

Senanan et al. stated in 2010 (as mentioned, for research conducted in Thailand) 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). Results in the yet-to-be published CIBA report indicated a lack of maturation amongst captured female specimens, but noted a small percentage of males showed maturation, and states that "the present study suggests that there is no established population of *P. vannamei* in Indian waters" (pers. comm. Indian government agency, July 2021). The FAO lists *L. vannamei* in India as "probably not established", though the data used for this Introduced Species Fact Sheet are sparse and outdated[40]. No other information regarding the establishment status of *L. vannamei* in India could be found.

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

[40] http://www.fao.org/fishery/introsp/6421/en

and its recorded presence in the wild in the Gulf of Mexico, Caribbean (Belize[41]), 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 India. As such, the final score for Factor 6.2 – Competitive and genetic interactions is 6 out of 10.

With respect to *P. monodon*, it is native to India and it is apparent that the vast majority (>99%) of *P. monodon* post-larvae are produced in hatcheries using wild-caught broodstock. As farmed stock are thus only one generation domesticated and exhibit high genetic similarity to wild conspecifics, the likelihood of genetic impacts is very low. Of note, wild *P. monodon* populations in India have been found to have high genetic variation, further limiting the risk of genetic impact from escaped farmed *P. monodon* (Khedkar et al., 2013; Mandal et al., 2012).

Wild broodstock are indeed selected for quality, though this is likely based on gross examination so as to avoid the introduction of pathogens, such as white spot syndrome virus (WSSV), to the hatchery (FAO, 2007). It is unlikely that this selection would generate any sort of competitive advantage for an escaped farmed *P. monodon* in the wild, though no information could be identified to support or challenge this assertion. With respect to competition, there is no information available to quantify the potential impacts; information regarding resource availability and regional stock statuses of *P. monodon* in India would be useful for estimating potential competitive effects of escaped shrimp, but no such information could not be found.

Overall, given the available data, it is concluded that farmed *P. monodon* are unlikely to present significant competitive or genetic risks to wild populations, given their native status and high genetic similarity to wild conspecifics, though limited data are available to inform the risk of competitive impacts. the final score for Factor 6.2 – Competitive and genetic interactions is 8 out of 10.

Conclusions and Final Score

On-farm escape prevention measures taken by Indian shrimp farmers (such as elevated dike/bund construction, screens on outlets, harvesting prior to large storms) helps to 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 India is high.

L. vannamei are non-native in India and have been found in the wild during shrimp population surveys. While limited evidence specific to India is available, research in similar environments has indicated their ability to outcompete and even consume native shrimp, as well as the development of reproductive organs. Despite this, there is no indication that *L. vannamei* have

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

established viable populations in India, or anywhere else in the world where they are cultured and non-native.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a moderate risk of competitive impacts (score of 6 out of 10 for Factor 6.2) results in a final score of 3 out of 10 for Criterion 6 – Escapes.

P. monodon are native to India and as farmed stock are almost entirely sourced from wild broodstock, it is unlikely that escaped farmed *P. monodon* present any significant competitive or genetic impact risk to wild populations.

Therefore, the combination of a high risk of escape (score of 1 out of 10 for Factor 6.1) and a low risk of competitive impacts (score of 8 out of 10 for Factor 6.2) results in a final score of 4 out of 10 for Criterion 6 – Escapes.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- *Impact:* Amplification of local pathogens and parasites on fish farms and their 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

Litopenaeus vannamei – Semi-intensive ponds

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

Penaeus monodon – Semi-intensive ponds

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**2**
Critical	No	Red

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 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 typically 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 3% of pond volume per day for *L. vannamei*, and farms strive to not discharge water to the environment over the course of a production cycle except at harvest; for *P. monodon*, water exchange during the cycle is more common, and daily water exchange is, on average, between 3% and 10% of pond volume.

Despite these efforts to limit pathogen risk, the shrimp farming industry 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 *L. vannamei* farms for Criterion 7 – Disease is 4 out of 10, due to limited water exchange during the production cycle; the final score for *P. monodon* farms for Criterion 7 – Disease is 2 out of 10, due to moderate daily water exchange during the production cycle.

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 India are challenged by a multitude of viral, bacterial, and parasitic pathogens; given moderate stocking densities, close proximity of farms, shared water supplies, and a variety of different vectors for these pathogens to enter and be discharged from farms, disease outbreaks throughout India 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

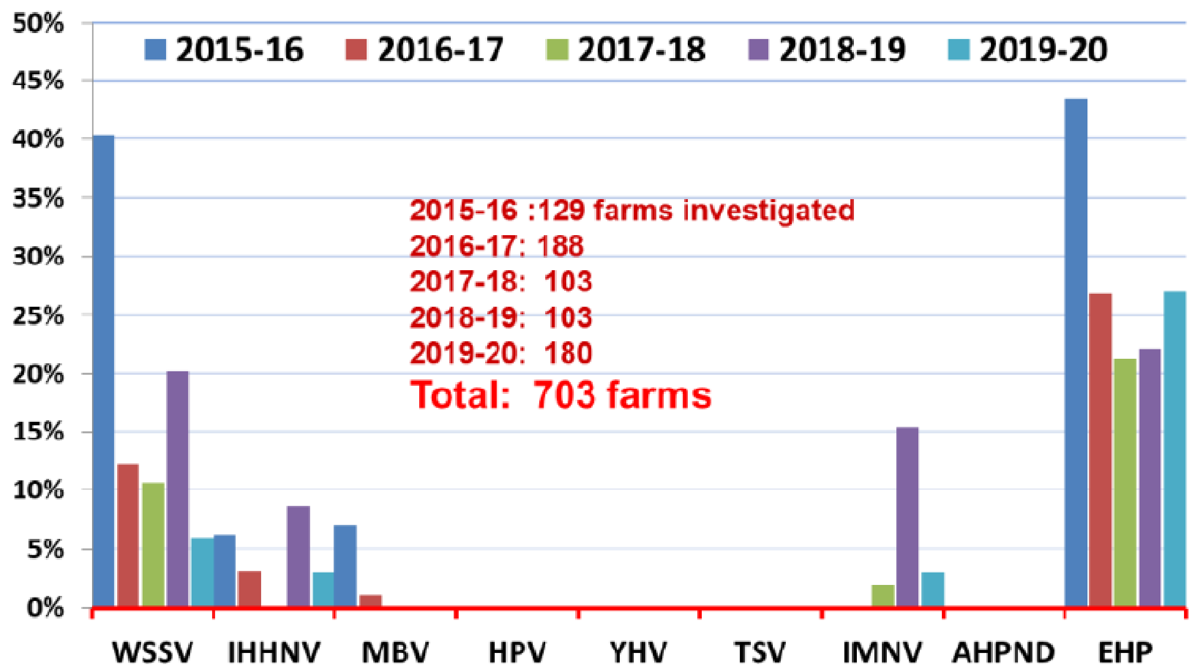
The primary viral pathogen affecting both *L. vannamei* and *P. monodon* culture in India is white spot syndrome virus (WSSV), the causative agent of white spot disease (WSD) (Tandel et al., 2017); indeed, this is considered the most significant viral pathogen affecting shrimp culture in all of Asia (Thitamadee et al., 2016). First reported in India on *P. monodon* farms in 1994 and on *L. vannamei* farms in 2011, WSSV is considered endemic in the environment today (Tandel et al., 2017; Balakrishnan et al., 2011).

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 (Mohan and De Silva, 2010; Padivar et al., 2003). 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 Thailand, though it has been stressed that drivers of WSD prevalence may differ between geographic locations and culture systems (Piamsomboon et al., 2016).

The World Organisation for Animal Health (OIE) publishes Quarterly Aquatic Animal Disease (QAAD) reports[42] 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 India, data going back to 2016 within the QAAD reports indicate the presence of WSSV in major shrimp farming regions in every quarter for both *P. monodon* and *L. vannamei*, though prevalence rates were not detailed.

Disease rates for WSD amongst *L. vannamei* in India were available through the Center for Brackishwater Aquaculture (CIBA) Annual Report, which reported disease prevalence amongst *L. vannamei* farms in three major producing states (Andhra Pradesh, Tamil Nadu, West Bengal; >90% Indian *L. vannamei* production by volume). The study sampled shrimp from 703 farms over the period of 2015-2020 and found annual WSD prevalence to range from 6% to 40% (CIBA, 2019). Information specific to *P. monodon* culture in West Bengal indicated an average prevalence amongst farms of 18.5% (n=65 farms) over the surveillance period of 2012-2018, though no more detailed data could be obtained (Abraham et al., 2020). Broadly, despite exhibiting a downward trend in prevalence amongst *L. vannamei* farms (Figure 5), WSSV is considered one of the primary disease threats to Indian farmed shrimp today.



---

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

Figure 5. "Prevalence of viral, bacterial and fungal diseases in Andhra Pradesh, Tamil Nadu and West Bengal during 2015 – 2020 (n=703 farms)" (CIBA 2019).

Another viral disease of concern affecting both Indian *L. vannamei* and *P. monodon* production is infectious hypodermal and haematopoietic necrosis virus (IHHNV) and is causative of "Runt Deformity Syndrome", though it is not associated with significant mortality (CIBA, 2019; Tandel et al., 2017; Joseph et al., 2015). First reported in India in 1998, the prevalence of IHHNV is variable but ranged from 0-8% annually (IHHNV) in *L. vannamei* farms across the same three major producer states mentioned previously during the period of 2015-2020 (CIBA, 2019; Figure 5). The same degree of recent viral prevalence data could not be obtained for *P. monodon* farms, though a somewhat dated study found overall prevalence amongst *P. monodon* post-larvae from a Kerala hatchery to be 76%, and it is understood that IHHNV is well-tolerated by *P. monodon* (Joseph et al., 2015). The OIE QAAD reports the presence of IHHNV regularly on *L. vannamei* farms throughout India, though only periodically on *P. monodon* farms throughout 2016 – 2020; however, again, no such prevalence is estimated.

An emerging virus of concern in India is infectious myonecrosis virus (IMNV), causative of infectious myonecrosis (IMN) and specific to *L. vannamei*. This virus was first reported in farmed *L. vannamei* in Brazil in 2003, and later in Indonesia in 2007, with mortality rates ranging from 40-70% (Hameed et al., 2017); while it does not appear to cause mortality in *P. monodon*, research has indicated that they too can carry IMNV (Hameed et al., 2017). Reports of its spread throughout Asia appear to have been exaggerated (Senapin et al., 2011), though it has now been confirmed present in India, first reported on *L. vannamei* farms in West Bengal in 2016 (Hameed et al., 2017). While unclear as to how IMNV entered India, it has been hypothesized that it entered via smuggled broodstock or post-larvae originating from either Indonesia or Brazil (Hameed et al., 2017); more recent research, however, has detected IMNV in wild *P. monodon* from the Indian Ocean, suggesting that the use of wild broodstock in India may be the vector by which IMNV entered the country's aquaculture industry. Initial surveillance indicated the absence of IMNV in Indian coastal states (Shyam et al., 2017), though recent monitoring by CIBA has indicated the presence of IMNV since then in major shrimp farming states, with prevalence peaking at 15% in 2018 and declining to 3% in 2019 (CIBA, 2019). Despite the concerns, IMNV is not currently perceived as posing a major threat to Indian shrimp aquaculture.

Additional viruses that affect shrimp culture in India are monodon baculovirus (MBV), hepatopancreatic parvovirus (HPV), and Laem-Singh virus (LSNV), though these are not OIE-listed diseases and as such, detailed information regarding their prevalence is limited due to a lack of widespread surveillance. While HPV and LSNV have been detected in both *L. vannamei* and *P. monodon* in India, MBV appears exclusive to *P. monodon* there, though it has been found in *L. vannamei* elsewhere (Arulmoorthy et al., 2020; Tandel et al., 2017; Kumar et al., 2011). Infections of all three are not known to be causative of widespread mortality nor are they considered widely prevalent, though they do affect feed intake, growth rates, and increase susceptibility to other pathogens such as the more deadly WSSV (Arulmoorthy et al., 2020;

Tandel et al., 2017; Jagadeesan et al., 2017). Notably, LSNV appears to be a necessary but not solely causative agent of monodon slow growth syndrome (MSGS) (Tandel et al., 2017).

Bacterial pathogens

The primary bacterial pathogens affecting shrimp culture in India are *Vibrio* spp., causative of vibriosis, though notably absent is the particular isolate of *Vibrio parahaemolyticus* that is the leading causative agent of acute hepatopancreatic necrosis disease (AHPND), previously referred to as early mortality syndrome (EMS) (Flegel and Sritunyaluucksana, 2018). Reports of AHPND in India have been speculated, though recent research sampling nearly 400 shrimp farms over the past four years has indicated that AHPND is not present in India, confirming previous investigations (Navaneeth et al., 2020; Ananda Raja et al., 2017; Kumar et al., 2014b). The recent study found that the strains of *V. parahaemolyticus* present today appear to be non-pathogenic to both shrimp and people (Navaneeth et al., 2020), in contrast to older reports which have indicated that *V. parahaemolyticus* was indeed causative of vibriosis outbreaks (Mastan and Begum, 2016; Kumar et al., 2014b). However, it is now known that other *Vibrio* spp., such as *V. campbelli* and *V. harveyi*, can carry the plasmid causative of AHPND, previously thought to have been restricted to *V. parahaemolyticus* (Kumar et al., 2020); as such, it is possible that the disease may indeed be present in India and more research is required.

Clinical signs of vibriosis can vary depending on the species of pathogenic *Vibrio* spp., though common symptoms include lethargy, loss of appetite, and changes in color or appearance of the body and/or gill tissue (Mastan and Begum, 2016).

Vibrio spp. are ubiquitous in the marine and estuarine environment, and as such, vectors carrying *Vibrio* spp. into shrimp ponds are nearly innumerable; strategies to mitigate this disease focus primarily on maintaining good water quality and minimizing organic content in ponds to limit bacterial growth, rather than exclusion (OIE, 2018). Certain environmental factors, such as salinity and temperature, seem to partly mediate vibriosis pressure, with higher salinity and temperature appearing to increase disease incidence (OIE, 2018).

Detailed information regarding the prevalence of vibriosis outbreaks in India could not be found, as the majority of research has focused on the presence of AHPND which, as stated, does not appear to be present in India at this time. There are several additional conditions/diseases of note that seem at least partly associated with *Vibrio* spp. infections, detailed below.

Other conditions/diseases of note

Another major condition of note is hepatopancreatic microsporidiosis (HPM), caused by the microsporidian *Enterocytozoon hepatopenaei* (EHP). First reported in Thai *P. monodon* farms in 2004, it soon spread across Asia and has been found in both *P. monodon* and *L. vannamei* in India since at least 2014 (Kmmari et al., 2018; Biju et al., 2016). 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). Recent prevalence rates of EHP in *L. vannamei* and *P. monodon* have been documented ranging from 27% to 84.9% of farms and vary by region/state (Patil et al., 2020; Behera et al., 2019; Rathipriya et al., 2019; CIBA, 2019; Biju et al., 2016; Figure 5)

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 vibriosis (Kmmari et al., 2018). Its link to other diseases, such as white feces syndrome (WFS), has been debated, however. 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). Research specific to India did find that WFS is consistently associated with EHP, where 94.6% of WFS-affected ponds were positive for EHP as compared to 39.7% positive for EHP in non-WFS-affected ponds (Rajendran et al., 2016). The interaction between EHP and other diseases and conditions is an area of ongoing study.

White feces syndrome (WFS) is thus also a condition of note in Indian shrimp production. This condition is characterized by the aggregation or accumulation of white fecal strands floating on the surface of production ponds (Kmmari et al., 2018). Similar to EHP, WFS causes economic losses to shrimp farmers not through direct mortality, but rather growth retardation and elevated feed conversion ratios (Kmmari et al., 2018). 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 *Vibrio* spp. or EHP (Tamilarasu et al., 2020; Sriurairatana et al., 2014). The link between WFS and these pathogens, however, is still uncertain.

Anecdotal reports suggest that WFS is common, though detailed prevalence rates in Indian shrimp could not be found; however, given its correlation with EHP, it is believed to be widespread throughout India (Patil et al., 2020; Behera et al., 2019; Rathipriya et al., 2019; CIBA, 2019; Biju et al., 2016; pers. comm. Aquaconnect, June 2020; Seafood Watch field research, September 2019).

Interviews with farmers and recent literature have also indicated other conditions affecting shrimp farms, though their etiology is still considered unknown. Loose shell syndrome disease (LSSD) was first reported in India in 1998 in *P. monodon* farms and is now considered fairly common amongst both *P. monodon* and *L. vannamei* farms (prevalence in Andhra Pradesh was recently recorded at 26%; Naik et al., 2020b). This condition results in severely reduced feed intake and growth rates and can cause progressive mortality throughout the production cycle (Naik et al., 2020b; Srinivas et al., 2016). High loads of *Vibrio* spp. have been associated with the condition, alongside poor soil and water quality management (Naik et al., 2020b; Srinivas et al., 2016). It is a similar story for running mortality syndrome (RMS), a condition in *L. vannamei* first described in 2011 that features similar symptoms to others caused by *Vibrio* spp. (lethargy and reddish discoloration, though the discoloration is initially limited to the uropods before progressing throughout the body), as well as the unique symptom of cut antennae (Rao et al., 2020). The condition results in continuous (e.g., running) low-level mortality that progresses throughout the production cycle, reaching acute levels at approximately 90 days of culture (Alavandi et al., 2019; Rao et al., 2020). As with other *Vibrio* spp. associated conditions, it appears that RMS is likely a pond management issue, where poor soil and water quality both stresses shrimp and allows naturally present *Vibrio* spp. to proliferate and attack the shrimp (Alavandi et al., 2019; Rao et al., 2020).

<u>Control Measures</u>

A variety of control measures intended to mitigate the occurrence and minimize the impact of disease are utilized in India. 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; pers. comm. Indian government agency, August 2020; Seafood Watch field research, September 2019).

The first step to exclude pathogens from farms involves the use of specific pathogen-free (SPF) post-larvae (PL) produced in domestic hatcheries. In India, broodstock are typically imported (or PLs imported and raised into broodstock at multiplication centers), often from the United States (pers. comm. Indian government agency, August 2020; pers. comm. Aquaconnect, August 2020) and this is further detailed in Criterion 10X – Introduction of secondary species. The Coastal Aquaculture Authority (CAA) regulates domestic hatchery biosecurity with the Guidelines for Regulating Coastal Aquaculture, and mandates that all imported *L. vannamei* broodstock and/or PLs must be SPF and quarantine through the Rajiv Gandhi Centre for Aquaculture (RGCA) Aquatic Quarantine Facility (AQF) located in Chennai, Tamil Nadu (CAA, 2014). 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 they or individual farms will 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 (Salunke et al., 2020; Vijayan and Balasubramanian, 2019; Kummari et al., 2018). 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 (Salunke et al. 2020).

On-farm exclusion strategies are typically limited to fencing surrounding ponds and screens and/or mesh placed over water pipe inlets, in an attempt to exclude disease vectors like fish and crabs, as well as bird netting/scares to prevent entry (Sivaramam et al., 2018; pers. comm. Indian government agency, August 2020; pers. comm. Devi Seafoods, September 2019; pers. comm. Avanti Feeds Ltd., September 2019; pers. comm. Aquaconnect, June 2020). 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. The adoption of these exclusion measures is not uniform, however, and low adoption rates of practices beyond screening inlets has been recently observed (~21-35% of farms surveyed in Andhra Pradesh) (Sivaramam et al., 2018; Kummari et al., 2018). Overall, the ability of the Indian 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 may 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. Typically, *L. vannamei* pond systems in India are managed with no water exchange during the production cycle, though some farmers still do exchange water on a daily basis at an average rate of 10% of pond volume daily (observed range of 0.1% to 40%); for the purposes of this assessment, *L. vannamei* farms are considered to exchange <3% water daily. Water exchange is more frequent in *P. monodon* systems, with expert review and literature indicating daily or weekly water exchange throughout the production cycle (Boyd et al., 2018; STIP, 2020; pers. comm. Aquaconnect, August 2020). While the volume of water exchanged varies based on stocking densities, pond conditions, and environmental conditions, the most recent information indicates roughly 20-25% of water volume is exchanged weekly (pers. comm. Aquaconnect, August 2020; STIP, 2020) with older information indicating average daily exchange of 13% (observed range of 4-45%); for the purposes of this assessment, *P. monodon* farms are considered to exchange >3% of pond water daily.

In order to minimize the risk of pathogen entry during filling ponds, influent water can be treated by farmers prior to stocking the production pond(s) using chemical compounds such as chlorine, potassium permanganate, and/or 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; however, while recommended by CAA and MPEDA, the adoption of this practice is not uniform amongst farms (Boyd et al., 2018; Kummari et al., 2018; Venkateswarlu and Venkatrayulu, 2019). Further, this type of sterilization is not possible for influent water during water exchange within a production cycle without a reservoir pond(s), which is also not a uniform feature of either *L. vannamei* or *P. monodon* farms (Boyd et al., 2018; Kummari et al., 2018; Sivaramam et al., 2018; pers. comm. Aquaconnect, June 2020). Between crops, farmers will typically remove sediment and rebuild bunds, dry pond bottoms for at least ten days and most apply burnt lime (calcium oxide) to raise the pH and kill disease organisms (Boyd et al., 2018; Sivaramam et al., 2018; Seafood Watch field research, September 2019).

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 *Vibrio* spp., though some research and experts have questioned the efficacy of probiotics (Flegel, 2019; Boyd et al., 2018; pers. comm. Aquaconnect, June 2020; pers. comm. Indian government agency, August 2020; Seafood Watch field research, September 2019).

Despite these measures – use of SPF PLs, vector exclusion, probiotics, and relatively 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 directly into canals (e.g., no sedimentation basin) which lead to waterbodies, and there is significant uncertainty regarding additional treatment to neutralize pathogens prior to water being released from the pond; at the very least, partial drainage to make harvesting easier prevents treatment before release. Recommended treatment options include chlorination (CAA, 2014; pers. comm. Indian government agency, August 2020), but adoption of these measures cannot be confirmed to be uniform (Kummari et al., 2018; Venkateswarlu and Venkatrayulu, 2019; Joseph et al., 2015b). 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 contains active pathogens if it has not been appropriately disinfected.

The implementation of best management practices (BMPs) is being assisted by extension personnel from various departments (such as the Department of Fisheries in each state) as well as the National Centre for Sustainable Aquaculture (NaCSA), the extension wing of the Marine Products Export Development Authority (MPEDA) (Seafood Watch field research, September 2019). In a form of area-based management, NaCSA works to group proximal small-scale farmers (minimum of 20 farmers per group) into a "society", whereby a NaCSA field manager performs a baseline assessment of BMP implementation (as dictated by MPEDA[43]) and works over the following six months to increase BMP adoption; after the six month period, an audit is conducted and "society" status is awarded if BMPs are being followed (Seafood Watch field research, September 2019). The benefits of being in a "society" for farmers include collective purchasing and bargaining power with respect to seed, feed, and harvest prices, alongside

[43] https://mpeda.gov.in/MPEDA/lv.php#

access to government support via MPEDA (Seafood Watch field research, September 2019). To date, however, only about 30% of farmers in India are involved in NaCSA societies (20,000 – 30,000 farmers in roughly 1,000 societies) (pers. comm. Indian government agency, September 2019; Seafood Watch field research, September 2019).

Additionally, as described in Criterion 4 – Chemicals, the use of antibiotics still occurs in India, resulting in regular rejections of products in export markets. The primary pathogens of concerns, WSD and EHP, are not bacterial and while *Vibrio* spp. present health challenges, strains found in shrimp ponds have been found to be resistant to multiple antibiotics and farmers are advised against their use given the inefficacy of the drug(s). In general, the use of chemicals to control disease (beyond in pond preparation) is not considered a primary disease control method, though some literature indicates prophylactic and therapeutic use still occurs (Parvez and Vijaya, 2020).

Lastly, commercially viable vaccines are not available to treat any of the diseases that affect shrimp culture in India (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 contrast with the amount of information available regarding disease pathology, there is limited research or evidence to indicate that shrimp farms in India 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 evidence which indicates the presence of viral pathogens – WSSV, IHHNV, LSNV, MBV, and/or IMNV – and *Vibrio* spp. amongst wild *P. monodon* and other crustaceans (including commercially relevant crustaceans, like *P. indicus*) in India and/or the neighboring Indian Ocean (Srisala et al., 2020; Mondal and Mandal, 2020; Kumar et al., 2011; Joseph et al., 2015b; Saravanan et al., 2017; Chandrakala and Rajeswari, 2015). These studies indicate varying levels of prevalence ranging from 0-100% of surveyed samples, depending on the pathogen, and could not determine any directionality (e.g., outbreaks on farms driving prevalence in wild populations, and vice versa). A particularly recent study shows a higher prevalence of white feces syndrome (WFS) amongst wild *P. monodon*, *P. semisulcatus*, and *F. indicus* captured proximal to shrimp farms, as compared to those not near shrimp farms, in the Gulf of Manna off the coast of Tamil Nadu, and while directionality is not established, it is clear that caution is indeed warranted (Vinod et al., 2020). Broadly, it is assumed that the pathogens are present and endemic in the environment, given the ban on importation of non-SPF broodstock and PLs into India; however, there is are questions with respect to the enforcement of these laws, and there is significant potential (and evidence) for farms to amplify pathogen rates and increase virulence, given the increased stocking density and poor water quality as compared to wild conditions.

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 typically 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 3% of pond volume per day for *L. vannamei*, and farms strive to not discharge water to the environment over the course of a production cycle except at harvest; for *P. monodon*, water exchange during the cycle is more common, and daily water exchange is, on average, between 3-10% of pond volume.

Despite these efforts to limit pathogen risk, the shrimp farming industry can clearly be considered to suffer from high disease or pathogen related infection and/or mortality. Further, the siting of farms 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 *L. vannamei* farms for Criterion 7 – Disease is 4 out of 10, due to limited water exchange during the production cycle; the final score for *P. monodon* farms for Criterion 7 – Disease is 2 out of 10, due to moderate daily water exchange during the production cycle.

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

Litopenaeus vannamei – Semi-intensive ponds

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

Penaeus monodon – Semi-intensive ponds

C8X Source of Stock – Independence from wild fish stocks	Value	Score
Percent of production dependent on wild sources (%)	99.0	-9
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)		**-9**
Critical?	No	Red

Brief Summary

Whiteleg shrimp farms in India only use hatchery-raised seed from domesticated broodstock, the majority of which are imported SPF largely from the United States. There is no reliance on wild shrimp for farm production, and as such, the final *L. vannamei* score for Criterion 8X – Source of Stock is 0 out of -10.

On the other hand, *P. monodon* production is nearly 100% reliant on wild captured broodstock of unknown sustainability. Despite recent advancements in the development of a domesticated broodstock supply in India, the current status of semi-intensive *P. monodon* production is estimated to be 90-99% reliant on wild captured broodstock – the fishery for which cannot be considered demonstrably sustainable – and as such, the final *P. monodon* score for Criterion 8X – Source of Stock is -9 out of -10.

Justification of Ranking
Whiteleg shrimp farms in India only use hatchery-raised seed from domesticated broodstock, the majority of which are imported SPF largely from the United States[44] (pers. comm. Indian government agency, August 2020). The final score for Criterion 8X – Source of Stock, is 0 out of -10.

On the other hand, the *P. monodon* industry is nearly 100% reliant on wild caught broodstock from domestic trawl fleets (pers. comm. Indian government agency, August 2020; Mondal and Mandal, 2020). Catch rates appear stable though data are sparse and at times, outdated, and no information regarding the broader sustainability of these fisheries (e.g., impacts on other species caught by the trawls, bycatch, etc.) could be found (CFMRI, 2019; Naik et al., 2020; Uddin et al., 2021). As such, the sustainability of these fisheries cannot be demonstrated to be of minimal concern.

Recently, the Indian government began taking steps towards the development of domestic *P. monodon* broodstock industry by allowing the import of domesticated SPF broodstock[45], and at the time of writing, only two foreign suppliers – Moana Technologies (Hawai'i, USA) and Aquaculture de la Mahajamba (Madagascar) have been approved (both in 2019). The first commercial *P. monodon* broodstock multiplication center (BMC) has since come online in Gujarat, which imported its first batch of Moana Technologies SPF *P. monodon* broodstock in early September 2020. It is unclear the degree to which current semi-intensive *P. monodon* production has originated from newly approved imported broodstock, though it is estimated to be <10%; thus, for the purposes of this assessment, the *P. monodon* industry is considered 90-99.9% reliant on wild broodstock of unknown sustainability. The final score for Criterion 8X – Source of Stock is -9 out of -10.

Conclusions and Final Score
Whiteleg shrimp farms in India only use hatchery-raised seed from domesticated broodstock, the majority of which are imported SPF largely from the United States. There is no reliance on wild shrimp for farm production, and as such, the final *L. vannamei* score for Criterion 8X – Source of Stock is 0 out of -10.

On the other hand, *P. monodon* production is nearly 100% reliant on wild captured broodstock of unknown sustainability. Despite recent advancements in the development of a domesticated broodstock supply in India, the current status of semi-intensive *P. monodon* production is estimated to be 90-99% reliant on wild captured broodstock – the fishery for which cannot be considered demonstrably sustainable – and as such, the final *P. monodon* score for Criterion 8X – Source of Stock is -9 out of -10.

[44] http://www.caa.gov.in/uploaded/doc/Overseas_suppliers_of_SPF_Shrimp_Broodstock.pdf
[45] https://www.undercurrentnews.com/2018/05/07/india-to-allow-imports-of-black-tiger-shrimp-broodstock/

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		-4
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score		**-4**
Critical?	No	Yellow

Brief Summary

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 Indian 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 evidence that suggests intentional mortality of animals may occur beyond the killing of fish as a biosecurity measure, though this is considered exceptional and the majority of species interacting with farms are considered "least concern" by the IUCN. It is thus unlikely that any mortalities that may indeed occur would significantly impact the population size of the affected species, but actual mortality numbers are unknown. Legislation explicitly prohibits the killing of wildlife, though exceptions may be made in the event that property, such as shrimp ponds, are threatened. The final score for Criterion 9X – Wildlife and Predator Mortalities is -4 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).

The Indian coasts are collectively some of the most biodiverse areas in the world, with a wide variety of ecosystems, landscapes, and habitats, and are home to thousands of species of mammals, birds, reptiles, amphibians, and fishes[46]. Shrimp farms are, as described in Criterion 3 – Habitat, sited in coastal areas where large tracts of mangrove forest and wetland ecosystems still remain. These ecosystems are home to a number of species, primarily birds, reptiles, and fishes that may interact with shrimp ponds. Somewhat outdated literature indicated that 14 different bird species groups (e.g., "cormorants" and "egrets") were found interacting with shrimp ponds in Tamil Nadu and Kerala, the majority of which are considered "least concern", though at least one – the Oriental Darter, *Anhinga melanogaster* – is considered "threatened" according to the IUCN (Roshnath et al., 2014; Roshnath, 2014). The primary deterrent methods employed on shrimp farms are non-lethal and include the use of plastic streamers, nylon threads, noise crackers, and floating pieces of thermocol (similar to Styrofoam) (Roshnath et al., 2014; Roshnath, 2014). In one survey, lethal control of cormorants via firearms was noted, with the caveat that farmer(s) were also consuming these birds (Roshnath, 2014); this, however, is not considered the norm or widespread, and as mentioned, the identified cormorant species are considered "least concern" by the IUCN.

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 bleaching agents applied to eliminate any animals or animal larvae that were able to enter the pond (Boyd et al., 2018; Seafood Watch field research, September 2019).

Further reference to specific predator species, the deterrents used to control them, or their impact on predator populations in the Indian shrimp farming industry were not available in the literature.

Legislation, such as the Wild Life Protection Act (1972)[47], prohibits the killing of protected species (listed within the Act), the list of which is quite broad and encompasses the majority, if not all, of the animals interacting with shrimp farms (birds, amphibians, reptiles, mammals, etc.). However, exceptions can be made to allow the hunting of animals listed on Schedules 2-4 (most birds) in the event that said animal "has become dangerous to human life or to property (including standing crops on any land)". The Coastal Aquaculture Authority (CAA) Rules were amended in 2009 to include, specific for *L. vannamei* farms, requirements to "establish adequate biosecurity measures including fencing, reservoirs, bird-scare, […] etc.", though no similar requirements are noted for *P. monodon* farms. The CAA Guidelines for Regulating Coastal Aquaculture (2005) make no specific reference to fencing or nets to prevent entry by wildlife beyond "proper screens should be used [during water exchange] to prevent the entry of pests and predators" (CAA, 2014). The best management practices outlined by MPEDA[48] for NaCSA society farms state that physical barriers should be implemented to "prevent crabs, birds and other animals" and to "put up bird net to prevent birds picking up dead shrimp and carrying it to other ponds", though no more specificity with respect to the implementation of

[46] https://www.cbd.int/countries/profile/?country=in
[47] http://legislative.gov.in/sites/default/files/A1972-53_0.pdf
[48] https://mpeda.gov.in/MPEDA/lv.php#

these measures was found. Additionally, 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.

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 Indian 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 evidence that suggests intentional mortality of animals may occur beyond the killing of fish as a biosecurity measure, though this is considered exceptional and the majority of species interacting with farms are considered “least concern” by the IUCN. It is thus unlikely that any mortalities that may indeed occur would significantly impact the population size of the affected species, but actual mortality numbers are unknown. Legislation explicitly prohibits the killing of wildlife, though exceptions may be made in the event that property, such as shrimp ponds, are threatened. The final score for Criterion 9X – Wildlife and Predator Mortalities is -4 out of -10.

Criterion 10X: Introduction 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

Litopenaeus vannamei – Semi-intensive ponds

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	100.0	0
Biosecurity score of the source of animal movements (0-10)		10
Biosecurity score of the farm destination of animal movements (0-10)		5
Species-specific score 10X Score		0.000
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**0.000**
Critical?	No	Green

Penaeus monodon – Semi-intensive ponds

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	100.0	0
Biosecurity score of the source of animal movements (0-10)		0
Biosecurity score of the farm destination of animal movements (0-10)		2
Species-specific score 10X Score		-8.000
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**-8.000**
Critical?	No	Red

Brief Summary

Given the available evidence, it is determined that 100% of both the Indian *L. vannamei* and *P. monodon* farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 0 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments.

The source of *L. vannamei* is entirely from fully biosecure international suppliers of broodstock and/or PLs, while the source of *P. monodon* broodstock is almost exclusively from the wild. The destination of animal movements, farms across India, for both *L. vannamei* and *P. monodon* have significant uncertainty regarding the implementation and effectiveness of biosecurity measures in place and are considered moderate-high biosecurity risks. This results in an overall score of 10 out of 10 for *L. vannamei* and 2 out of 10 for *P. monodon* for Factor 10Xb.

The final score for Criterion 10x – Escape of Secondary Species is 0 out of -10 for *L. vannamei*.
The final score for Criterion 10x – Escape of Secondary Species is -8 out of -10 for *P. monodon*.

Justification of Ranking

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

Whiteleg shrimp farms in India only use hatchery-raised seed from domesticated broodstock, the majority of which are imported SPF largely from the United States[49] (pers. comm. Indian government agency, August 2020). The rules set out by the CAA for *L. vannamei* culture dictate that all broodstock in hatcheries must be SPF and cleared through quarantine at the Aquatic Quarantine Facility (AQF) at the Rajiv Gandhi Center for Aquaculture (RGCA) in Chennai, Tamil Nadu (CAA, 2014; pers. comm. Indian government agency, August 2020; Jayaraman, 2017). The origin of all *L. vannamei* broodstock in India are international and imported either as adult broodstock or as post-larvae, all of which must pass through the AQF prior to distribution; the Indian government operates at least two broodstock multiplication centers (BMCs), one of which is the Andhra Pradesh Shrimp Seed Production, Supply and Research Centre (TASPARC) in Andhra Pradesh[50], which raises imported PLs into SPF broodstock which are then sold to CAA approved hatcheries throughout the country (pers. comm. Indian government agency, August 2020; Salunke et al., 2020; Jayaraman, 2017). It is estimated that roughly 30% of broodstock in use in India are "domestic" in that they have come from this BMC, though given that they were grown from imported PLs, the origin of these animals is indeed international (pers. comm. Indian government agency, September 2019). The remaining 70% of broodstock are imported directly by approved hatcheries, but again, must pass through the AQF upon arrival in India.

The destination of these broodstock is hatcheries throughout India, though these are heavily concentrated in Andhra Pradesh where the majority of *L. vannamei* production takes place. According to the CAA Annual Report[51] (2018), there were 298 authorized SPF *L. vannamei* hatcheries in 2017 and 220 of these were in Andhra Pradesh, followed by 65 in Tamil Nadu, six each in Gujarat and Odisha, and one in Karnataka. More recent information indicates that 311 hatcheries have been registered as of November 2019, remaining largely concentrated in Andhra Pradesh and Tamil Nadu[52].

The use of local, pond-reared *L. vannamei* broodstock in hatcheries is explicitly prohibited by the CAA Rules for *L. vannamei* culture, though it has been known to occur (Salunke et al., 2020; Vijayan and Balasubramanian, 2019; Kummari et al., 2018); despite this, however, as described, all *L. vannamei* in India originate from international sources.

Post-larvae (PL) produced by the hatcheries are then distributed to *L. vannamei* farms, which, again, are heavily concentrated in Andhra Pradesh, with significant production also occurring in

[49] http://www.caa.gov.in/uploaded/doc/Overseas_suppliers_of_SPF_Shrimp_Broodstock.pdf
[50] http://www.rgca.org.in/tech_proj.php?id=10
[51] http://caa.gov.in/uploaded/doc/annualreport/Annual%20Report%202017-2018.pdf
[52] http://caa.gov.in/uploaded/doc/LIST_OF_REGISTERED_HATCHERIES_11-01-2019.pdf

Gujarat, Tamil Nadu, Odisha, and West Bengal. While it is assumed that hatcheries in each of these states do supply the proximal farms, it is clear that PLs are regularly transported across states as well (STIP, 2020). As such, it is considered that 100% of the Indian *L. vannamei* industry relies on international or trans-waterbody live animal shipments (internationally sourced broodstock and/or domestic trans-waterbody movements of shrimp). The final score for Factor 10Xa – International or trans-waterbody live animal shipments is 0 out of 10 for *L. vannamei*.

With respect to *P. monodon*, nearly 100% of the broodstock in use are sourced from the wild by trawlers operating in Indian waters (pers. comm. Indian government agency, August 2020; Mondal and Mandal, 2020). Limited information is available to determine the precise origin of these catches, though it appears that broodstock are fished for and landed on both the east and west coast of India (Mondal and Mandal, 2020). The majority of *P. monodon* culture takes place in West Bengal, and it is assumed that the ecology of source waters for broodstock in Kochi, Kerala (southwest India) is different than that of Digha, a major landing location in West Bengal (Mondal and Mandal, 2020). However, while no official statistics could be found, the majority of the *P. monodon* hatcheries appear to be clustered in Andhra Pradesh and Tamil Nadu, with literature and personal communications indicating that the movement of post-larvae from hatcheries in Andhra Pradesh to farms in West Bengal commonly occurs (STIP, 2020; Sahu et al., 2013; pers. comm. Sudhakar Mathsa, April 2021). However, recent personal communications with Indian government officials state that there is currently no production of *P. monodon* seed in hatcheries in Andhra Pradesh (pers. comm. Indian government agency, July 2021), adding to the uncertainty.

Recently, the Indian government began taking steps towards the development of domestic *P. monodon* broodstock industry by allowing the import of domesticated SPF broodstock[53], and at the time of writing, only two foreign suppliers – Moana Technologies (Hawai'i, USA) and Aquaculture de la Mahajamba (Madagascar) have been approved (both in 2019). The first commercial *P. monodon* broodstock multiplication center (BMC) has since come online in Gujarat, which imported its first batch of Moana Technologies SPF *P. monodon* broodstock in early September 2020. It is unclear the degree to which current semi-intensive *P. monodon* production has originated from newly approved imported broodstock, though it is estimated to be insignificant.

With no additional information, on a precautionary basis it is estimated that >90% of the semi-intensive *P. monodon* industry is reliant on international or trans-waterbody live animal shipments (internationally sourced broodstock and/or domestic trans-waterbody movements of shrimp), given the numerous landing areas, apparent concentration of hatcheries in Andhra Pradesh and Tamil Nadu, and vast majority of production taking place in West Bengal. The final score for Factor 10Xa – International or trans-waterbody live animal shipments is 0 out of 10 for *P. monodon*.

[53] https://www.undercurrentnews.com/2018/05/07/india-to-allow-imports-of-black-tiger-shrimp-broodstock/

Factor 10Xb – Biosecurity of source and destination

Source of movements – *L. vannamei*
The available information indicates that 100% of the broodstock and PLs that are imported originate from tank-based recirculating systems with appropriate biosecurity practices, considered fully biosecure sources[54]. In order for a supplier to receive approval to be imported into India, they must be first be evaluated by the "Technical Evaluation Committee", comprised of representatives from CAA, MPEDA, National Fisheries Development Board (NFDB), and Central Institute of Brackishwater Aquaculture (CIBA)[55]. The evaluation requires certificates assuring SPF status of the animals, two years history of disease occurrence in the facility, a pre-shipment quarantine of 12 days, alongside negative test results for OIE-listed diseases, including IHHNV, WSSV, TSV, YHV, and IMNV.

As such, these sources are considered fully biosecure and the final score for Factor 10Xb – Biosecurity of source for *L. vannamei* is 10 out of 10.

Source of movements – *P. monodon*
As the primary source of *P. monodon* broodstock is the wild, the biosecurity risk is considered high and the final score for Factor 10Xb – Biosecurity of source for *P. monodon* is 0 out of 10.

It is important to note, however, that requirements for imported SPF *P. monodon* broodstock are just as stringent as those for *L. vannamei*[56]. As noted previously, the Indian government recently allowed the import of domesticated SPF broodstock[57]; the first commercial *P. monodon* broodstock multiplication center (BMC) has since come online in Gujarat, which imported its first batch of Moana Technologies SPF *P. monodon* broodstock in early September 2020. These sources are considered fully biosecure and increasing the proportion of the industry supplied by SPF *P. monodon* broodstock will considerably improve this score.

Destination of movements – *L. vannamei* and *P. monodon*
The destination of broodstock are hatcheries all across India and the destination of PLs are farms all across India, where a range of biosecurity practices are in place in both. The CAA Guidelines and Rules detail strict biosecurity requirements for hatcheries of both species, yet the implementation of these requirements is certainly not uniform, especially amongst those hatcheries that are not registered and operating illegally (Salunke et al., 2020; Venkateswarlu and Venkatrayulu, 2019; Kummari et al., 2018; Raja et al., 2012; Seafood Watch field research, September 2019). There are over 300 hatcheries legally operating in India and while the supply of post-larvae appears to be dominated by several groups[58] that practice with stringent biosecurity measures, such as BMR Group and Charoen Pokphand (CP), no such quantification of their collective market share could be obtained. Further, limited information regarding the

[54] http://www.caa.gov.in/uploaded/doc/Overseas_suppliers_of_SPF_Shrimp_Broodstock.pdf
[55] http://www.caa.gov.in/uploaded/doc/notification-2482(E).pdf
[56] http://www.caa.gov.in/uploaded/doc/Gazette14-09-12.pdf
[57] https://www.undercurrentnews.com/2018/05/07/india-to-allow-imports-of-black-tiger-shrimp-broodstock/
[58] https://seafood-tip.com/sourcing-intelligence/countries/india/shrimp/inputs/

water exchange practices and openness of the hatchery systems was obtained; though outdated, a 2007-2009 survey found that only 8% of *P. monodon* hatcheries were using recirculation and very limited adoption of sanitary biosecurity practices (Raja et al., 2012). In the absence of additional information, it must be considered that some hatcheries today are also operating as tanks or raceways that are at least >10% daily water discharge.

As described in Criterion 7 – Disease, the biosecurity measures implemented on farms vary considerably as well, though farmers of both *L. vannamei* and *P. monodon* typically 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 3% of pond volume per day for *L. vannamei*, and farms strive to not discharge water to the environment over the course of a production cycle except at harvest; for *P. monodon*, water exchange during the cycle is more common, and daily water exchange is, on average, between 3-10% of pond volume. Further, the siting of farms 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.

Overall, both *L. vannamei* and *P. monodon* farms are considered a moderate-high biosecurity concern due to the uncertainty of the effectiveness and robustness of biosecurity prevention measures implemented, despite the varied water exchange between the two species. Therefore, as farms are the final destination of live animal movements, the final score for Factor 10Xb – Biosecurity of destination is 2 out of 10 for both *L. vannamei* and *P. monodon*.

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 10 out of 10 for *L. vannamei* and 2 out of 10 for *P. monodon*.

Conclusions and Final Score

Given the available evidence, it is determined that 100% of both the Indian *L. vannamei* and *P. monodon* farming industry is reliant on international or trans-waterbody movements of live animals, resulting in a score of 0 out of 10 for Factor 10Xa – international or trans-waterbody animal shipments.

The source of *L. vannamei* is entirely from fully biosecure international suppliers of broodstock and/or PLs, while the source of *P. monodon* broodstock is almost exclusively from the wild. The destination of animal movements, farms across India, for both *L. vannamei* and *P. monodon* have significant uncertainty regarding the implementation and effectiveness of biosecurity measures in place and are considered moderate-high biosecurity risks. This results in an overall score of 10 out of 10 for *L. vannamei* and 2 out of 10 for *P. monodon* for Factor 10Xb.

The final score for Criterion 10x – Escape of Secondary Species is 0 out of -10 for *L. vannamei*. The final score for Criterion 10x – Escape of Secondary Species is -8 out of -10 for *P. monodon*.

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

India

Semi-intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	5.00	Yellow	n/a
C2 Effluent	5.00	Yellow	No
C3 Habitat	0.67	Red	No
C4 Chemicals	0.00	Red	No
C5 Feed	3.21	Red	No
C6 Escapes	3.00	Red	No
C7 Disease	4.00	Yellow	No
C8X Source	0.00	Green	No
C9X Wildlife	-4.00	Yellow	No
C10X Introduction of secondary species	0.00	Green	n/a
Total	16.88		
Final score (0-10)	2.41		

OVERALL RANKING

Final Score	2.41
Initial rank	Red
Red criteria	4
Interim rank	Red
Critical Criteria?	0

Final Rank
Red

Black tiger shrimp

Penaeus monodon

India

Semi-intensive ponds

Criterion	Score	Rank	Critical?
C1 Data	4.09	Yellow	n/a
C2 Effluent	5.00	Yellow	No
C3 Habitat	0.67	Red	No
C4 Chemicals	0.00	Red	No
C5 Feed	2.78	Red	No
C6 Escapes	4.00	Yellow	No
C7 Disease	2.00	Red	No
C8X Source	-9.00	Red	No
C9X Wildlife	-4.00	Yellow	No
C10X Introduction of secondary species	-8.00	Red	n/a
Total	-2.47		
Final score (0-10)	-0.35		

OVERALL RANKING

Final Score	-0.35
Initial rank	Red
Red criteria	6
Interim rank	Red
Critical Criteria?	0

Final Rank
Red

Acknowledgements

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

Seafood Watch would like to thank the following individuals and organizations for their review of this document:

Sudhakar Mathsa
Thai Union Group
Aquaconnect
Global Aquaculture Alliance Best Aquaculture Practices
Lisa van Wageningen, IDH, The Sustainable Trade Initiative
Sreerupa Guha

Seafood Watch would also like to thank those reviewers that have chosen to remain anonymous.

References

Abraham, T.J., Mondal, A., Patra, A. and Adikesavalu, H., 2020. Prevalence of white spot virus and monodon baculovirus in shrimp culture systems of West Bengal, India. *Journal of Fisheries*.

Alavandi, S.V., Muralidhar, M., Dayal, J.S., Rajan, J.S., Praveena, P.E., Bhuvaneswari, T., Saraswathy, R., Chitra, V., Vijayan, K.K. and Otta, S.K., 2019. Investigation on the infectious nature of Running Mortality Syndrome (RMS) of farmed Pacific white leg shrimp, Penaeus vannamei in shrimp farms of India. *Aquaculture*, *500*, pp.278-289.

Anand, P.S., Balasubramanian, C.P., Christina, L., Kumar, S., Biswas, G., De, D., Ghoshal, T.K. and Vijayan, K.K., 2019. Substrate based black tiger shrimp, Penaeus monodon culture: Stocking density, aeration and their effect on growth performance, water quality and periphyton development. *Aquaculture*, *507*, pp.411-418.

Ananda Raja, R., Sridhar, R., Balachandran, C., Palanisammi, A., Ramesh, S. and Nagarajan, K., 2017. Prevalence of Vibrio spp. with special reference to Vibrio parahaemolyticus in farmed penaeid shrimp Penaeus vannamei (Boone, 1931) from selected districts of Tamil Nadu, India. *Indian Journal of Fisheries*, *64*, pp.122-128.

Aranguren, L.F., Han, J.E., Tang, K.F.J., 2017. Enterocytozoon hepatopenaei (EHP) is a risk factor for acute hepatopancreatic necrosis disease (AHPND) and septic hepatopancreatic necrosis (SHPN) in the Pacific white shrimp Penaeus vannamei. Aquaculture 471, 37–42. https://doi.org/10.1016/j.aquaculture.2016.12.038

Arulmoorthy, M.P., Anandajothi, E., Vasudevan, S. and Suresh, E., 2020. Major viral diseases in culturable penaeid shrimps: a review. *Aquaculture International*, *28*(5), pp.1939-1967.

Balakrishnan, G., Peyail, S., Kumaran, R., Theivasigamani, A., Anil, K.S., Jitesh, S.B. and Srinivasan, N., 2011. First report on white spot syndrome virus (WSSV) infection in white leg shrimp Litopenaeus vannamei (Crustacea, Penaeidae) under semi intensive culture condition in India. *Aquaculture, Aquarium, Conservation & Legislation*, *4*(3), pp.301-305.

Barbieri, E., Coa, F., Rezende, K.F.O., 2016. The exotic species Litopenaeus vannamei (Boone, 1931) occurrence in Cananeia, Iguape and Ilha Comprida lagoon estuary complex. Boletim do Instituto de Pesca 42, 479–485. https://doi.org/10.20950/1678-2305.2016v42n1p479

Behera, B.K., Das, A., Paria, P., Sahoo, A.K., Parida, P.K., Abdulla, T. and Das, B.K., 2019. Prevalence of microsporidian parasite, Enterocytozoon hepatopenaei in cultured Pacific White shrimp, Litopenaeus vannamei (Boone, 1931) in West Bengal, East Coast of India. *Aquaculture International*, *27*(2), pp.609-620.

Biju, N., Sathiyaraj, G., Raj, M., Shanmugam, V., Baskaran, B., Govindan, U., Kumaresan, G., Kasthuriraju, K.K. and Chellamma, T.S.R.Y., 2016. High prevalence of Enterocytozoon hepatopenaei in shrimps Penaeus monodon and Litopenaeus vannamei sampled from slow growth ponds in India. *Diseases of aquatic organisms*, *120*(3), pp.225-230.

Bir, J., Howlader, P., Ray, S., Sultana, S., Khalil, S.I. and Banu, G.R., 2017. A critical review on white spot syndrome virus (WSSV): A potential threat to shrimp farming in Bangladesh and some Asian countries. *International Journal of Microbiology and Mycology*, *6*(1), pp.39-48.

Boyd, C.E., McNevin, A.A., Davis, R.P., Godumala, R. and Mohan, A.B.C., 2018. Production methods and resource use at Litopenaeus vannamei and Penaeus monodon farms in India compared with previous findings from Thailand and Vietnam. *Journal of the World Aquaculture Society, 49*(3), pp.551-569.

Boyd, C.E., Tucker, C.S., McNevin, A, Bostick, K., and Clay, J. (2007). Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. Reviews in Fisheries Science. 15: 327-360.

Briggs, M., S. Funge-Smith, R. Subasinghe & M. Phillips. 2004. Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific. RAP publication 2004/10. Bangkok: Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific. 88 pp.

Chandrakala, N. and Rajeswari, S., Isolation and Screening of Vibrio spp. from Cultured and Wild Penaeus monodon (Fab) along the South East Coast of India. http://www.ijamicro.com/18-2-2015/03.pdf

Chavanich, S., Viyakarn, V., Senanan, W., Panutrakul, S., 2016. Laboratory assessment of feeding-behavior interactions between the introduced Pacific white shrimp Litopenaeus vannamei (Boone, 1931) (Penaeidae) and five native shrimps plus a crab species in Thailand. Aquatic Invasions 11, 67–74. https://doi.org/10.3391/ai.2016.11.1.07

CIBA, 2017. Annual Report 2016-17. Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India, pp. 208. https://krishi.icar.gov.in/jspui/handle/123456789/7310

CIBA, 2019. Annual Report 2019. Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India, pp. 240. http://www.ciba.res.in/stuff/AR2019.pdf

CMFRI 2019. Annual Report 2018-19. Central Marine Fisheries Research Institute, Kochi. pp. 320. http://eprints.cmfri.org.in/13922/

Coastal Aquaculture Authority (CAA), 2014. Compendium of Act, Rules, Guidelines, Regulations and Other Notifications (Updated March 2014), pages 244. http://www.caa.gov.in/uploaded/doc/COMPUPD2014.pdf

Dien, L.D., Van Hao, N., Sammut, J. and Burford, M.A., 2018. Comparing nutrient budgets in integrated rice-shrimp ponds and shrimp grow-out ponds. *Aquaculture*, *484*, pp.250-258.

Dissanayake, N.G., Frid, C.L., Drylie, T.P. and Caswell, B.A., 2018. Ecological functioning of mudflats: global analysis reveals both regional differences and widespread conservation of functioning. *Marine Ecology Progress Series*, *604*, pp.1-20.Giri et al., 2011

FAO Fisheries, Aquaculture Dept. Aquaculture Management, Conservation Service, Agriculture Organization of the United Nations. Aquaculture Management and Conservation Service, 2007. *Improving Penaeus Monodon hatchery practices: Manual based on experience in India* (No. 446). Food & Agriculture Org.

Fernández de Alaiza García Madrigal, R., da Silva, U. de A.T., Tavares, C.P. dos S., Ballester, E.L.C., 2018. Use of native and non-native shrimp (Penaeidae, Dendrobranchiata) in world shrimp farming. Reviews in Aquaculture 10, 899–912. https://doi.org/10.1111/raq.12206

Flegel, T. and Sritunyaluucksana, K., 2018. Recent Research on Acute Hepatopancreatic Necrosis Disease (AHPND) and Enterocytozoon hepatopenaei in Thailand. *ASIAN FISHERIES SOCIETY*, *31*, pp.257-269.

Flegel, T., Sritunyaluucksana, K., Thitamadee, S., 2015. Diseases of Crustaceans – *Hepatopancreatic microsporidiosis* caused by Enterocytozoon hepatopenaei (EHP). NACA Disease Card. https://enaca.org/?id=723

Flegel, T.W., 2019. A future vision for disease control in shrimp aquaculture. Journal of the World Aquaculture Society 50, 249–266. https://doi.org/10.1111/jwas.12589

Food and Agriculture Organization of the United Nations (FAO), 1986. Shrimp Culture: Pond Design, Operation and Management. NACA Training Manual Series No. 2. Available at: http://www.fao.org/3/contents/76b2641d-29e4-51b0-b9e5-6ca46beb0d9f/AC210E00.htm

Ghoshal, T.K., De, D., Biswas, G., Kumar, P. and Vijayan, K.K., 2019. Brackishwater aquaculture: opportunities and challenges for meeting livelihood demand in Indian sundarbans. In *The Sundarbans: A Disaster-Prone Eco-Region* (pp. 321-349). Springer, Cham.

Girijan, S.K., Paul, R., VJ, R.K. and Pillai, D., 2020. Investigating the impact of hospital antibiotic usage on aquatic environment and aquaculture systems: A molecular study of quinolone resistance in Escherichia coli. *Science of The Total Environment*, *748*, p.141538.

Gräslund, S. and Bengtsson, B.E., 2001. Chemicals and biological products used in south-east Asian shrimp farming, and their potential impact on the environment—a review. *Science of the total Environment*, *280*(1-3), pp.93-131.

Green, B. W., Teichert-Coddington, D. R., Boyd, C. E., Harvin, J. L., Corrales, H. L., Zelaya, R., & Ramirez, E. (1997). The effects of pond management strategies on nutrient budgets, Honduras. Pond Dynamics/Aquaculture Collaborative Research Support Program, Fourteenth Annual Technical Report. PD/A CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, 8-121.

Hamza, F., Valsala, V., Mallissery, A. and George, G., 2021. Climate impacts on the landings of Indian oil sardine over the south-eastern Arabian Sea. *Fish and Fisheries*, *22*(1), pp.175-193.

Hein, L.G., 2000. Impact of shrimp farming on mangroves along India's East Coast. *Unasylva*, *51*(203), pp.48-55.

Holmström, K., Gräslund, S., Wahlström, A., Poungshompoo, S., Bengtsson, B.E. and Kautsky, N., 2003. Antibiotic use in shrimp farming and implications for environmental impacts and human health. *International journal of food science & technology*, *38*(3), pp.255-266.

Jagadeesan, V., Praveena, P.E., Bhuvaneshwari, T., Jithendran, K.P. and Otta, S.K., 2017. Screening of Penaeus vannamei Boone, 1931 collected from east coast of India for monodon baculovirus (MBV) and hepatopancreatic parvovirus (HPV).

Jannathulla, R., Dayal, J.S., Ambasankar, K. and Muralidhar, M., 2018c. Effect of Aspergillus niger fermented soybean meal and sunflower oil cake on growth, carcass composition and haemolymph indices in Penaeus vannamei Boone, 1931. *Aquaculture*, *486*, pp.1-8.

Jannathulla, R., Dayal, J.S., Ambasankar, K., Eugine, A.C. and Muralidhar, M., 2018b. Fungus, Aspergillus niger, fermented groundnut oil cake as a fishmeal alternative in the diet of Penaeus vannamei. *Aquaculture Research*, *49*(8), pp.2891-2902.

Jannathulla, R., Dayal, J.S., Vasanthakumar, D., Ambasankar, K. and Muralidhar, M., 2018. Effect of fungal fermentation on apparent digestibility coefficient for dry matter, crude protein and amino acids of various plant protein sources in Penaeus vannamei. *Aquaculture Nutrition*, *24*(4), pp.1318-1329.

Jayanthi, M., Muralidhar, M., Kumaran, M. and Vijayan, K.K., 2017. Improving shrimp farm design in flood-prone areas of India. *Global Aquaculture Advocate*. https://www.aquaculturealliance.org/advocate/shrimp-farm-design-improvements-india/

Jayanthi, M., Ravisankar, T., Nagaraj, G., Thirumurthy, S., Muralidhar, M. and Saraswathy, R., 2019. Is aquaculture abandonment a threat to sustainable coastal resource use?–a case study of Andhra Pradesh, India, with options for reuse. *Land Use Policy*, *86*, pp.54-66.

Jayanthi, M., Thirumurthy, S., Muralidhar, M. and Ravichandran, P., 2018. Impact of shrimp aquaculture development on important ecosystems in India. *Global Environmental Change*, *52*, pp.10-21.

Jayanthi, M., Thirumurthy, S., Samynathan, M., Duraisamy, M., Muralidhar, M., Ashokkumar, J. and Vijayan, K.K., 2018b. Shoreline change and potential sea level rise impacts in a climate hazardous location in southeast coast of India. *Environmental monitoring and assessment*, *190*(1), pp.1-14.

Jayaraman, R., 2017. Sustainable coastal aquaculture in India. *Aquaculture Asia Magazine*, *21*(2), pp.21-23.

Joint Committee, 2020. Joint Committee Report In Application No.91 of 2020(SZ). Accessed online on 28 July 2021: https://greentribunal.gov.in/sites/default/files/news_updates/9120%20Report.pdf

Joseph, T.C., James, R., Rajan, L.A., Surendran, P.K. and Lalitha, K.V., 2015. Occurrence of viral pathogens in Penaeus monodon post-larvae from aquaculture hatcheries. *Data in Brief*, *4*, pp.170-176.

Joseph, T.C., James, R., Rajan, L.A., Surendran, P.K. and Lalitha, K.V., 2015b. White spot syndrome virus infection: Threat to crustacean biodiversity in Vembanad Lake, India. *Biotechnology Reports*, *7*, pp.51-54.

Khedkar, G.D., Reddy, A.C., Ron, T.B., Haymer, D. (2013). High levels of genetic diversity in Penaeus monodon populations from the east coast of India. SpringerPlus 2:671.

Kmmari, S., Rathlavath, S., Pillai, D., Rajesh, G., 2018. Hepatopancreatic Microsporidiasis (HPM) in Shrimp Culture: A Review. International Journal of Current Microbiology and Applied Sciences 7, 3208–3215. https://doi.org/10.20546/ijcmas.2018.701.383

Kumar, B.K., Deekshit, V.K., Raj, J.R.M., Rai, P., Shivanagowda, B.M., Karunasagar, I. and Karunasagar, I., 2014b. Diversity of Vibrio parahaemolyticus associated with disease outbreak among cultured Litopenaeus vannamei (Pacific white shrimp) in India. *Aquaculture*, *433*, pp.247-251.

Kumar, R., Ng, T. H., & Wang, H. C. (2020). Acute hepatopancreatic necrosis disease in penaeid shrimp. Reviews in Aquaculture, 12(3), 1867-1880.

Kumar, S., Anand, P.S., De, D., Sundaray, J.K., Raja, R.A., Biswas, G., Ponniah, A.G., Ghoshal, T.K., Deo, A.D., Panigrahi, A. and Muralidhar, M., 2014. Effects of carbohydrate supplementation on water quality, microbial dynamics and growth performance of giant tiger prawn (Penaeus monodon). *Aquaculture international*, *22*(2), pp.901-912.

Kumar, T.S., Krishnan, P., Makesh, M., Chaudhari, A., Purushothaman, C.S. and Rajendran, K.V., 2011. Natural host-range and experimental transmission of Laem-Singh virus (LSNV). *Diseases of aquatic organisms*, *96*(1), pp.21-27.

Kumaran, M., Sundaram, M., Mathew, S., Anand, P.R., Ghoshal, T.K., Kumararaja, P., Anandaraja, R., Anand, S. and Vijayan, K.K., 2020. Is Pacific white shrimp (Penaeus vannamei) farming in India sustainable? A multidimensional indicators-based assessment. *Environment, Development and Sustainability*, pp.1-15.

Kummari, S., Haridas, D.V., Handique, S., Peter, S., Rakesh, C.G., Sneha, K.G., Manojkumar, B. and Pillai, D., 2018. Incidence of hepatopancreatic microsporidiasis, by enterocytozoon hepatopenaei (EHP) in Penaeus vannamei culture in Nellore District, Andhra Pradesh, India and the role of management in its prevention and transmission. *Int. J. Curr. Microbiol. App. Sci*, *7*(2), pp.2125-2134.

Kundu, S., Rath, S., Tyagi, K., Chakraborty, R. and Kumar, V., 2018. Identification of penaeid shrimp from Chilika Lake through DNA barcoding. *Mitochondrial DNA Part B*, *3*(1), pp.161-165.

Limsuwan, C., 2010. White feces disease in Thailand. *Buletines Nicovita Mgazine. Thailand*, *3*. http://www.nicovita.com/en/extranet/Boletines/Abril-Junio_2010.pdf

Lira, C. and Vera-Caripe, J., 2016. Alien marine decapod crustaceans in the Caribbean: a review with first record of Athanas dimorphus. Ortmann, 1894 (Caridea: Alpheidae). *Acta Biologica Venezuelica*, *36*(1), pp.1-17.

Mandal, A., Rao, D., Karuppaiah, D., Gopalakrishnan, A., Pozhoth, J., Samraj, Y.C., & Doyle, R.W. (2012). Population genetic structure of Penaeus monodon, in relation to monsoon current patterns in Southwest, East and Andaman coastal waters of India. Gene. 491(2):149-57.

Marine Products Exports Development Authority (MPEDA), 2021. State-wise details of Shrimp and Scampi Production. Accessed online 2nd March 2021 at: https://mpeda.gov.in/?page_id=651

Mastan, S.A. and Begum, S.A., 2016. Vibriosis in farm reared white shrimp, Litopenaeus vannamei in Andhra Pradesh-natural occurrence and artificial challenge. *International Journal of Applied Sciences and Biotechnology*, *4*(2), pp.217-222.

Ministry of Agriculture (MoA). (2009). G.S.R.302(E).

Mohan CV, De Silva SS (2010) Better management practices (BMPs) — gateway to ensuring sustainability of small scale aquaculture and meeting modern day market challenges and opportunities. Aquacult Asia 15: 9−14

Mohanty, R.K. and Mohapatra, A., 2017. Cyclic feed restriction on growth compensation of Penaeus monodon (Fabricius): science meets practice.

Mondal, D. and Mandal, N., 2020. Ecological perspective of disease-resistance prevalence in Penaeus monodon. *Transboundary and Emerging Diseases*.

Muralidhar, M., Kumaran, M., Jayanthi, M., Muniyandi, B., Ponniah, A.G., Nagothu, U.S., White, P. and Eknath, A., 2012. Case study on the impacts of climate change on shrimp farming and developing adaptation measures for small-scale shrimp farmers in Krishna District, Andhra Pradesh, India, Network of Aquaculture Centers in Asia-Pacific, 126 p. *The report is also available online*.

Naik, M.K., Reddy, M.H. and Reddy, M.S., 2020b. Occurrence of loose shell syndrome disease in culture operation of shrimp Litopenaeus vannamei in different regions of Andhra Pradesh. https://www.fisheriesjournal.com/archives/2020/vol8issue4/PartD/8-4-41-388.pdf

Naik, R., Maheswarudu, G., Jayasankar, J., Varma, J.B., Rao, K. and Rao, T.N., 2020. Appraisal of penaeid prawn fishery by large mechanized trawlers (Sona boats) off Visakhapatnam, SE coast of India. *Journal of Entomology and Zoology Studies*, *8*(4), pp.699-703.

Nair, S. (2015). Shrimp Aquaculture in Ca Mau, Vietnam. *with Tanja Havemann*, 123. Available at: http://ecoagriculture.org/wp-content/uploads/2015/08/Steps-Toward-Green-Book-File-Final-for-Upload.pdf

National Marine Fisheries Service (NMFS), 2021. Foreign Fishery Trade Data. Accessed online 02 March 2021 at: https://www.fisheries.noaa.gov/foss/f?p=215:2:5928391148224::NO:::

Navaneeth, K.A., Bhuvaneswari, T., Rajan, J.J.S., Alavandi, S.V., Vijayan, K.K. and Otta, S.K., 2020. Characterization of Vibrio parahaemolyticus isolates from shrimp farms of Southeast coast of India with special reference to Acute Hepatopancreatic Necrosis Disease (AHPND) status. *Aquaculture*, *518*, p.734813.

Padiyar P, Phillips M, Primphon M, Mohan C and others (2003) Extension in shrimp health management:experiences from an MPEDA/NACA program in Andhra Pradesh, India. Aquacult Asia 8: 7−13

Palaniyappan, V., Nagalingam, A.K., Ranganathan, H.P., Kandhikuppam, K.B., Kothandam, H.P. and Vasu, S., 2013. Antibiotics in South Indian coastal sea and farmed prawns (Penaeus monodon). *Food Additives & Contaminants: Part B*, *6*(3), pp.196-199.

Panutrakul, S., Senanan, W., Chavanich, S., Tangkrock-Olan, N., Viyakarn, V., 2010. Ability of Litopenaeus vannamei to survive and compete with local marine shrimp species in the Bangpakong River, Thailand., in: Hoanh, C.T., Szuster, B., Kam, S., Ismail, A., Noble, A. (Eds.), Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land and Water Interface. CABI, Wallingford, pp. 80–92. https://doi.org/10.1079/9781845936181.0080

Parvez, S. and Vijaya, C., 2020. Studies on the Antibiotic Usage in Aquaculture Practices of Selected Areas in Andhra Pradesh, India. *International Journal of Recent Innovations in Academic Research*, *4*(4), pp.34-40.

Patel, A., Jeyasekaran, G., Jeyashakila, R., Anand, T., Wilwet, L., Pathak, N., Malini, A.H. and Neethiselvan, N., 2020. Prevalence of antibiotic resistant Salmonella spp. strains in shrimp farm source waters of Nagapattinam region in South India. *Marine Pollution Bulletin*, *155*, p.111171.

Pathak, S.C., Ghosh, S.K. and Palanisamy, K., 2000. The use of chemicals in aquaculture in India. In *Use of Chemicals in Aquaculture in Asia: Proceedings of the Meeting on the Use of Chemicals in Aquaculture in Asia 20-22 May 1996, Tigbauan, Iloilo, Philippines* (pp. 87-112). Aquaculture Department, Southeast Asian Fisheries Development Center.

Patil, P.K., Geetha, R., Ravisankar, T., Avunje, S., Solanki, H.G., Abraham, T.J., Vinoth, S.P., Jithendran, K.P., Alavandi, S.V. and Vijayan, K.K., 2020. Economic loss due to diseases in Indian shrimp farming with special reference to Enterocytozoon hepatopenaei (EHP) and white spot syndrome virus (WSSV). *Aquaculture*, p.736231.

Perez-Velazquez, M., González-Félix, M.L., Zúñiga-Panduro, M., Barraza-Guardado, R.H., 2010. Evidence of pre-zygotic barriers in attempts to cross-breed Penaeus (Litopenaeus) vannamei (Boone) and P. (Litopenaeus) stylirostris (Stimpson) by means of artificial insemination. Aquaculture 304, 100–103. https://doi.org/10.1016/j.aquaculture.2010.03.021

Piamsomboon, P., Inchaisri, C., Wongtavatchai, J., 2016. Climate factors influence the occurrence of white spot disease in cultured penaeid shrimp in Chanthaburi province, Thailand. Aquaculture Environment Interactions 8, 331–337. https://doi.org/10.3354/aei00176

Puthucherril, T.G., 2016. Sustainable aquaculture in India: looking back to think ahead. In *Aquaculture Law and Policy*. Edward Elgar Publishing.

Rabobank, 2019. Trade dynamics in key aquaculture industries. Presented at GOAL 2019 – Chennai, India. Accessed online 13 January 2020 at: https://docplayer.net/164294272-Trade-dynamics-in-key-aquaculture-industries.html

Raja, S., Kumaran, M. and Ravichandran, P., 2012. Implementation of Biosecurity Measures in Commercial Shrimp Hatcheries in India. https://www.researchgate.net/profile/Selvaraju_Raja/publication/263966940_Implementation_of_Biosecurity_Measures_in_Commercial_Shrimp_Hatcheries_in_India/links/0deec53c72b619059b000000/Implementation-of-Biosecurity-Measures-in-Commercial-Shrimp-Hatcheries-in-India.pdf

Rajendran, K.V., Shivam, S., Praveena, P.E., Rajan, J.J.S., Kumar, T.S., Avunje, S., Jagadeesan, V., Babu, S.P., Pande, A., Krishnan, A.N. and Alavandi, S.V., 2016. Emergence of Enterocytozoon hepatopenaei (EHP) in farmed Penaeus (Litopenaeus) vannamei in India. *Aquaculture*, *454*, pp.272-280.

Ramasamy, P., 2018. Sujatha Ran j, Gunasekaran DR. Assessment of antibiotic sensitivity and pathogenicity of Vibrio spp. and Aeromonas spp. from aquaculture environment. *MOJ. Eco. Environ. Sci*, *3*(3), pp.128-136.

Rao, B.M. and Prasad, M.M., 2015. Residues of Veterinary Medicinal Products (antibiotics) in shrimp exported from India to the European Union (EU) trends in the last decade.

Rao, N.V. and Satyanarayana, A., 2020. Running Mortality Syndrome (RMS)-A New Disease that Struck the Indian Shrimp Industry. *Int. J. Curr. Microbiol. App. Sci*, *9*(1), pp.1928-1934.

Rathipriya, A., Anand, T., Uma, A. and Marx, K.K., 2019. Prevalence of Diseases caused by White Spot Virus and Enterocytozoon Hepatopenaei in Penaeus vannamei Shrimp Farms in Nagapattinam District, Tamil Nadu, India. *Int. J. Curr. Microbiol. App. Sci*, *8*(6), pp.2616-2622.

Ray, A.K., Gopal, C., Solanki, H.G., Ravisankar, T. and Patil, P.K., 2017. Effect of orally administered vibrio bacterin on immunity, survival and growth in tiger shrimp (Penaeus monodon) grow-out culture ponds. *Letters in applied microbiology*, *65*(6), pp.475-481.

Rico, A., Satapornvanit, K., Haque, M.M., Min, J., Nguyen, P.T., Telfer, T.C., van den Brink, P.J., 2012. Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: a critical review: Environmental risks of Asian aquaculture. Reviews in Aquaculture 4, 75–93. https://doi.org/10.1111/j.1753-5131.2012.01062.x

Rico, A., Van den Brink, P.J., 2014. Probabilistic risk assessment of veterinary medicines applied to four major aquaculture species produced in Asia. Science of The Total Environment 468–469, 630–641. https://doi.org/10.1016/j.scitotenv.2013.08.063

Roshnath, R., 2014. Fishing for living; Shrimp farmer's perception of heronry birds in Kannur District Kerala, India. *International Journal of Research*, *1*(6), pp.188-199.

Roshnath, R., Chandramohan, B. and Ashokkumar, M., 2014. BIRD MENACE: STATUS, THREATS AND MITIGATION MEASURES IN SHRIMP FARMS OF CUDDALORE AND VILLUPURAM DISTRICT OF TAMIL NADU, INDIA. *Journal of FisheriesSciences. com*, *8*(4), p.303.

Roy, A.K., Naskar, M., Chakraborty, T., Neogy, S. and Datta, D., 2021. Assessing the impact of aquafarming on landscape dynamics of coastal West Bengal, India using remotely sensed data and spatial metrics. In *Remote Sensing of Ocean and Coastal Environments* (pp. 117-138). Elsevier.

Sahu, S., Biswas, P.K., Dora, K.C., Adhikari, S., Maity, A. and Majhi, A., 2013. Management strategy for shrimp (Penaeus Monodon, Fabricius) farming at Bhagbanpur region in Purba Medinipur District of West Bengal, India. *Exploratory Animal and Medical Research*, *3*(1), pp.65-69.

Sahul Hameed, A.S., Abdul Majeed, S., Vimal, S., Madan, N., Rajkumar, T., Santhoshkumar, S. and Sivakumar, S., 2017. Studies on the occurrence of infectious myonecrosis virus in pond-reared Litopenaeus vannamei (Boone, 1931) in India. *Journal of fish diseases*, *40*(12), pp.1823-1830.

Salunke, M., Kalyankar, A., Khedkar, C.D., Shingare, M. and Khedkar, G.D., 2020. A Review on Shrimp Aquaculture in India: Historical Perspective, Constraints, Status and Future Implications for Impacts on Aquatic Ecosystem and Biodiversity. *Reviews in Fisheries Science & Aquaculture*, pp.1-20.

Sanathkumar, H., Ravi, C., Padinhatupurayil, S.B., Mol, M., Prasad, J.K. and Nayak, B.B., 2014. Microbiological investigation of persistent mortalities in Litopenaeus vannamei grown in low saline waters in India. *Journal of aquatic animal health*, *26*(3), pp.154-159.

Sandilyan, S., Thiyagesan, K. and Nagarajan, R., 2010. Major decline in species-richness of waterbirds in the Pichavaram mangrove wetlands, southern India. *Wader Study Group Bull*, *117*(2), pp.91-98.

Sanguanrut, P., Munkongwongsiri, N., Kongkumnerd, J., Thawonsuwan, J., Thitamadee, S., Boonyawiwat, V., Tanasomwang, V., Flegel, T.W., Sritunyalucksana, K., 2018. A cohort study of 196 Thai shrimp ponds reveals a complex etiology for early mortality syndrome (EMS). Aquaculture 493, 26–36. https://doi.org/10.1016/j.aquaculture.2018.04.033

Saravanan, K., Kumar, P.P., Baruah, A., Praveenraj, J., Kumar, T.S., Kumar, S.P., Sivaramakrishnan, T., Anuraj, A., Angel, J.R.J., Sankar, R.K. and Roy, S.D., 2017. IHHNV infection from the wild shrimps of Andaman and Nicobar Islands, India. https://pdfs.semanticscholar.org/2b4e/25562297f10ff65337a0f76f76996814a33b.pdf

Sarkar, D.J., Mukherjee, I., Shakil, N.A., Rana, V.S., Kaushik, P. and Debnath, S., 2019. Antibiotics in agriculture: use and impact.

Seafood Trade Intelligence Portal (STIP), 2020. Shrimp in India. Accessed online 9th December 2020 at: https://seafood-tip.com/sourcing-intelligence/countries/india/shrimp/

Senanan, W., Panutrakul, S., Barnette, P., Manthachitra, V., Chavanich, S., Kapuscinski, A.R., Tangkrock-Olan, N., Intacharoen, P., Viyakarn, V., Wongwiwatanawute, C., Padetpai, K., 2010. Ecological risk assessment of an alien aquatic species: a case study of Litopenaeus vannamei (Pacific whiteleg shrimp) aquaculture in the Bangpakong River, Thailand, in: Hoanh, C.T., Szuster, B., Kam, S., Ismail, A., Noble, A. (Eds.), Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land and Water Interface. CABI, Wallingford, pp. 64–79. https://doi.org/10.1079/9781845936181.0064

Senanan, W., Tangkrock-Olan, N., Panutrakul, S., Barnette, P., Wongwiwatanawute, C., Niphonkit, N., Anderson, D.J., 2007. THE PRESENCE OF THE PACIFIC WHITELEG SHRIMP (LITOPENAEUS VANNAMEI, BOONE, 1931) IN THE WILD IN THAILAND. Journal of Shellfish Research 26, 1187–1192. https://doi.org/10.2983/0730-8000(2007)26[1187:TPOTPW]2.0.CO;2

Senapin, S., Phiwsaiya, K., Gangnonngiw, W. and Flegel, T.W., 2011. False rumours of disease outbreaks caused by infectious myonecrosis virus (IMNV) in the whiteleg shrimp in Asia. *Journal of negative results in biomedicine*, *10*(1), pp.1-5.

Shyam, K.U., Jeena, K., Paniprasad, K., Rathore, G. and Tripathi, G., 2017. Surveillance for infectious myonecrosis virus in Indian shrimp aquaculture. *Indian J. Fish*, *64*(2), pp.69-75.

Silvester, R., Alexander, D., George, M. and Hatha, A.A.M., 2017. Prevalence and multiple antibiotic resistance of Vibrio coralliilyticus, along the southwest coast of India. *Current Science (00113891)*, *112*(8).

Silvester, R., Pires, J., Van Boeckel, T.P., Madhavan, A., Balakrishnan Meenakshikutti, A. and Hatha, M., 2019. Occurrence of β-Lactam Resistance Genes and Plasmid-Mediated Resistance Among Vibrios Isolated from Southwest Coast of India. *Microbial Drug Resistance*, *25*(9), pp.1306-1315.

Sivagami, K., Vignesh, V.J., Srinivasan, R., Divyapriya, G. and Nambi, I.M., 2020. Antibiotic usage, residues and resistance genes from food animals to human and environment: An Indian scenario. *Journal of Environmental Chemical Engineering*, *8*(1), p.102221.

Sivaraman, I., Krishnan, M. and Radhakrishnan, K., 2018. Better Management Practices for sustainable small-scale shrimp farming. *Journal of Cleaner Production*, *214*, pp.559-572.

Srinivas, D., Venkatrayalu, C. and Laxmappa, B., 2016. Identifying diseases affecting farmed Litopenaeus vannamei in different areas of Nellore district in Andhra Pradesh, India. *International Journal of Fisheries and Aquatic Studies*, *4*(2), pp.447-451.

Srisala, J., Sanguanrut, P., Laiphrom, S., Siriwattano, J., Khudet, J., Thaiue, D., Powtongsook, S., Flegel, T.W. and Sritunyalucksana, K., 2020. Infectious myonecrosis virus (IMNV) and decapod iridescent virus 1 (DIV1) detected in Penaeus monodon from the Indian Ocean. *bioRxiv*.

Sriurairatana, S., Boonyawiwat, V., Gangnonngiw, W., Laosutthipong, C., Hiranchan, J., Flegel, T.W., 2014. White Feces Syndrome of Shrimp Arises from Transformation, Sloughing and Aggregation of Hepatopancreatic Microvilli into Vermiform Bodies Superficially Resembling Gregarines. PLoS ONE 9, e99170. https://doi.org/10.1371/journal.pone.0099170

Surendran, P.K., 2003. Antibiotic residues in seafood-a hazard.

Swapna, K.M., Rajesh, R. and Lakshmanan, P.T., 2012. Incidence of antibiotic residues in farmed shrimps from the southern states of India.

Tacon, A.G. and Metian, M., 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, *285*(1-4), pp.146-158.

Tacon, A.G.J., 2018. Global trends in aquaculture and compound aquafeed production. World Aquaculture, June 2018, pp.33-46.

Tamilarasu, A., Nethaji, M., Bharathi, S., Lloyd Chrispin, C. and Somu Sunder Lingam, R., Review on the emerging white feces syndrome in shrimp industry. https://www.researchgate.net/profile/Bharathi_Subramaniam/publication/344359628_Review_on_the_emerging_white_faeces_syndrome_in_shrimp_industry/links/5f6c045a299bf1b53eedc441/Review-on-the-emerging-white-faeces-syndrome-in-shrimp-industry.pdf

Tandel, G.M., John, K.R., George, M.R. and Jeyaseelan, M.P., 2017. Current status of viral diseases in Indian shrimp aquaculture. *Acta virologica*, *61*(2), pp.131-137.

Tang, K.F.J., Han, J.E., Aranguren, L.F., White-Noble, B., Schmidt, M.M., Piamsomboon, P., Risdiana, E., Hanggono, B., 2016. Dense populations of the microsporidian Enterocytozoon hepatopenaei (EHP) in feces of Penaeus vannamei exhibiting white feces syndrome and pathways of their transmission to healthy shrimp. Journal of Invertebrate Pathology 140, 1–7. https://doi.org/10.1016/j.jip.2016.08.004

Tangprasittipap, A., Srisala, J., Chouwdee, S., Somboon, M., Chuchird, N., Limsuwan, C., Srisuvan, T., Flegel, T.W., Sritunyalucksana, K., 2013. The microsporidian Enterocytozoon hepatopenaei is not the cause of white feces syndrome in whiteleg shrimp Penaeus (Litopenaeus) vannamei. BMC Veterinary Research 9, 139. https://doi.org/10.1186/1746-6148-9-139

Thitamadee, S., Prachumwat, A., Srisala, J., Jaroenlak, P., Salachan, P.V., Sritunyalucksana, K., Flegel, T.W., Itsathitphaisarn, O., 2016. Review of current disease threats for cultivated penaeid shrimp in Asia. Aquaculture 452, 69–87. https://doi.org/10.1016/j.aquaculture.2015.10.028
Thitamadee, S., Prachumwat, A., Srisala, J., Jaroenlak, P., Salachan, P.V., Sritunyalucksana, K., Flegel, T.W., Itsathitphaisarn, O., 2016. Review of current disease threats for cultivated penaeid shrimp in Asia. Aquaculture 452, 69–87. https://doi.org/10.1016/j.aquaculture.2015.10.028
Thornber, K., Verner-Jeffreys, D., Hinchliffe, S., Rahman, M.M., Bass, D. and Tyler, C.R., 2020. Evaluating antimicrobial resistance in the global shrimp industry. *Reviews in Aquaculture*, *12*(2), pp.966-986.

Towers, L. 2016. The Fish Site – Management of intensive Vannamei shrimp ponds. Accessed online 13 January 2020 at: https://thefishsite.com/articles/management-of-vannamei-shrimp-culture-ponds-with-high-stocking-density-zero-water-exchange-in-relation-to-growth-survival-and-water-quality

Uddin, S.N., Maity, J. and Ghosh, S., 2021. Study the present trawl fishery of Penaeus monodon (Fabricius, 1798) in coastal waters off digha coast, West Bengal, India.

Ulate, K., Alfaro-Montoya, J., 2010. Sperm–egg incompatibility in inter-specific inseminations of Penaeus (Litopenaeus) occidentalis, P. (Litopenaeus) stylirostris and P. (Litopenaeus) vannamei. Aquaculture 309, 290–292. https://doi.org/10.1016/j.aquaculture.2010.08.029

Valderrama, D., Iyemperumal, S. and Krishnan, M., 2014. Building consensus for sustainable development in aquaculture: a delphi study of better management practices for shrimp farming in India. *Aquaculture Economics & Management*, *18*(4), pp.369-394.

Van Nguyen, H. and Maeda, M., 2015. Nutrient mass balances in intensive shrimp ponds with a sludge removal regime: A case study in the Tam Giang Lagoon, central Vietnam. *Journal of Agricultural Science and Technology A & B & Hue University Journal of Science*, *5*, pp.539-548.

Venkatesh, P., Kumar, N.A., Prasad, R.H., Krishnamoorthy, K.B., Prasath, K.H. and Soumya, V., 2013. LC–MS/MS analysis of tetracycline antibiotics in prawns (Penaeus monodon) from south India coastal region. *Journal of pharmacy research*, *6*(1), pp.48-52.

Venkateswarlu, V. and Venkatrayulu, C., 2019. Prevalence of disease problems affecting shrimp Litopenaeus vannamei farming in Andhra Pradesh, India. https://www.fisheriesjournal.com/archives/2019/vol7issue5/PartD/7-5-1-604.pdf

Vijayan, K.K. and Balasubramanian, C.P., 2019. aquaculture in India: A driver for Blue economy. https://www.researchgate.net/profile/Balasubramanian_C_P/publication/340091750_Brackishwater_aquaculture_in_India_A_driver_for_Blue_economy/links/5e7798c6299bf1892c01fd2f/Brackishwater-aquaculture-in-India-A-driver-for-Blue-economy.pdf

Vinod, B., Haq, M.B., Prathap, T., Meetei, K., Baharlooeian, M., Sureandiran, B. and Tiwary, C., Surveillance of White feces syndrome (WFS) in penaeid shrimps captured from the Tuticorin group of islands near an area of semi intensive aquaculture activity. https://www.researchgate.net/profile/Haq_Badhul/publication/345980749_Surveillance_of_White_feces_syndrome_WFS_in_penaeid_shrimps_captured_from_the_Tuticorin_group_of_islands_near_an_area_of_semi_intensive_aquaculture_activity/links/5fb3c9cc92851cf24cd8992b/Surveillance-of-White-feces-syndrome-WFS-in-penaeid-shrimps-captured-from-the-Tuticorin-group-of-islands-near-an-area-of-semi-intensive-aquaculture-activity.pdf

Wakida-Kusunoki, A., Amador-del-Angel, L., Alejandro, P., Brahms, C., 2011. Presence of Pacific white shrimp Litopenaeus vannamei (Boone, 1931) in the Southern Gulf of Mexico. Aquatic Invasions 6, S139–S142. https://doi.org/10.3391/ai.2011.6.S1.031

World Organisation for Animal Health (OIE), 2018. Manual of Diagnostic Tests for Aquatic Animals. http://www.oie.int/en/standard-setting/aquatic-manual/access-online/

Appendix 1 - Data points and all scoring calculations

Litopenaeus vannamei – semi-intensive ponds

Criterion 1: Data	
Data Category	**Data Quality**
Production	5.0
Management	5.0
Effluent	5.0
Habitat	5.0
Chemical Use	2.5
Feed	2.5
Escapes	2.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	2.5
Escape of secondary species	10.0
C1 Data Final Score (0-10)	**5.000**
	Yellow

	Shrimp

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**6**
Critical?	NO

Select the species or "System" from the list Shrimp

Only select "System" if C2 was done as a multi-species risk-based assessment.

Criterion 2 - Effluent Risk-based assessment	
2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	35.500
eFCR	1.400
Fertilizer N input (kg N/ton fish)	1.200
Protein content of harvested fish (%)	17.800
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	80.720
N output in each ton of fish harvested (kg)	28.480
Waste N produced per ton of fish (kg)	52.240

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.420
Adjustment 1 (if applicable)	-0.200
Adjustment 2 (if applicable)	0.000
Adjustment 3 (if applicable)	0.000
Boundary adjustment (if applicable)	0.000
Discharge (Factor 2.1b) score (0-1)	0.220
Waste discharged per ton of production (kg N ton-1)	11.493
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	1
2.2 Effluent management effectiveness	1.200
C2 Effluent Final Score (0-10)	**5**
Critical?	No

C3 applies to all species

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	1
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	0
3.2 Habitat management effectiveness	0.000
C3 Habitat Final Score (0-10)	**0.667**
Critical?	No

For C4, copy either the single species table or the all-species "system" table below

Single species

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

Shrimp

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

Select the species or "System" again from the list — Shrimp

Only select "System" if the C5 Feed Assessment was done as a multi-species system.

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 %	8.250
Fishmeal from byproducts, weighted inclusion %	6.750
Byproduct fishmeal inclusion (@ 5%)	0.338
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.630
Fish oil from byproducts, weighted inclusion %	0.460
Byproduct fish oil inclusion (@ 5%)	0.023
Fish oil yield value, weighted %	5.000
eFCR	1.400
FFER Fishmeal value	**0.534**
FFER Fish oil value	**0.183**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	0.950
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	**1.920**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	35.500
Protein INPUT kg/100kg harvest	49.700
Whole body harvested fish protein content	17.800
Net protein gain or loss	-64.185
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)	**14.714**
Contribution (%) from fishmeal from whole fish	4.108
Contribution (%) from fish oil from whole fish	3.361
Contribution (%) from fishmeal from byproducts	0.220
Contribution (%) from fish oil from byproducts	0.160
Contribution (%) from crop ingredients	92.125
Contribution (%) from land animal ingredients	0.000
Contribution (%) from other ingredients	0.025
Factor 5.3 score	**6**
C5 Final Feed Criterion Score	**3.2**
Critical?	**No**

Select species again Shrimp

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	1
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	1.000
F6.2 Invasiveness score	6
C6 Escape Final Score (0-10)	**3.0**
Critical?	No

Shrimp

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

Shrimp

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

	Shrimp

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	-4
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-4**
Critical?	No

	Shrimp

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	100
Factor 10Xa score	0
Biosecurity of the source of movements (0-10)	10
Biosecurity of the farm destination of movements (0-10)	2
Species-specific score 10X score	0.000
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**0.000**
Critical?	n/a

Penaeus monodon – semi-intensive ponds

Criterion 1: Data	
Data Category	**Data Quality**
Production	5.0
Management	5.0
Effluent	5.0
Habitat	5.0
Chemical Use	2.5
Feed	2.5
Escapes	7.5
Disease	5.0
Source of stock	2.5
Wildlife mortalities	2.5
Escape of secondary species	2.5
C1 Data Final Score (0-10)	**4.091**
	Yellow

	Shrimp

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**6**
Critical?	NO

Select the species or "System" from the list Shrimp

Only select "System" if C2 was done as a multi-species risk-based assessment.

Criterion 2 - Effluent Risk-based assessment	
2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	38.000
eFCR	1.500
Fertilizer N input (kg N/ton fish)	8.500
Protein content of harvested fish (%)	18.900
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	99.700
N output in each ton of fish harvested (kg)	30.240
Waste N produced per ton of fish (kg)	69.460

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.510

Adjustment 1 (if applicable)	-0.240
Adjustment 2 (if applicable)	0.000
Adjustment 3 (if applicable)	0.000
Boundary adjustment (if applicable)	0.000
Discharge (Factor 2.1b) score (0-1)	0.270
Waste discharged per ton of production (kg N ton-1)	18.754
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	1
2.2 Effluent management effectiveness	1.200
C2 Effluent Final Score (0-10)	**5**
Critical?	No

C3 applies to all species

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	1
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	0
3.2 Habitat management effectiveness	0.000
C3 Habitat Final Score (0-10)	**0.667**
Critical?	No

For C4, copy either the single species table or the all-species "system" table below

Single species

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

Shrimp

Criterion 4: Chemical Use	

All-species assessment	Data and Scores
Chemical use initial score (0-10)	0
Trend adjustment	0
C4 Chemical Use Final Score (0-10)	**0**
Critical?	No

Select the species or "System" again from the list Shrimp

Only select "System" if the C5 Feed Assessment was done as a multi-species system.

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 %	13.500
Fishmeal from byproducts, weighted inclusion %	3.500
Byproduct fishmeal inclusion (@ 5%)	0.175
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	1.750
Fish oil from byproducts, weighted inclusion %	0.250
Byproduct fish oil inclusion (@ 5%)	0.013
Fish oil yield value, weighted %	5.000
eFCR	1.500
FFER Fishmeal value	**0.912**
FFER Fish oil value	**0.529**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	0.950
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	**1.050**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	38.000
Protein INPUT kg/100kg harvest	57.000
Whole body harvested fish protein content	18.900
Net protein gain or loss	-66.842
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)	**14.444**
Contribution (%) from fishmeal from whole fish	6.910
Contribution (%) from fish oil from whole fish	1.791
Contribution (%) from fishmeal from byproducts	0.627
Contribution (%) from fish oil from byproducts	0.090
Contribution (%) from crop ingredients	90.556
Contribution (%) from land animal ingredients	0.000
Contribution (%) from other ingredients	0.026
Factor 5.3 score	**6**
C5 Final Feed Criterion Score	**2.8**
Critical?	**No**

Select species again Shrimp

Criterion 6: Escapes	Data and Scores
F6.1 System escape risk	1
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	1.000
F6.2 Invasiveness score	8
C6 Escape Final Score (0-10)	**4.0**
Critical?	No

Shrimp

Criterion 7: Disease	Data and Scores
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**2**
Critical?	No

Shrimp

Criterion 8X Source of Stock	Data and Scores
Percent of production dependent on wild sources (%)	99.0
Initial Source of Stock score (0-10)	-9.0
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)	**-9**

Critical?	No

	Shrimp

Criterion 9X Wildlife Mortality parameters	Data and Scores
Single species wildlife mortality score	-4
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-4**
Critical?	No

	Shrimp

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on transwaterbody movements (%)	100
Factor 10Xa score	0
Biosecurity of the source of movements (0-10)	0
Biosecurity of the farm destination of movements (0-10)	2
Species-specific score 10X score	-8.000
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-8.000**
Critical?	n/a