Whiteleg Shrimp, Giant Tiger Prawn

Litopenaeus vannamei, Penaeus monodon

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Vietnam
Ponds

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About Seafood Watch

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

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

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

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

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

Farmed shrimp, *L. vannamei* and *P. monodon* produced in ponds in Vietnam

	Production system and species					
	Intensive		**Extensive**	**Rice-shrimp**		**Shrimp-mangrove**
Criteria	***L. vannamei***	***P. monodon***	***P. monodon***	***L. vannamei***	***P. monodon***	***P. monodon***
C1 Data	5.23	5.23	5.23	5.23	5.23	5.23
C2 Effluent	5.00	5.00	6..00	10.00	10.00	10.00
C3 Habitat	1.47	1.47	1.47	5.47	5.47	1.47
C4 Chemicals	0.00	0.00	6.00	6.00	6.00	8.00
C5 Feed	3.68	3.05	10.00	10.00	10.00	10.00
C6 Escapes	3.00	4.00	4.00	3.00	4.00	4.00
C7 Disease	4.00	4.00	6.00	6.00	6.00	6.00
C8X Source of stock	0.00	–6.00	–6.00	0.00	–6.00	–6.00
C9X Wildlife mortalities	–5.00	–5.00	–5.00	–5.00	–5.00	–5.00
C10X Introductions	–2.00	–0.80	–0.80	–2.00	–0.80	–0.80
Total	15.37	9.94	26.89	38.69	34.89	32.89
Final score (0-10)	2.20	1.42	3.84	5.53	4.98	4.70

OVERALL RATING

	Production system and species					
	Intensive		**Extensive**	**Rice-shrimp**		**Shrimp-mangrove**
	L. vannamei	***P. monodon***	***P. monodon***	***L. vannamei***	***P. monodon***	***P. monodon***
Final Score	2.20	1.42	3.84	5.53	4.98	4.70
Initial rating	🟥	🟥	🟨	🟨	🟨	🟨
Red criteria	2	2	1	1	0	1
Interim rating	🟥	🟥	🟨	🟨	🟨	🟨
Critical Criteria?	1	1	0	0	0	0
Final Rating	Red	Red	Yellow	Yellow	Yellow	Yellow

Scoring note—scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of –10 reflects a very significant impact. White text with a black background indicates a Critical score. Two or more Red criteria or one Critical criterion result in a Red final rating.

Summary

- The final numerical scores for *L. vannamei* and *P. monodon* produced in intensive pond systems in Vietnam are 2.20 and 1.42 out of 10, respectively, which are in the Red range, and with one critical criterion (Chemical Use), the final rating is Avoid.

- The final numerical score for *P. monodon* produced in improved extensive pond systems in Vietnam is 3.84 out of 10, which is in the Yellow range, and with one Red criterion (Habitat), the final rating is Good Alternative.
- The final numerical scores for *L. vannamei* and *P. monodon* produced in rice-shrimp pond systems in Vietnam are 5.53 and 4.98 out of 10, respectively, which are in the Yellow range, and with one Red criterion for *L. vannamei* (Escapes), the final rating for both species is a Good Alternative.
- The final numerical score for *P. monodon* produced in shrimp-mangrove pond systems in Vietnam is 4.70 out of 10, which is in the Yellow range, and with one Red criterion (Habitat), the final rating is a Good Alternative.

Executive Summary

Vietnam produces approximately 1 million metric tons (mt) of farmed shrimp per year (996,269 mt in 2021) and has a complex industry of >150,000 shrimp farms dominated by small-scale household producers using a variety of production systems. The primary species are the nonnative whiteleg shrimp *L. vannamei* (approximately 70% of production by weight) and the native giant tiger prawn (or black tiger shrimp) *P. monodon* (30% of production by weight). The total pond area is approximately 750,000 hectares (754,200 ha in 2021), of which approximately 85% is used to grow *P. monodon* and 15% to grow *L. vannamei*. These figures demonstrate the dominance of intensive systems for *L. vannamei*, with high stocking densities, high feed inputs, complex pond management, and high yields per hectare, and a dominance of extensive systems (with opposite characteristics) for *P. monodon*. Production is concentrated in the Mekong Delta region in the south of Vietnam, with approximately 90% of the total shrimp pond area and approximately 80% of production. The remainder is spread somewhat thinly throughout Vietnam's central and northern coastal provinces, including the Red River Delta in the north.

In 2021, the U.S. imported 86,163 mt of warm-water shrimp from Vietnam (including wild-caught shrimp of uncertain quantities), of which approximately 75% is *L. vannamei*. The United States (U.S.) is the largest single market for Vietnamese shrimp, receiving approximately one-quarter of Vietnam's total shrimp exports. Vietnamese shrimp represent approximately 13% of the U.S. market. Shrimp farms in Vietnam use a spectrum of pond-based production systems, typically categorized by key characteristics including stocking density, the use of feed, and yields (but also by the use of mechanical aeration, pond size, chemical use, water exchange, and other factors). While some systems produce shrimp only, others are integrated with crops (typically rice) or mangrove forestry. Although recognizing that there is a spectrum of production characteristics in each, the following four categories of system have been assessed here:

- Intensive systems: including semi-intensive, intensive, and super-intensive, for which *L. vannamei* and *P. monodon* are assessed separately
- Improved extensive: primarily for *P. monodon*
- Rice-shrimp systems: primarily for *P. monodon* but also some *L. vannamei* (assessed separately where relevant)
- Shrimp-mangrove (silvoculture): for *P. monodon* only.

The assessment involves criteria covering impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability.[2] With the

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[2] The full Seafood Watch Aquaculture Standard is available at: http://www.seafoodwatch.org/seafood-recommendations/our-standards

dominance of production in the Mekong Delta (and a focus of academic study), this assessment focuses on this southern region, but also includes examples from other provinces of Vietnam when relevant.

It should be noted that Seafood Watch has separate recommendations for farmed shrimp certified to various assurance schemes. See the Seafood Watch information on certified seafood here.[3] Seafood Watch is also working directly on improvement projects with shrimp farmers in Vietnam. Further information is available here.[4]

With >150,000 shrimp farms using a variety of production systems (and dominated in number by small household farms), it is perhaps inevitable that data availability and quality in Vietnam is fundamentally challenging, but for a large industry and an important product in the U.S. seafood market, the information that Is readily available is limited. It is clear that a large amount of data is collected (e.g., by the General Statistics Office, the Ministry of Agriculture and Rural Development [MARD], or the Vietnam Association of Seafood Exporters and Producers [VASEP]) and online translation services greatly facilitate access, but there continue to be many challenges in data availability for an interested U.S. consumer or seafood buyer. Attempts to contact MARD, VASEP, and the Research Institute for Aquaculture (RIA1) were unsuccessful. Much of the understanding of the industry and its impacts is therefore gleaned from the substantial academic interest in the industry. But, with the typical multiyear lag between fieldwork and publication, and often a limited sample size of farms, academic studies must be used with caution in understanding a developing industry. For example, the government's 2017 "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)" and the 2021 "National Action Plan on Antibiotic Resistance Prevention and Control in the Field of Agriculture in the Period of 2021–2025" are welcomed regarding the important topic of antimicrobial use, but there do not appear to be any publicly available data with which to evaluate their progress. For this Seafood Watch assessment, the limitations in data availability necessitate a precautionary approach to the scoring in many criteria. The industry is urged to improve data availability in order to recognize current practices and any improvements being made. Though there is some variability in data availability between production systems and species, the overall score for Criterion 1—Data is 5.2 out of 10, based largely on the available academic studies.

There are well-documented concerns regarding effluent pollution from shrimp farms in Vietnam because of the discharge of soluble and particulate wastes during water exchanges and harvest, and the disposal of sludge during pond cleaning. The focus of these concerns is predominantly on intensive farms with high nutrient inputs in the form of feed. There is a regulatory system for wastewater in place in Vietnam, but documented concerns regarding weak enforcement appear to greatly reduce its effectiveness. Water quality monitoring by the Department of Agriculture and Rural Development (DARD) in Cà Mau is an encouraging example of improving management, but the results also indicate improper disposal of effluent

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[3] https://www.seafoodwatch.org/recommendations/certified-seafood

[4] https://www.seafoodwatch.org/our-projects/farmed-shrimp-in-vietnam

wastes. Because of the high density of farms covering large areas, the potential remains high for cumulative impacts from multiple farms discharging effluent and sludge wastes into shared waterbodies.

In unfed shrimp-mangrove production systems, pond effluents often contain fewer nutrients than the influent tidal water exchange (i.e., there is a net uptake of nutrients in ponds and removal in the form of harvested shrimp) and *P. monodon* in this system are not considered to have a significant potential for effluent impacts at the farm level or cumulatively across multiple farms. Using the evidence-based assessment option, the final score for Criterion 2—Effluent for shrimp-mangrove systems is 10 out of 10.

For improved extensive and rice-shrimp production systems that are considered here to typically have zero or minimal feed inputs, there are still some nutrient inputs in the form of fertilizer to enhance natural food production in the ponds. The net effluent waste production per ton of shrimp in both systems is minor; however, because of the regulatory uncertainty, the potential is higher for cumulative impacts from the high density of improved extensive systems farms covering large areas (and which have slightly higher fertilizer use) and remains a moderate concern. The final score for Criterion 2—Effluent for improved extensive systems is 6 out of 10, and for rice-shrimp systems is 10 out of 10 (for both species).

For intensive systems, there is commonly a high feed input (but minimal, if any, fertilizer use), and the net waste production from a farm can be substantial. It is emphasized here that not all intensive farms are considered to discharge their effluent wastes; the use of settling ponds is common and the treatment/reuse of water is increasing, but the disposal of sludge remains uncertain. Overall, the amount of waste discharged per ton of shrimp is considered to be low, but the documented pollution concerns and the low confidence in the ability of the regulatory system to limit cumulative impacts of multiple farm result in a lower final score for intensive farms in Criterion 2—Effluent of 5 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*.

A remarkable change in the coastal land cover regarding aquaculture began in the 1990s as shrimp farming expanded rapidly in coastal areas, with the encouragement of the Vietnamese Government and organizations such as the World Bank and the Asia Development Bank. Several recent academic studies analyzing satellite images provide a useful time series of land use change and show a rapid conversion of mangrove forests and agricultural land into shrimp farms, particularly in the Mekong Delta in southern Vietnam. Nevertheless, quantifying the land use change in terms of areas and timelines for different production systems is challenging, particularly regarding recent or ongoing conversions of high value habitats after 1999, when the ecological value of mangrove forests was considered to be formally recognized. Although the majority of shrimp farms are shown to be located in former agricultural land, the conversion of a large proportion of Vietnam's ecologically important mangrove forest into shrimp farms, including shrimp-mangrove farms (noting prior damage to these areas from the use of defoliants by the United States during the Vietnam War), is considered to have caused a loss of ecosystem services and a loss of habitat functionality because of large-scale habitat fragmentation and changes in mangrove cover, diversity, ecology, access, and hydrodynamics.

Recent academic studies have indicated that this has continued after 1999 and more recently (though at a much slower pace), and shrimp farming continues to be the most important factor affecting mangroves in Vietnam. There are some differences in the likelihood of the different production systems being located in former mangrove areas, but without an ability to robustly differentiate their respective contributions, the score for Factor 3.1 is 1 out of 10 for intensive, extensive, and shrimp-mangrove systems. The modification of rice farms for the production of rice and shrimp is not considered to result in the loss of functionality of the agricultural land, but there is a moderate concern about increasing soil salinity (the score for Factor 3.1 is 7 out of 10).

The Vietnamese government has clearly recognized the value of mangrove forests and their ecosystem services and has been active in their management and restoration; however, the management measures have focused on the development of shrimp-mangrove farms and efforts to reach a forest-to-pond ratio of 60%, i.e., 60% of the total farm area (which is typically allocated in small parcels to tens of thousands of individual households) must be forested. It is considered here that this ratio still results (cumulatively) in a loss of habitat functionality, and it is apparent that this ratio is often not met because of limitations in enforcement (and driven by a high price for shrimp, which encourages a larger pond area). Therefore, the overall effectiveness of the management system (for all production systems) is considered to be limited (the score for Factor 3.2 is 2.4 out of 10). Overall, Factors 3.1 and 3.2 combine to give a final score for Criterion 3—Habitat for rice-shrimp systems of 5.47 out of 10. For intensive, improved extensive and shrimp-mangrove systems, the final score for Criterion 3—Habitat is 1.47 out of 10. These scores apply to both species.

Aquaculture in Vietnam, including shrimp farming, has frequently been associated with high use of antimicrobials. There are no readily available official data on use, but multiple academic papers indicate that it has been common, primarily in intensive and semi-intensive farms. The types of antimicrobials documented include several listed as highly important and critically important to human medicine by the World Health Organization, and also some banned for use in aquaculture by the Ministry of Agriculture and Rural Development (MARD). Bacteria that are resistant to the same antimicrobials (including to multiple types) are detected in farmed shrimp, and because of the common practices of water exchange and sludge disposal, shrimp farms are also associated with the detection of antimicrobials and resistant bacteria in the environment (also associated are other types of aquaculture, terrestrial livestock, municipal sources, and the manufacture of the pharmaceutical themselves).

The regulatory oversight of antimicrobial use in Vietnam has also been criticized due to the limited control of their availability, purchase, and use by farmers, but in 2017, the Vietnamese government (via MARD) launched the "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)," which has the potential to substantially change the patterns of antimicrobial use and resistance in shrimp farms. With some concerns regarding the implementation of the National Action Plan, in 2021, a "Plan for Antibiotic Resistance Prevention in the Agricultural Sector in the Period of 2021–

2025" was launched. To date, there have been no comprehensive results generated from either project.

The U.S. Food and Drug Administration's inspections of imported shrimp from Vietnam continue to detect residues of antimicrobials that are banned for use in aquaculture in Vietnam, with 22 import refusals in 2021. For intensive (and semi-intensive) shrimp farms, illegal and critically important antimicrobials are considered to be used in significant and unknown quantities, and the final score for Criterion 4—Chemical use is Critical. The three remaining production systems assessed here are considered to have a demonstrably low need for chemical use, but data limitations urge some precaution. For improved extensive and rice-shrimp systems where there is some evidence that chemicals may occasionally be used, the final score for Criterion 4—Chemical Use is 6 out of 10. For mangrove-shrimp systems, there is sufficient confidence that chemicals are used less than once per production cycle, and the final score for Criterion 4—Chemical Use is 8 out of 10. With little evidence to robustly differentiate *L. vannamei* and *P. monodon*, these scores apply to both species in the production systems in which they are assessed.

Intensive systems have a complete reliance on formulated feed. In contrast, some feed may be used in extensive and rice-shrimp farms and may occasionally be significant, but the bulk of academic studies indicate that shrimp rely primarily on natural organisms in the ponds (particularly in shrimp-mangrove systems), and external feed use is typically zero or minimal. Thus, feed use is not assessed for extensive rice-shrimp and shrimp-mangrove systems, and the final score for Criterion 5—Feed for both species in these systems is 10 out of 10. Academic studies provide examples of typical feed ingredients, with which a general feed formulation can be approximated for each species in feed-dependent systems, but it is noted that data availability for *P. monodon* is particularly poor. Data on the use of fishmeal and fish oil from by-products were provided anonymously from one large feed company. Using the available data, intensive systems are calculated to have a Forage Fish Efficiency Ratio (FFER) of 0.29 and 0.51 for *L. vannamei* and *P. monodon*, respectively (the higher value for *P. monodon* results from a greater inclusion level of marine ingredients and a higher feed conversion ratio). With substantial quantities of fishmeal and fish oil coming from unknown species or unknown fisheries (34.9% of the fishmeal and fish oil comes from mixed-fish fisheries in Vietnam and just over half the total comes from known species but unknown fisheries), the sustainability score for marine ingredients is low (1.11 out of 10 for whole fish sources, and 2.83 out of 10 for by-product sources). As a result, the Wild Fish Use scores for *L. vannamei* and *P. monodon* in intensive systems are 2.35 out of 10 and 1.6 out of 10, respectively.

With estimated average feed protein contents of 38.3% and 40.9% for *L. vannamei* and *P. monodon* feeds, respectively, there is a substantial net protein loss in intensive systems of 60.9% and 70.0% for *L. vannamei* and *P. monodon*, respectively, and the scores for Factor 5.2—Net Protein Gain or Loss are 3 out of 10 and 2 out of 10, respectively. The Feed Footprint (Factor 5.3) assessed as the feed-related Global Warming Potential of 1 kg of farmed shrimp protein is 9.60 kg CO_2-eq kg^{-1} and 11.22 kg CO_2-eq kg^{-1} for *L. vannamei* and *P. monodon*, respectively, in the feed-dependent systems (scores of 7 out of 10 for both species). When the scores are combined, the final score for Criterion 5—Feed in intensive systems is 3.68 out of 10 for *L. vannamei* and 3.05 out of 10 for *P. monodon*, using the available data.

Farmed shrimp can escape from ponds in various ways, including during water exchanges, harvesting, and pond cleaning, as well as from hatcheries and during transport, and although there are no specific data, the dominant cause of large-scale escapes is considered to be flooding. The Mekong Delta, by its hydrographic nature, is prone to flooding, and the loss of large areas of farms during heavy rains has been reported. The region is also highly vulnerable to further flooding from sea level rise and increasingly severe weather as a result of climate change and land subsidence. The escape risk is therefore high (a score of 1 out of 10 for Factor 6.1). *L. vannamei* is nonnative to Vietnam but there is no evidence of the species establishing viable populations anywhere in the world, so it is concluded that *L. vannamei* is likely to be present in the wild in Vietnam though not established, and highly unlikely to establish viable populations (a score of 6 out of 10 for Factor 6.2). *P. monodon* in farms come from a combination of wild-caught (70%) and farm-raised domesticated broodstocks (30%). Those from wild-caught broodstocks have minimal genetic differentiation or risk of competitive interactions if they were to escape. Similarly, although domesticated farm-raised stocks have been shown to be genetically distinct and to have selected characteristics such as higher growth rates, the genetic diversity of wild *P. monodon* populations means that there is limited potential for competitive or genetic impacts if these stocks were to escape into the wild. This results in a weighted score of 7 out of 10 for Factor 6.2 for *P. monodon*. The final scores for Criterion 6—Escapes are 3 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*, and apply to all production systems.

Shrimp farming in Vietnam has been plagued with several severe viral disease epidemics, and these and other diseases caused by bacteria, parasites, and protozoans are dominant concerns for farmers. Although biosecurity characteristics and practices are considered likely to be highly variable among production systems and individual farms, it is clear that pathogens are commonly discharged from farms in wastewater, sediment, and sludge and enter neighboring farms in influent waters. The development of specific pathogen-free (SPF) breeding lines and postlarvae has been important in mitigating some of the pathogens of highest concern, but shrimp continue to be vulnerable to infection during grow-out in all but the most contained and biosecure facilities. Intensive production systems with high stocking densities are typically considered more vulnerable to disease outbreaks (supported by reports of higher antimicrobial use in these systems), yet with more common use of water treatment and recirculation, they have the potential for greater biosecurity compared to the low stocking densities but simpler practices of extensive and shrimp-mangrove systems in the thousands of small family farms in Vietnam. Although there are regulations relating to fish and shrimp health and biosecurity in aquaculture in Vietnam, academic studies indicate that there are limited resources for enforcement and that farmers may still choose to dump infected water or not report disease outbreaks to neighboring farms or the authorities. Despite clear evidence of the discharge of pathogens from farms and the presence of many of the same pathogens in the environment and wild shrimp (e.g., in wild broodstock), it remains challenging to determine what impacts, if any, these pathogens have on wild shrimp. Without clear data or evidence with which to understand the impacts of farm pathogens on wild shrimp, the risk-based assessment has been used. Although all systems are considered at least partly open to the introduction and discharge of pathogens, the greater risk of disease in intensive systems results in a final numerical score for Criterion 7—Disease of 4 out of 10 for intensive systems. With lower density and less likelihood of pathogen amplification, the score for extensive shrimp-rice and shrimp-mangrove systems is 6 out of 10. Without clearly differing risk characteristics between the two species of farmed shrimp, the score applies to both *L. vannamei* and *P. monodon*.

Farm production of *L. vannamei* in Vietnam relies entirely on farm-raised broodstock, so this criterion is not applicable to this species (i.e., the final score for Criterion 8X—Source of Stock is a deduction of 0 out of –10 for *L. vannamei*).

For *P. monodon*, although production of domesticated broodstock is increasing, the shrimp farming industry is still largely dependent on wild-caught broodstock from a fishery located approximately 30 miles south of Vietnam. With an estimated annual capture of 197,100 *P. monodon* broodstock and an estimated 60,000 farm-raised broodstock, the *P. monodon* shrimp farming industry is approximately 69.6% reliant on wild-caught sources. Although overseen by the national fisheries regulations, there are no specific regulations regarding the broodstock fishery, and without formal assessments, the sustainability of the fishery is currently considered unknown. The final score for Criterion 8X—Source of Stock for *P. monodon* is a deduction of –6 out of –10. Though it is possible that the use of wild-caught versus farm-raised broodstock varies by production system, there are insufficient data with which to separate them, and the scores are applied to all production systems for each species.

Overall, there is no specific evidence of wildlife mortality concerns on Vietnamese shrimp farms, but the available evidence indicates that nonlethal exclusion and deterrents are commonly used, so a potential for the use of lethal control remains, and mortality numbers are unknown. According to the International Union for the Conservation of Nature (IUCN), there are 57 "Red-Listed" animals in Vietnam, and the IUCN lists "small holder farming," "shifting agriculture," and "agro-industry farming" as the top three threats; however, little appears to be known about their specific interaction with shrimp farms. Some regulations are in place (and others may be present), but enforcement measures are uncertain. The types and abundance of species interacting with different types of farms in former agricultural areas or mangrove areas may vary considerably (in addition to the responses of the farmers in each case), but there is insufficient evidence with which to distinguish specific concerns between the different production systems (or species) assessed here. Because of the lack of data, the risk assessment must be used (i.e., the data score for wildlife mortalities is 2.5 out of 10 in Criterion 1—Data), and the final score for Criterion 9X—Wildlife Mortalities is –5 out of –10.

The global shrimp farming industry has been severely affected by a variety of pathogens that have been moved from one country to another as unintentional "hitchhiker" species during live animal shipments. The industry for *L. vannamei* in Vietnam is largely dependent on movements of broodstock and postlarvae from international breeding centers to broodstock facilities and hatcheries in Vietnam. The score for Factor 10Xa for *L. vannamei* is 0 out of 10 (indicating >90%

reliance on international or trans-waterbody movements). Because the large majority of *P. monodon* broodstock comes from domestic wild capture in southern Vietnam and there are more hatcheries closer to the main grow-out regions, there are fewer international or trans-waterbody movements of this species. The score for Factor 10Xa is 9 out of 10 for *P. monodon*, based on the 2% dependence on international movements of farm-raised domesticated broodstock or postlarvae.

The international sources of *L. vannamei* typically have high biosecurity and testing for specific pathogen-free (SPF) certification; therefore, the score for Factor 10Xb is 8 out of 10 (indicating a low risk of unintentionally introducing a secondary species during shipments). For *P. monodon*, the fishery landings must be quarantined and screened for pathogens, which indicates that at least some biosecurity measures are in place for the otherwise nonbiosecure capture fishery. The score for Factor 10Xb for *P. monodon* is 2 out of 10 (indicating a higher risk of unintentionally transporting a secondary species from the coastal fishery). The scores for Factors 10Xa and 10Xb combine to give final score for Criterion 10X—Introduction of Secondary Species of –2 out of –10 for *L. vannamei* and –0.8 out of –10 for *P. monodon*, indicating an overall low risk for both species.

The final scores and Seafood Watch recommendations are summarized as follows:

- The final numerical scores for *L. vannamei* and *P. monodon* produced in intensive pond systems in Vietnam are 2.20 and 1.42 out of 10, respectively, which are in the Red range, and with one critical criterion (Chemical Use), the final rating is Avoid.
- The final numerical score for *P. monodon* produced in improved extensive pond systems in Vietnam is 3.84 out of 10, which is in the Yellow range, and with one Red criterion (Habitat), the final rating is Good Alternative.
- The final numerical scores for *L. vannamei* and *P. monodon* produced in rice-shrimp pond systems in Vietnam are 5.53 and 4.98 out of 10, respectively, which are in the Yellow range, and with one Red criterion for *L. vannamei* (Escapes), the final rating for both species is Good Alternative.
- The final numerical score for *P. monodon* produced in shrimp-mangrove pond systems in Vietnam is 4.70 out of 10, which is in the Yellow range, and with one Red criterion (Habitat), the final rating is Good Alternative.

This suite of six final recommendations for two shrimp species in four production systems is effectively divided into two categories. For intensive systems (including semi-intensive and super-intensive*[5]) with high stocking densities and a high reliance on formulated feed inputs, the available evidence indicates that the associated impacts (particularly relating to chemical use, effluent, feed use, and habitat conversion) are a high concern, so the final recommendation is Avoid for both *L. vannamei* and *P. monodon*. For systems that operate at a

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[5] Seafood Watch also has an assessment and recommendations for indoor tank-based recirculation systems, which may be applicable to some super-intensive shrimp systems in Vietnam.

low intensity with minimal or no feed, the available evidence indicates that the same impacts mostly have a lower concern, so the final recommendation is a Good Alternative for both species produced in improved extensive rice-shrimp or shrimp-mangrove systems.

Introduction

Scope of the Analysis and Ensuing Recommendation

Species

Whiteleg shrimp (*Litopenaeus vannamei*)
Giant tiger prawn, also known as black tiger shrimp (*Penaeus monodon*)

Geographic Coverage

Vietnam

Production Methods

- Intensive ponds
- Improved extensive ponds
- Rice-shrimp ponds
- Shrimp-mangrove ponds

Certified Farms

It should be noted that Seafood Watch has separate recommendations for farmed shrimp from farms certified to various assurance schemes. See Seafood Watch information on certified seafood here.[6] Seafood Watch is also working directly on improvement projects with shrimp farmers in Vietnam. Further information is available here.[7]

Species Overview

Two tropical marine shrimp species dominate the shrimp farming industry in Vietnam: the giant tiger prawn[8] (*Penaeus monodon*) and the whiteleg shrimp (*Litopenaeus vannamei*). *P. monodon* is indigenous to Vietnam and is found naturally in the western Pacific Ocean (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. *L. vannamei* is native to the Eastern Pacific Ocean coast from Sonora, Mexico in the north to Tumbes, Peru in the south. It was introduced into Vietnam for aquaculture in the year 2000. As for all Penaeid species, adults live and spawn in the open ocean, while postlarvae (PL) migrate inshore to spend their juvenile, adolescent, and subadult stages in coastal estuaries, lagoons, or mangrove areas (FAO 2006).

Production Systems

Shrimp farming in Vietnam encompasses a broad spectrum of pond-based production systems, typically categorized by the key characteristics of stocking density, the use of feed, and yields

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[6] https://www.seafoodwatch.org/recommendations/certified-seafood

[7] https://www.seafoodwatch.org/our-projects/farmed-shrimp-in-vietnam

[8] *P. monodon* is also commonly referred to as the giant tiger shrimp. Avoid confusing giant tiger prawn with the giant freshwater prawn (*Macrobrachium rosenbergi*), also farmed in Vietnam.

(but also by the use of mechanical aeration, pond size, chemical use, water exchange, and other factors). Some systems produce shrimp only, while others are integrated with crops (typically rice) or mangrove forestry. The four main types of production systems (and the ones assessed here) are briefly outlined below in two categories: intensive systems and extensive systems. Further details on their operation are discussed where relevant in each criterion of this assessment.

- Intensive Pond Systems

  L. vannamei is the primary species cultured, but production of *P. monodon* in intensive systems is increasing with the increasing availability of disease-free postlarvae (Schuur et al., 2022). Intensive systems vary from semi-intensive through intensive to super-intensive, each with increasing stocking density, increasing feed inputs, and increasingly complex pond management in terms of water treatment and recirculation, mechanical aeration, and the use of chemicals and other inputs. Ponds are typically small, at approximately 0.44 ha to 1.25 ha (Thakur et al., 2018)(Le et al., 2022)(Hai et al., 2015)(Nguyen and Tien, 2021), and typically have natural substrates in semi-intensive systems, but they are plastic-lined in intensive systems and often also covered in super-intensive systems.[9] Stocking densities are approximately 30 PL/m^2 in semi-intensive systems, approximately 50 to 100 PL/m^2 in intensive, and 160 to >350 PL/m^2 in super-intensive systems (Nguyen and Tien, 2021)(Thakur et al., 2018)(Trang et al., 2022)(Van Nguyen, 2021). The dominant or exclusive feed source is external formulated feed (Tu et al., 2021)(Le et al., 2022). Yields range from 1.5 to 2 mt/ha/crop for semi-intensive ponds (Le et al., 2022), 5 to 12 mt/ha/crop for intensive ponds (Hai et al., 2020a)(Le et al., 2022)(Thakur et al., 2018)(Thach et al., 2021) and 20 to 70 mt/ha/crop for super-intensive ponds (Giao, 2021)(Hai et al., 2020a).

- Extensive Pond Systems

  The key characteristics of extensive systems are a low stocking density and a lack (or very minor use) of added feed. Traditionally, the ponds would be stocked passively with naturally occurring juvenile shrimp, but hatchery-raised postlarvae are now used and the systems are now commonly referred to as "improved extensive." They typically exchange water using tidal cycles. Various government policy documents and aquaculture development plans[10] indicate that the promotion of *L. vannamei* production in Vietnam is limited to intensive production systems only. As noted below, rice-shrimp production is increasing rapidly in Vietnam because of increasing saltwater intrusion in the Mekong Delta, and recent academic studies note significant production of *L. vannamei* in extensive rice-shrimp systems (e.g., Hai et al., 2020a). Although this report focuses on *P. monodon* as the primary species in extensive systems, *L. vannamei* is also assessed for the rice-shrimp system only.

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[9] Seafood Watch has a separate assessment and recommendations for aquaculture production in indoor tank-based recirculating systems, which may be applicable for some super-intensive shrimp farms in Vietnam.

[10] Official Dispatch 3278/BNN-TCTS, 19/04/2017, of MARD; Decision 3475/QD-BNN-TCTS, 30/08/2018; Decision 3550/QD-BNN-TCTS, 12/08/2021

There are three main subcategories of extensive production systems: shrimp monoculture, shrimp-rice, and shrimp-mangrove:

- Extensive—shrimp monoculture (improved extensive)
  Species cultured: Primarily *P. monodon* (Li, 2021).
  Ponds are typically relatively large (average of 2.1 ha) (Le et al., 2022), with a natural substrate, and they rely on tidal exchange to bring in natural food organisms to the ponds in addition to primary productivity in the ponds (small amounts of fertilizer may be used). Unlike the extensive shrimp-mangrove system, there are few if any mangrove or other wetland trees in the ponds. Stocking densities are low (typically 1–6 PL/m^2) (Nguyen et al. 2019)(Anh et al., 2020). External feeds are typically not used, or sometimes used only in minor amounts (Vo et al., 2021)(Le et al., 2022), and yields are approximately 300–400 kg/ha per year (Le et al., 2022)(Hai et al., 2020b).
- Extensive—shrimp-rice
  Species cultured: Primarily *P. monodon* (Tan et al., 2020)(Anh et al., 2020)(Leigh et al., 2020)(Burford et al., 2020) but also some *L. vannamei* (Dang et al., 2020)(Hai et al., 2020b).
  Rice-shrimp production is increasing rapidly in Vietnam because of increasing saltwater intrusion in the Mekong Delta,[11] especially during 2016 and 2020 (Hai et al., 2020). Two types of shrimp-rice systems exist in Vietnam: rotational rice-shrimp systems, where the two crops are produced consecutively/separately in the paddy fields/ponds, and combined co-culture systems, where both crops are produced at the same time with ditches and platforms in the ponds for the shrimp and rice, respectively. In many cases, the giant freshwater prawn (*Macrobrachium rosenbergii*) (not assessed here) is the species stocked simultaneously with rice in combined co-culture systems because of its similar preferences for low salinity during the rainy season (Dang et al., 2020)(Nam et al., 2022a); therefore, the rotational system (which is stocked with brackishwater shrimp in the dry season with higher salinity) is assessed here. According to Hai et al. (2020a), during the dry season, shrimp are cultured with either one crop of *P. monodon*, two crops of *L. vannamei*, or one crop of each. Pond/field sizes are variable but are commonly 0.55 to 2.0 ha, with natural substrates (Dien et al., 2019)(Trang, et al., 2018). Stocking densities are variable and most commonly low, ranging from 1 to 15 PL/m^2 (Ahn et al. 2020)(Dien et al., 2019)(Dang et al., 2020)(Burford et al., 2020), but occasionally, farms will operate ponds at higher stocking densities that are similar to those of semi-intensive systems. The more common low stocking density is assessed here. Shrimp typically feed on the detritus within the rice crop (or the remains of it after

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[11] This intrusion is because of factors such as rising sea levels, decreasing freshwater river flows because of upstream dams, and excessive extraction of groundwater.

harvest) but some additional feed may be added (Burford et al., 2020)(Anh et al., 2020)(Le et al.,2022). Yields typically range from 250 kg/ha to 500kg/ha (Anh et al., 2020)(Dien et al., 2019). The rotation may include three crops per year (two shrimp and one rice, or two rice and one shrimp). In some cases, where stocking densities are higher, daily feed may be added, and yields reach the range of semi-intensive production at 1,500kg/ha (Hai et al., 2020a). Shrimp-rice production at these higher intensities and with substantial feed use is not included here and is considered to be addressed in the "intensive" assessment and recommendation.

- Extensive—shrimp-mangrove

  Species cultured: black tiger shrimp (giant tiger prawn) (Ahn et al., 2020)(Nguyen et al., 2019).

  Also known as silvoculture,[12] this combined production of shrimp and mangrove forestry has varying ratios of open water to mangrove stands in the ponds (see Criterion 3—Habitat) and typical pond sizes of 3–10 ha with natural substrates (Ahn et al., 2020). Stocking densities are low (approximately 1–6 PL/m^2) (Nguyen et al., 2019)(Anh et al., 2020), external feed or fertilizer is not used, and the shrimp feed on natural organisms within the pond (Anh et al., 2020)(Ha et al., 2012a,b)(Jonell and Henriksson, 2015). Water is exchanged tidally. Shrimp yields are 300–400 kg/ha per year (Nguyen et al., 2019)(Anh et al., 2020). The mangrove trees are also harvested at 10- to 20-year cycles.

Assessed Systems

This Seafood Watch assessment of shrimp farming in Vietnam focuses on four categories of production systems:

- Intensive systems

  Given their common dependence on formulated feed (see Criterion 5—Feed), semi-intensive, intensive and super-intensive systems are assessed together, but where relevant, the specific characteristics of *L. vannamei* and *P. monodon* are assessed separately.
- Improved extensive: primarily for *P. monodon*
- Rice-shrimp systems: for *L. vannamei* and *P. monodon* (assessed separately where relevant)
- Shrimp-mangrove (silvoculture): for *P. monodon* only.

For this Seafood Watch assessment, the latter three systems are considered to be unfed (see Criterion 5—Feed). Determining the proportions of production of each species in each system is challenging because of the piecemeal nature of the available data and the mix of area and

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[12] Also referred to as silviculture or silvaculture: derived from the word "silva" which is Latin for "forest"

volume values. Table 1 shows an approximate estimate of the proportions, based loosely on data in Li (2021), Van Nguyen (2021), Hai et al. (2020a), Anh et al. (2020), Merican (2022), and Schuur et al. (2021).

Table 1: Approximate estimate of the proportions of production in each system and species. Data from various sources.

	Percent of production		
System	**Total**	***L. vannamei***	***P. monodon***
Super-intensive	6	6	0
Semi-intensive and intensive	65	56	9
Extensive mono	12	0	12
Extensive: rice-shrimp	10	8	2
Extensive : mangrove	7	0	7
Total	**100**	**70**	**30**

Production Statistics

According to the General Statistics Office (GSO), the total shrimp production in 2021 was 996,269 mt (GSO, 2022a).The GSO data are not differentiated by species, but UN FAO data from the FishStatJ database for 2020 show 616,080 mt of *L. vannamei* and 263,149 mt of *P. monodon* with a total of 879,229 mt (i.e., 70% *L. vannamei* and 30% *P. monodon*). The FAO data show 50,769 mt of *Metapenaeid* shrimp species were also harvested in 2020 (not assessed here), which account for most of the discrepancy between the GSO and FAO totals.

The FAO data first show aquaculture harvests of *P. monodon* in Vietnam in 1962 (10 mt), which gradually increased to exceed 1,000 mt by 1976. After continuing to increase slowly, production rapidly increased at the end of the 1990s, as shown in Figure 1 (1980 to 2020). Production nearly tripled between 1998 and 2001, and multiplied nine times over between 1998 and 2008. *L. vannamei* production continues to increase rapidly.

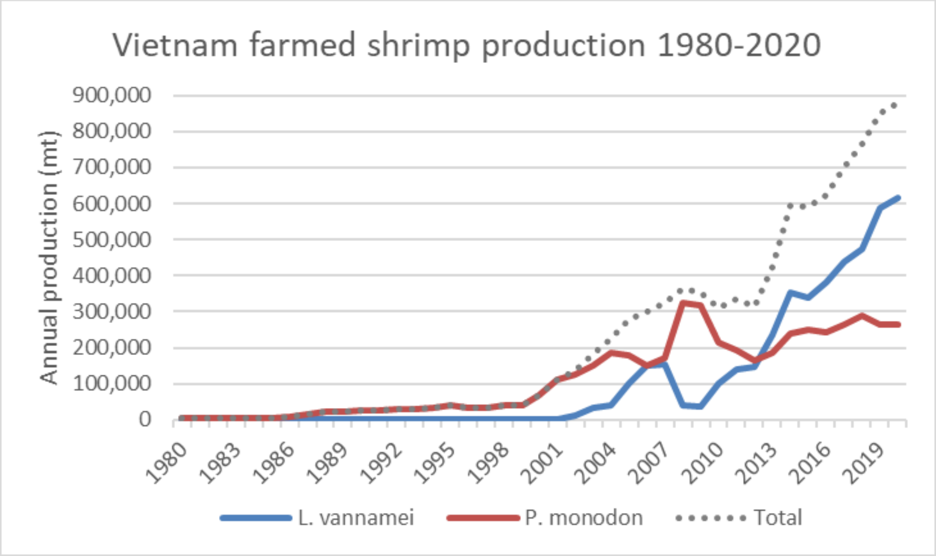

Figure 1: Vietnam shrimp production for *L. vannamei* and *P. monodon* from 1980 to 2020. Data from FAO FishStatJ database.

Robust data on the numbers of shrimp farms in Vietnam do not appear to be readily available; the GSO has data on numbers of farms categorized by economic activity, but the data are not realistic (e.g., for “fishing farms” in Cà Mau Province in 2020, the GSO data indicate 211 farms). Other values are not readily available, but an anecdotal estimate of 2015 shrimp farm numbers in Kontali data[13] was around 14,524 *L. vannamei* farms and 167,449 *P. monodon* farms (a total of 181,973 farms).

Vietnam has approximately 750,000 hectares (ha) of shrimp aquaculture (754,200 ha in 2021[14]), of which approximately 85% is used to grow *P. monodon* and 15% to grow white shrimp (*L. vannamei*) (GSO, 2022). Production is concentrated in the Mekong Delta region in the south (Figure 2), with approximately 90% of Vietnam’s total shrimp pond area (Schuur et al., 2021)(Quyen et al., 2020) and approximately 80% of production (Anh et al., 2020)(Quyen et al., 2020). The remaining production area is spread somewhat thinly throughout Vietnam’s central and northern coastal provinces, including the Red River Delta.

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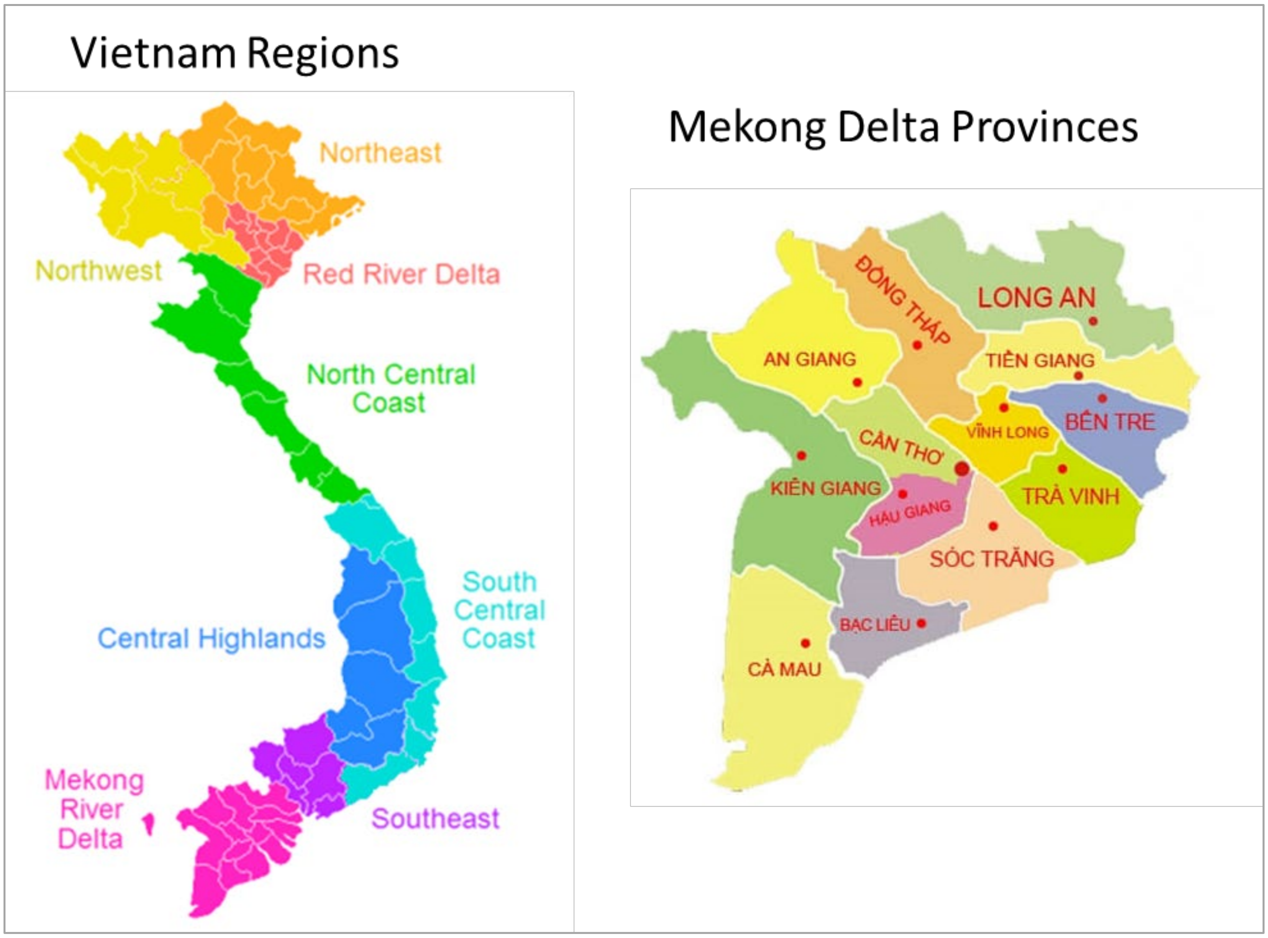
[13] www.seafood-tip.com/sourcing-intelligence/countries/vietnam/shrimp/farming/

[14] Note: this is the pond water area, whereas the total farming area including other non-aquatic areas will be somewhat larger; see Criterion 3—Habitat.



Vietnam Regions

Mekong Delta Provinces

Figure 2: Map of Vietnam regions and a provincial map of the Mekong Delta. Maps reproduced from Wikipedia and www.vietnmdrive.com.

GSO provides total aquaculture production figures by province, but they are not differentiated by the type of aquaculture (e.g., shrimp or fish). An approximation of provincial production can be made from the 2020 estimates from the 2018 National Action Plan to Develop Vietnam's Shrimp Industry to 2025 (No. 79/Qd-Ttg) (Figure 3). It is stressed that these are planned estimates, but they give another useful indication of the focus on the Mekong Delta.

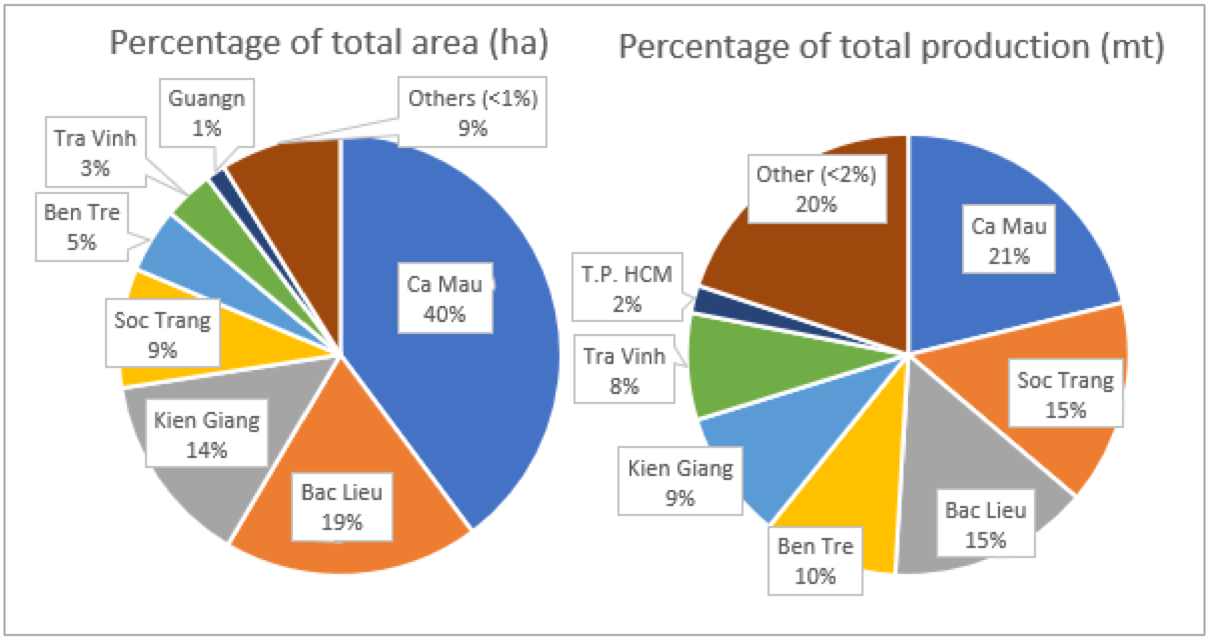


Figure 3: Approximate share of pond area and production in key shrimp farming provinces of Vietnam. Data are planned 2020 figures from a 2018 National Action Plan to Develop Vietnam's Shrimp Industry to 2025 (No. 79/Qd-Ttg), and must only be used as an approximate indication of current production.

Comparing the total production and total pond area for the two species shows the much higher average yields per ha for *L. vannamei* (5.22 mt/ha compared to 0.63 mt/ha for *P. monodon*) that result from the higher proportion of intensive production systems used for *L. vannamei* culture in Vietnam. An approximation of these systems' sizes in 2020 is shown in Figure 4, taken from the same 2018 National Action Plan to Develop Vietnam's Shrimp Industry to 2025 (No. 79/Qd-Ttg). Although it is noted that the approximately 60:40 ratio of *L. vannamei* to *P. monodon* production shown is different from the 70:30 ratio obtained from the harvest data, Figure 4 still gives a useful perspective on the high use of extensive systems by *P. monodon* versus intensive systems for *L. vannamei*.

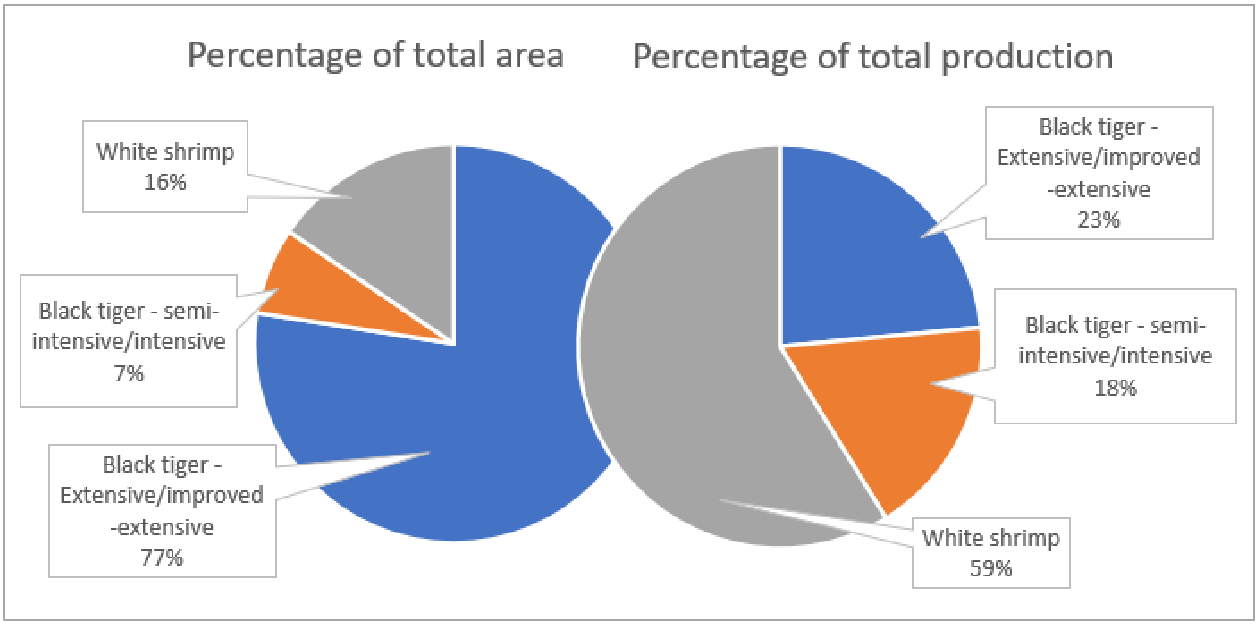


Figure 4: Approximate spread of production by area and weight for *L. vannamei* and *P. monodon* in different production systems. Data represent planned 2020 values from a 2018 National Action Plan to Develop Vietnam's Shrimp Industry to 2025 (No. 79/Qd-Ttg) and must only be used as an approximate indication of current production.

Import and Export Sources and Statistics

In 2021, the United States imported 86,163 mt of warm-water shrimp from Vietnam, up from 66,154 mt in 2020, but this includes wild-caught shrimp of uncertain quantities (NOAA Fisheries data[15]). In 2020, the Vietnamese Association of Seafood Exporters and Producers (VASEP) reported that 73% of exported shrimp were *L. vannamei* and 15% were *P. monodon*, and the remaining 12% were marine shrimp (which would include the wild-caught shrimp plus some farmed shrimp).[16] VASEP has detailed export data available with an account or for purchase in various trade reports, but not freely available.

According to VASEP, the United States is the largest single market for Vietnamese shrimp, receiving approximately one-quarter of Vietnam's total shrimp exports (28% in 2021) (VASEP, 2022). Vietnam's exports to the United States exceeded USD 1 billion for the first time in 2021, representing a substantial 20% increase on 2020.[17] In 2021, Vietnam's shrimp represented 13% of the U.S. market.[18]

Common and Market Names

Scientific Names	*Litopenaeus vannamei*	*Penaeus monodon*

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[15] NOAA Fisheries—Foreign Trade: https://www.fisheries.noaa.gov/foss/f?p=215:2:15163475375365::NO:::

[16] VASEP: https://seafood.vasep.com.vn/key-seafood-sectors/shrimp/sector-profile

[17] VASEP: https://seafood.vasep.com.vn/key-seafood-sectors/shrimp/news/vietnam-shrimp-exports-in-2021-surpassed-the-covid-storm-with-nearly-4-billion-usd-23708.html

[18] VASEP: https://seafood.vasep.com.vn/key-seafood-sectors/shrimp/news/the-us-and-eu-two-bright-markets-for-vietnams-shrimp-exports-in-2021-23605.html

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

According to NOAA Fisheries import data,[19] the majority of shrimp from Vietnam are in the form of frozen shell-on or peeled, but other listed forms include fresh shell-on and peeled, breaded (frozen), in prepared meals (frozen), and "other preparations," and a small amount is canned.

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[19] NOAA Fisheries—Foreign Trade: https://www.fisheries.noaa.gov/foss/f?p=215:2:15163475375365::NO:::

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.
- 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—all species and production systems

C1 Data Category	Data Quality
Production	7.5
Management	5.0
Effluent	5.0
Habitat	7.5
Chemical Use	5.0
Feed	5.0
Escapes	5.0
Disease	5.0
Source of stock	5.0
Wildlife mortalities	2.5
Introduction of secondary species	5.0
C1 Data Final Score (0–10)	**5.23**

Brief Summary

With >150,000 shrimp farms using a variety of production systems (and dominated in number by small household farms), it is perhaps inevitable that data availability and quality in Vietnam is fundamentally challenging, but for a large industry and an important product in the U.S. seafood market, the information that is readily available is limited. It is clear that a large amount of data is collected (e.g., by the General Statistics Office, the Department of Agriculture and Rural Development, or the Vietnam Association of Seafood Exporters and Producers) and online translation services greatly facilitate access, but there continue to be many challenges in data availability for an interested U.S. consumer or seafood buyer. Attempts to contact VASEP, MARD, and the Research Institute for Aquaculture (RIA1) were unsuccessful. Much of the understanding of the industry and its impacts is therefore gleaned from the substantial academic interest in the industry. But, with the typical multiyear lag between fieldwork and publication, and often a limited sample size of farms, academic studies must be used with caution in understanding a developing industry. For example, the Vietnam government's 2017

"National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)" and the 2021 "National Action Plan on Antibiotic Resistance Prevention and Control in the Field of Agriculture in the Period of 2021–2025" are welcomed regarding the important topic of antimicrobial use, but there do not appear to be any publicly available data with which to evaluate their progress. For this Seafood Watch assessment, the limitations in data availability necessitate a precautionary approach to the scoring in many criteria. The industry is urged to improve data availability in order to recognize current practices and any improvements being made. Although there is some variability in data availability between production systems and species, the overall score for Criterion 1—Data is 5.2 out of 10, based largely on the available academic studies.

Justification of Rating

Industry or Production Statistics

Vietnam's General Statistics Office (GSO)[20] has a large amount of data on aquaculture production in terms of pond surface area and weight, by province, but it is only possible to robustly distinguish shrimp from general aquaculture figures in a few of the datasets. The Vietnamese Association of Seafood Exporters and Producers (VASEP) has detailed production and trade data for purchase in various monthly and annual reports, but for some provinces it is possible to find detailed data by species (e.g., from the Department of Agriculture and Rural Development in Cà Mau[21]). The FAO FishstatJ database has annual production figures by species from the 1960s to 2020. An enduring challenge in this assessment has been determining the typical characteristics of the different production systems in Vietnam and their locations, which necessitates a review of many academic studies and their surveys of farms. VASEP was contacted with information requests, but no replies were received. Overall, the data regarding industry and production statistics are considered to give a reliable representation, and the data score is 7.5 out of 10.

Management and Regulations

Overviews of the management systems can be obtained from sources such as the FAO (e.g., Figure 26 in Criterion 7—Disease), and VASEP has a useful list of many relevant regulations.[22] Although legal documents are typically available from sources such as Thư Viện Pháp Luật[23] and are translatable, a detailed understanding is hampered by the complex array of Decrees, Decisions, Circulars, and other legal measures, and some details are inevitably lost in translation. In contrast to the availability of documents, information on enforcement activities in Vietnam is limited, which substantially hampers the ability to assess the effectiveness of management and regulations. MARD and the Research Institute for Aquaculture (RIA1)[24] were contacted with an information request, but no replies were received. The data score for Management is 5 out of 10.

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[20] General Statistics Office of Vietnam (gso.gov.vn)

[21] Nông nghiệp Cà Mau - Thống kê kết quả nuôi tôm (nongnghiepcamau.vn)

[22] Regulations (vasep.com.vn)

[23] THƯ VIỆN PHÁP LUẬT Tra cứu, Nắm bắt Pháp Luật Việt Nam (thuvienphapluat.vn)

[24] http://www.ria1.org/ria1/Default.aspx

Effluent

Recent academic studies confirm a concern regarding effluent pollution from shrimp farms in Vietnam (e.g., Nguyen et al., 2019; Joffre et al., 2018; Giao et al., 2021; Tan, 2021). Information on typical production characteristics of the assessed systems (e.g., feed and fertilizer inputs, water exchanges, the use of treatment or settling ponds, and the disposal of sludge) can be gleaned from similar academic studies but is often from surveys of relatively small numbers of farms in discrete areas (note: the shrimp-mangrove system is an exception here, and the fundamental characteristics of the production system and its effluent impacts can be identified with high confidence). With some difficulty, references to relevant regulations can be found (e.g., from VASEP), and the regulatory documents can be found (in Vietnamese) online (e.g., from Thư Viện Pháp Luật[25]). These regulations can be satisfactorily translated online, but information on the enforcement measures and their effectiveness is limited to anecdotal content in academic studies. Examples of environmental water quality by DARD are available from Cà Mau province; although this monitoring is considered to be repeated to some extent in other provinces, other data are not readily available (or could not be readily accessed from DARD's website). Other examples of manual and automated water quality monitoring are available from southern Vietnam (e.g., by the Southern Center for Environmental Monitoring, SCEM;[26] AQUAM;[27] or by provincial governments), but applicable data to environmental impacts are limited. Overall, there are few data available on specific effluent impacts (or lack of impacts) from shrimp farms in Vietnam, and information on typical production characteristics must be used as a proxy with some support from regulations and the limited monitoring data. Though confidence is higher for some systems, such as shrimp-mangrove,[28] the overall data score for Effluent across all production systems is 5 out of 10.

Habitat

Annual statistics from the GSO on the total aquaculture area in each province from 1995 (as pond area in ha) enable a focused assessment of habitat impacts in dominant regions (i.e., the Mekong Delta) and provide a useful time series of the industry's development and land use changes. Academic studies using a time-series of satellite images illustrate the types of habitats into which shrimp farming expanded (e.g., Liu et al., 2020; Phan and Stive, 2022; Van et al., 2015; Hong et al., 2019), and direct the focus onto mangrove forests (as opposed to former agricultural land). Maps of mangroves areas are readily available (e.g., Veettil et al., 2019), and there are many studies of these habitats and their conversion to shrimp farms. Also, a detailed map-based database of every farm and every mangrove block in the Cà Mau area, including their categorization by forest type and condition, is available from the AQUAM project.[29] Nevertheless, determining the extent and the timeframes of the conversion of mangroves to

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[25] https://thuvienphapluat.vn/en/index.aspx

[26] https://scem.gov.vn/vi/

[27] Forest resource management and monitoring system in Ca Mau province (aquam.com.au)

[28] The higher confidence in the effluent characteristics of unfed shrimp-mangrove systems is considered equivalent to a data score of at least 7.5 out of 10 and allows the use of the evidence-based assessment in Criterion 2—Effluent.

[29] Forest resource management and monitoring system in Ca Mau province (aquam.com.au)

shrimp farms (particularly differentiated by production system) remains imprecise. Data in Thach et al. (2021) allow an approximate separation of habitat impacts by shrimp species and production system, and online resources such as Google Earth Pro also offer an impressive view of past and present developments of shrimp farming in Vietnam. For rice-shrimp systems, studies such as Park et al. (2021) and Dien et al. (2019) provide details on other impacts, such as increased salinity of soils. Although some regulatory information can be obtained and translated from MARD, information on the regulatory controls and enforcement was largely obtained from academic studies (e.g., Thuy et al., 2021; Boyd et al., 2021b; Nguyen et al., 2022; Pham et al., 2019; Jhaveri et al., 2018). Overall, there is a substantial amount of information available on land use changes in Vietnam, particularly of mangrove forests, but some important details on timeframes and production systems remain challenging to pinpoint. The data score for Habitat is 7.5 out of 10.

Chemical Use

There do not appear to be any readily available official data on chemical use from the government in Vietnam (e.g., the Department of Animal Health) but many academic papers address the issue, typically based on surveys of variable numbers and types of farms. A relatively robust impression of typical recent chemical use, particularly antimicrobials, can be obtained, but some gaps in understanding current chemical use in different species and production systems remain. Many academic studies refer to the detection of antimicrobial resistance in Vietnamese aquaculture and shrimp farms, as well as in the environment (e.g., Binh et al., 2018; Pham et al., 2018; Thornbur et al., 2019; Yen et al., 2021). Inspections of imported shrimp from Vietnam by the U.S. Food and Drug Administration provide useful information on import refusals because of different types of chemical residues. A large amount of information is available regarding recent developments in regulations (particularly changes associated with the FAO-supported 2017 “National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture”), with overviews in Hue (2021)[30] and FAO (2017a,b), but there does not appear to be any readily available information on the practical impacts of this legislation on antimicrobial use in shrimp farms. Thus, the current practices remain sufficiently uncertain that a precautionary approach must be made to the scoring, and the data score for Chemical Use is 5 out of 10.

Feed

Merican (2021a) and Tu et al. (2021) identified the dominant feed manufacturers in Vietnam, and their websites provided basic information on feed types, primary ingredients, and nutritional contents (of which the total protein is used here).[31] Several recent Vietnamese studies in peer-reviewed and grey literature (particularly the AQUA Culture Asia Pacific Magazine[32]) provided information on typical feed formulations and important values such as feed conversion ratios (see Criterion 5—Feed for references). Information on the fishmeal and fish oil sources in Vietnam (and their status as whole fish or by-products) was provided

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[30] Dr. Le Thi Hue is from Vietnam’s Department of Animal Health.

[31] E.g., Uni President Vietnam, https://uniaqua.com.vn/thuc-an-tom

[32] https://aquaasiapac.com/

anonymously by one major feed manufacturer (pers. comm., Anon, November 21, 2022), but some uncertainty remained regarding other feed companies. The potential for some of these sources to come from illegal, unreported, or unregulated (IUU) fisheries remains uncertain. Although sufficient information was available to approximate a typical feed formulation and to determine the general characteristics of feed use in different production systems, the limited amount of specific data from feed companies, and particularly on the sources and sustainability of fishmeal and fish oil, results in a data score of 5 out of 10 for Feed.

Escapes

There are no specific data on numbers or quantities of escaping shrimp in Vietnam. A small number of academic papers refer to large scale flooding events (e.g., Cristoplos et al., 2017; Folorunso et al., 2021) in addition to seafood and general media stories, but a greater number of academic studies note the general flood risk of important shrimp farming areas such as the Mekong Delta, particularly regarding climate change (e.g., Di Giusto et al., 2021). There continue to be minimal data with which to understand the potential impacts of *L. vannamei* in the wild in Vietnam, and older studies from other regions, particularly Thailand, must be used (e.g., Senanan et al., 2010; Panutrakul et al., 2010; Chanavich et al., 2016). For *P. monodon*, snippets of useful information on the domestication efforts and their results are available from McIntosh and Jeerajit (2021) and from company websites (e.g., Moana Marine Biotech in Vietnam). The population structure and genetic diversity study of wild and domesticated *P. monodon* broodstocks by Wong et al. (2021) is very useful. In general, these resources provide some useful information, but uncertainties remain regarding both escape numbers and their potential impacts. The data score for Escapes is 5 out of 10.

Disease

General information on the disease concerns in Vietnamese shrimp farms is abundant, but there are minimal specific data on pathogen detection, identification, treatment, or mortality rates on farms. The International Organization for Animal Health (OIE) produces quarterly and annual regional reports, which include Vietnam, for seven listed viral pathogens; though these reports are useful, they do not relate to the plethora of other pathogens affecting farms. Information on industry practices such as the development of specific pathogen-free breeding lines is generally available and has been a subject of academic publication (e.g., Emerenciano et al., 2022). The structure of the overarching management system is available from MARD, and relevant regulations are available, but academic studies must be relied on to understand the effectiveness of their enforcement. Of key importance to the Disease Criterion, the information on the transmission and impact (if any) of pathogens from wild shrimp populations is particularly limited. The Department of Animal Health was contacted with an information request, but no reply was received. The data score for Disease is 5 out of 10 (and the risk assessment in Criterion 7—Disease must be used).

Source of Stock

There do not appear to be any readily available government data on the numbers of broodstock used and their sources. General information on broodstock numbers and industry characteristics are available in industry media (e.g., Aquaculture Asia Pacific Magazine,[33] Vietnam Fisheries Magazine,[34] and Shrimp Insights[35]) but specific numbers from different sources continue to be challenging to accurately determine. A report from a 2021 MARD conference in Sóc Trăng Province (referred to here as Le, 2021) provided some key data points on broodstock numbers of both species, and personal communication from Dr. Vo Nam Son at Can Tho University was quite helpful in understanding the *P. monodon* broodstock fishery. Moana Marine Biotech facility in Vietnam provided information on the number of domesticated *P. monodon* produced at their facility in Vietnam. Although many important data points could be obtained, the analysis here relied on various estimates, and the data score for the Source of Stock is 5 out of 10.

Wildlife Mortalities

There are no data available on wildlife mortalities on shrimp farms in Vietnam. Lists of species of concern are available from international organizations such as the International Union for the Conservation of Nature (IUCN) and from Vietnam's equivalent Red Book, but the interactions of listed species (or any other species) with shrimp farms are poorly documented. Information from the IUCN on threats to listed species includes categories in which aquaculture may play a role (e.g., "smallholder farming"), but it is not possible to distinguish aquaculture from agriculture. Some data on chemical use can be used to understand the control of aquatic predators in influent waters, and audit reports and Biodiversity-inclusive Environmental Impact Assessments (B-EIA) from certification schemes such as the Aquaculture Stewardship Council provide some indications of the types of wildlife deterrents used, but these cannot be extrapolated to noncertified farms. Information on regulations regarding wildlife control (or trade) are available, but no information is readily available on enforcement. Overall, there is little useful information, and data are not sufficient to give confidence that wildlife mortalities are well understood, so the data score is 2.5 out of 10 (and the risk assessment in Criterion 9X—Wildlife Mortalities must be used).

Introduction of Secondary Species

General information identifying the concern regarding pathogen introduction during live shrimp movements is available in academic literature (e.g., Arulmoorthy et al., 2020; Lee et al., 2022), and similar information to that used in Criterion 8X—Source of Stock illustrated the typical movement characteristics of broodstock and PLs both internationally and domestically (e.g., Aquaculture Asia Pacific Magazine[36] and Vietnam Fisheries Magazine[37]). A report from a 2021 MARD conference in Sóc Trăng Province (referred to here as Le, 2021) also provided useful information on the primary locations of hatcheries in Vietnam as the source of domestic movements. Joffre et al. (2018) provided useful information on the effectiveness of the regulatory system regarding quarantine and health certification in Vietnam. Overall, the readily

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[33] https://aquaasiapac.com/

[34] https://vietfishmagazine.com/

[35] A 2022 Update of the Shrimp Broodstock Market | Shrimp Insights

[36] https://aquaasiapac.com/

[37] https://vietfishmagazine.com/

available data provide some useful information, but there is some uncertainty if they fully represent the farming operations in Vietnam, so the data score is 5 out of 10.

Conclusions and Final Score

With >150,000 shrimp farms using a variety of production systems (and dominated in number by small household farms), it is perhaps inevitable that data availability and quality in Vietnam is fundamentally challenging, but for a large industry and an important product in the U.S. seafood market, the information that is readily available is limited. It is clear that a large amount of data is collected (e.g., by the General Statistics Office, the Department of Agriculture and Rural Development, or the Vietnam Association of Seafood Exporters and Producers) and online translation services greatly facilitate access, but there continue to be many challenges in data availability for an interested U.S. consumer or seafood buyer. Attempts to contact VASEP, MARD, and the Research Institute for Aquaculture (RIA1) were unsuccessful. Much of the understanding of the industry and its impacts is therefore gleaned from the substantial academic interest in the industry. But, with the typical multiyear lag between fieldwork and publication, and often a limited sample size of farms, academic studies must be used with caution in understanding a developing industry. For example, the Vietnam government's 2017 "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)" and the 2021 "National Action Plan on Antibiotic Resistance Prevention and Control in the Field of Agriculture in the Period of 2021–2025" are welcomed regarding the important topic of antimicrobial use, but there do not appear to be any publicly available data with which to evaluate their progress. For this Seafood Watch assessment, the limitations in data availability necessitate a precautionary approach to the scoring in many criteria. The industry is urged to improve data availability in order to recognize current practices and any improvements being made. Although there is some variability in data availability between production systems and species, the overall score for Criterion 1—Data is 5.2 out of 10, based largely on the available academic studies.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.
- Unit of sustainability: 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

Shrimp-Mangrove production system—*P. monodon* only

Effluent Evidence-Based Assessment	**P. monodon**	
C2 Effluent Final Score (0–10)	**10.00**	**Green**

Intensive, Improved-extensive, and Rice-shrimp production systems

Effluent Risk-Based Assessment	***L. vannamei***		***P. monodon***	
Effluent parameters	**Value**	**Score**	**Value**	**Score**
Intensive production systems				
F2.1a Waste (nitrogen) production per ton of shrimp (kg N mt^{-1})	52.1		87.3	
F2.1b Waste discharged from farm (%)	34.0		34.0	
F2.1 Waste discharge score (0–10)		8		7
Improved-extensive production system				
F2.1a Waste (nitrogen) production per ton of shrimp (kg N mt^{-1})	Not assessed		12.5	
F2.1b Waste discharged from farm (%)			27.0	
F2.1 Waste discharge score (0–10)				9
Rice-shrimp production systems				
F2.1a Waste (nitrogen) production per ton of shrimp (kg N mt^{-1})	0.0		0.0	
F2.1b Waste discharged from farm (%)	51.0		51.0	
F2.1 Waste discharge score (0–10)		10		10
All production systems				
F2.2a Content of regulations (0–5)		2		2
F2.2b Enforcement of regulations (0–5)		1		1
F2.2 Regulatory or management effectiveness score (0–10)		0.8		0.8
Intensive systems: C2 Effluent Final Score (0–10)	**5.0**		**4.0**	
Improved-extensive systems: C2 Effluent Final Score (0–10)	Not assessed		**6.0**	
Rice-shrimp systems: C2 Effluent Final Score (0–10)	**10.0**		**10.0**	

Brief Summary

There are well-documented concerns regarding effluent pollution from shrimp farms in Vietnam because of the discharge of soluble and particulate wastes during water exchanges and harvest, and from the disposal of sludge during pond cleaning. The focus of these concerns is predominantly on intensive farms with high nutrient inputs in the form of feed. There is a regulatory system for wastewater in place in Vietnam, but documented concerns regarding weak enforcement appear to greatly reduce its effectiveness. Water quality monitoring by the Department of Agriculture and Rural Development (DARD) in Cà Mau is an encouraging example of improving management, but the results also indicate improper disposal of effluent wastes. Because of the high density of farms covering large areas, the potential for cumulative impacts from multiple farms discharging effluent and sludge wastes into shared waterbodies remains high.

In unfed shrimp-mangrove production systems, pond effluents often contain fewer nutrients than the influent tidal water exchange (i.e., there is a net uptake of nutrients in ponds and removal in the form of harvested shrimp), and *P. monodon* in this system are not considered to have a significant potential for effluent impacts at the farm level or cumulatively across multiple farms. Using the evidence-based assessment option, the final score for Criterion 2—Effluent for shrimp-mangrove systems is 10 out of 10.

For improved extensive and rice-shrimp production systems that are considered here to typically have zero or minimal feed inputs, there are still some nutrient inputs in the form of fertilizer to enhance natural food production in the ponds. The net effluent waste production per ton of shrimp in both systems is minor, but because of the regulatory uncertainty, the potential for cumulative impacts from the high density of improved extensive systems farms covering large areas (and which have slightly higher fertilizer use) is higher, and remains a moderate concern. The final score for Criterion 2—Effluent for improved extensive systems is 6 out of 10, and for rice-shrimp systems is 10 out of 10 (for both species).

For intensive systems, there is commonly a high feed input (but minimal, if any, fertilizer use), and the net waste production from a farm can be substantial. It is emphasized here that not all intensive farms are considered to discharge their effluent wastes; the use of settling ponds is common and the treatment/reuse of water is increasing, but the disposal of sludge remains uncertain. Overall, the amount of waste discharged per ton of shrimp is considered to be low, but the documented pollution concerns and the low confidence in the ability of the regulatory system to limit cumulative impacts of multiple farm result in a lower final score for intensive farms in Criterion 2—Effluent of 5 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*.

Justification of Rating

There are many academic studies and other grey literature that refer to or associate shrimp farms in Vietnam with “pollution” (e.g., Quyen et al., 2020; Nguyen et al., 2019; Joffre et al., 2018; Giao et al., 2021; Tan, 2021; Phan and Stive, 2022). Feeds and fertilizer increase the nutrient load in aquaculture systems, and without appropriate management, they can impair water quality and cause nutrient and organic pollution in waterbodies receiving aquaculture effluents (Chatvijitkul et al., 2017)(Tucker and Hargreaves, 2008). 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; therefore, the characteristics of feed use in the various production systems in Vietnam are important for estimating waste nutrient production.

Waste nutrients are either assimilated by physical, chemical, or biological processes within ponds or discharged in effluents (Chatvijitkul et al., 2017b). Shrimp farms have two primary routes of potential discharge of effluent wastes: through the discharge of nutrient-rich water during routine water exchanges during the production cycle, and through the discharge of settled sludge from the ponds (either during pond-draining at harvest, or during pond cleaning and maintenance) (Dien et al., 2018). It must be noted that farms also have various options for treating effluent wastes before discharge, with the primary one being settling ponds that, at least in super-intensive systems, are commonly used to treat the large quantities of wastes generated (Nam et al., 2022b).

Regarding the scale of the industry, Phan and Stive (2022) consider that enormous amounts of harmful substances have been released via discharge channels into the coastal zone of Vietnam, including solid waste (sludge), which is often discharged directly into the river or discharge canal. In its 2021 annual report on water quality monitoring in Cà Mau (referred to and discussed further in the next section), the Department of Agriculture and Rural Development (DARD) noted that shrimp farming in Cà Mau has many consequences, of which the outstanding problem is water pollution. DARD notes that shrimp farming in Cà Mau is distributed on a large scale and that the river system is physically constrained, and because there is no separate water supply and drainage system, the whole surface water source is mixed together, leading to the deterioration of the quality of the aquatic environment.

But, the different production systems, along with various management options within them, have the potential to dramatically alter the nutrient output characteristics of effluent from the ponds (e.g., the quantity of nutrient inputs such as feed or fertilizer, the rate of external water exchanges, the use of settling or treatment ponds, and the appropriate disposal of sludge). As noted above regarding the scale of the industry, the cumulative impacts of multiple farms discharging into the same receiving water must also be considered.

Water Quality Monitoring

Nguyen et al. (2019) considered that there was little evidence or readily available data that indicate routine monitoring of water quality in the receiving waters of shrimp farms, and because of the complex nature of agricultural-aquacultural landscapes in Vietnam, the specific impacts from shrimp farms may be challenging to define. But, this situation appears to be changing, and several examples of manual and automated systems are now present (although the data are not always readily available). For example, MARD established an Environmental Water Quality Monitoring Project for Aquaculture from 2014 to 2020 (Decision No. 5204/QĐ-

BNN-TCTS, 05/12/2014) with 105 monitoring stations of relevance to farmed shrimp. The monitoring was focused on the suitability of water for use by shrimp farms as opposed to assessing any potential environmental impact. Data from the project do not appear to be readily available, and it is not clear if this project is continuing, but other examples of ongoing monitoring are available.

For example, DARD has routine water quality monitoring of major river routes and watersheds in nine districts/cities in Cà Mau and produces water quality reports approximately weekly.[38] These reports refer to water quality limits defined according to the suitability of water for aquaculture use in regulation QCVN 02-19:2014/BNNPTNT[39] and particularly the National Technical Regulation on Surface Water Quality (QCVN 08-MT:2015/BTNMT). Table 1 in the Surface Water Quality regulation lists the water quality limit values for different users, specifically domestic, irrigation, and "traffic commissary and other purposes with low water quality requirement."[40] The water quality requirements are highest for domestic use, and lowest for "traffic commissary and other purposes with low water quality requirement," which includes aquaculture. It is noted that these water quality limits for different users do not appear to be set according to the needs of natural aquatic organisms, or more broadly to the ecological functionality of the water bodies.

The Southern Center for Environmental Monitoring[41] (SCEM; Trung Tâm Quan Trắc Môi Trường Miền Nam), which is part of the Ministry of Natural Resources and Environment, has 360 environmental monitoring stations in 19 provinces in southern Vietnam that record air quality, air pollution, surface water, underground water, and wastewater. Although some SCEM data are available in real time in online apps, the surface water quality (of relevance here) is limited to average annual values for 58 monitoring stations from approximately 4 samples per year, aggregated into a water quality index. The data output is a map layer in Google Maps,[42] from which it can be seen that the distribution of stations is not focused on areas of shrimp aquaculture (Figure 5). The most recent results (accessed November 22, 2022) show Good or Very Good water quality in all areas except in the vicinity of the large city of Ho Chi Minh.

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[38] Available at https://nongnghiepcamau.vn/. Translate, then select Seafood—Aquaculture—Environmental information.

[39] This regulation is the "National technical regulation on brackishwater shrimp culture farm—conditions for veterinary hygiene, environmental protection and food safety" and includes a water quality limit of pond water before discharge.

[40] Quoted text is according to a Google translation of the regulatory document.

[41] https://scem.gov.vn/vi/

[42] https://scem.gov.vn/vi/quan-trac-dinh-ky/thong-tin-hoat-dong/ban-do-wqi-chat-luong-nuoc-mat-khu-vuc-mien-nam-nam-2021-7.html

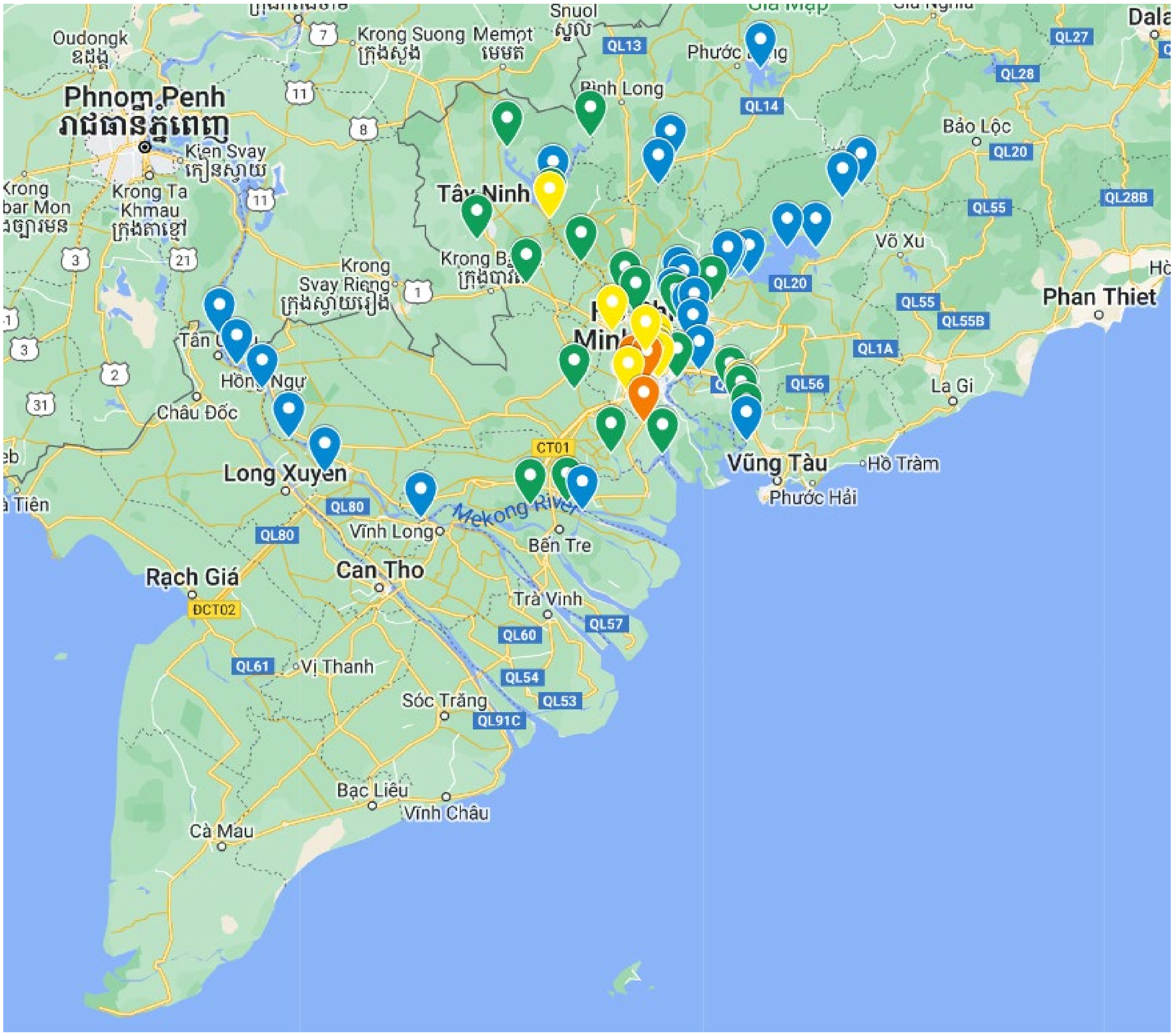

Figure 5: Average 2021 Water Quality Index from 8 sampling occasions at 58 stations in southern Vietnam conducted by SCEM. Blue markers indicate Very Good water quality, green = Good, yellow = Moderate, red = Bad water quality. Image reproduced from SCEM.

An additional set of automated water quality monitoring stations has been established by a joint Vietnamese-Australian project, AQUAM Cà Mau[43] (in addition to a mangrove forest monitoring project described in Criterion 3—Habitat). The set of 15 monitoring stations has been established across Cà Mau, but the variables measured (dissolved oxygen, salinity, total suspended solids, pH, and alkalinity) are again directed at the suitability of the water for use in shrimp farms, and the data do not provide any direct indication of potential environmental impacts from shrimp farm discharges. Data are provided online and via mobile apps, but the online data[44] (accessed November 22, 2022) are limited to only a few physical variables.

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[43] Forest resource management and monitoring system in Ca Mau province (aquam.com.au)

[44] Hệ thống quản lý, giám sát chất lượng nước nuôi trồng thủy sản, giám sát rừng tỉnh Cà Mau (aquam.com.au)

Nevertheless, such applications of automated monitoring technology and real-time data availability are encouraging.

In addition to these government programs (DARD and SCEM), each province has its own environmental monitoring center, which conducts quarterly sampling for a range of physical and chemical parameters (pers. comm., Do Vu Linh, Seafood Watch, November 22, 2022). But the data, and information on their applicability to understanding effluent impacts (if any) from shrimp farms, are not readily available.

Though Le and Le (2019) indicate that government monitoring (i.e., by DARD or SCEM) is conducted in other provinces, it was not possible to navigate the DARD website to find further results. In Cà Mau (as an area of particular interest for shrimp aquaculture), DARD measures a suite of water quality parameters including nitrite, ammonia, phosphorus, hydrogen sulfide, chemical oxygen demand, counts of *Vibrio parahaemolyticus*, total Vibrio *spp*. and coliforms, pH, dissolved oxygen, clarity, salinity, and alkalinity. Two examples of the results from the 2021 annual report[45] for nitrite and ammonium at nine locations from July to December 2021 are shown in Figures 6 and 7. They show that, for nitrite, the surface water levels were above the limit values (for aquaculture use) of 0.05 mg/l at almost all sampling locations and periods. The average over the sampling period was 0.14 mg/l. For this parameter, the same limit of 0.05 mg/l is set for domestic water supply purposes and was therefore similarly exceeded. For ammonium, the limit value for aquaculture use of 0.9 mg/l was exceeded at some locations in some months, but DARD reported that the average of 0.86 was “within the appropriate value range for aquaculture development.” But for domestic supply purposes, the limit value is lower (0.3 mg/l), which was exceeded in all samples at all locations.

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[45] Báo cáo kết quả thực hiện công tác quan trắc môi trường năm 2021 (BC số 611/BC-TS ngày 31/12/2021)

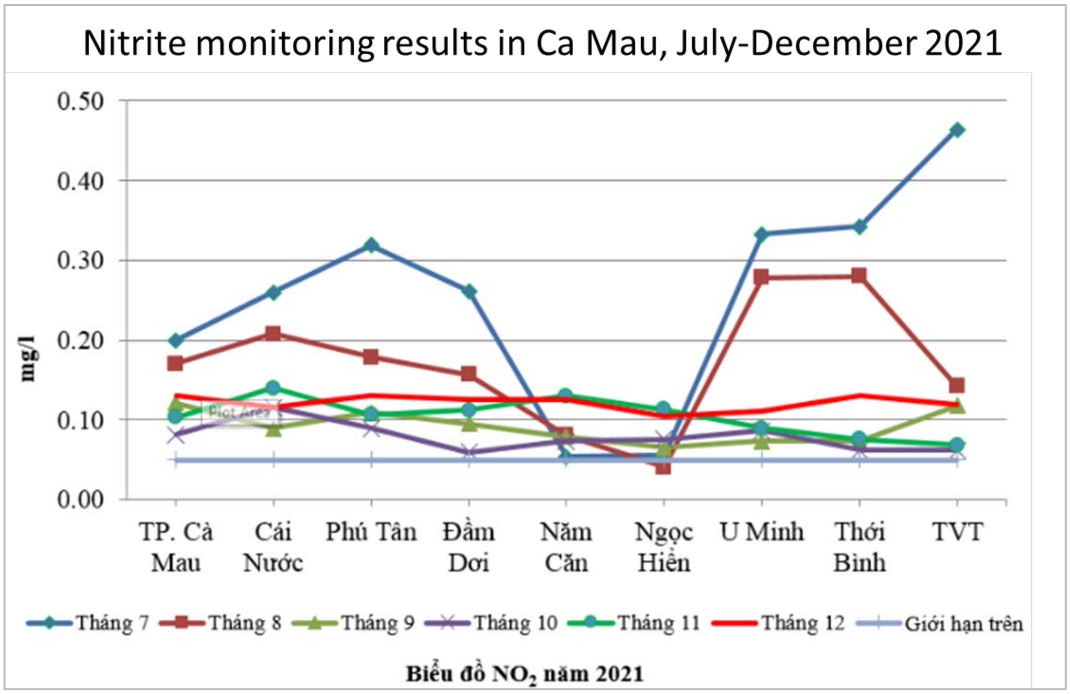

Figure 6: Example of DARD water quality monitoring results for nitrite from nine locations (along the x-axis) for the months of July to December 2021 (one line per month). The quality limit value at 0.05 mg/l is shown by the pale blue line. Graph reproduced from the DARD 2021 monitoring summary report.

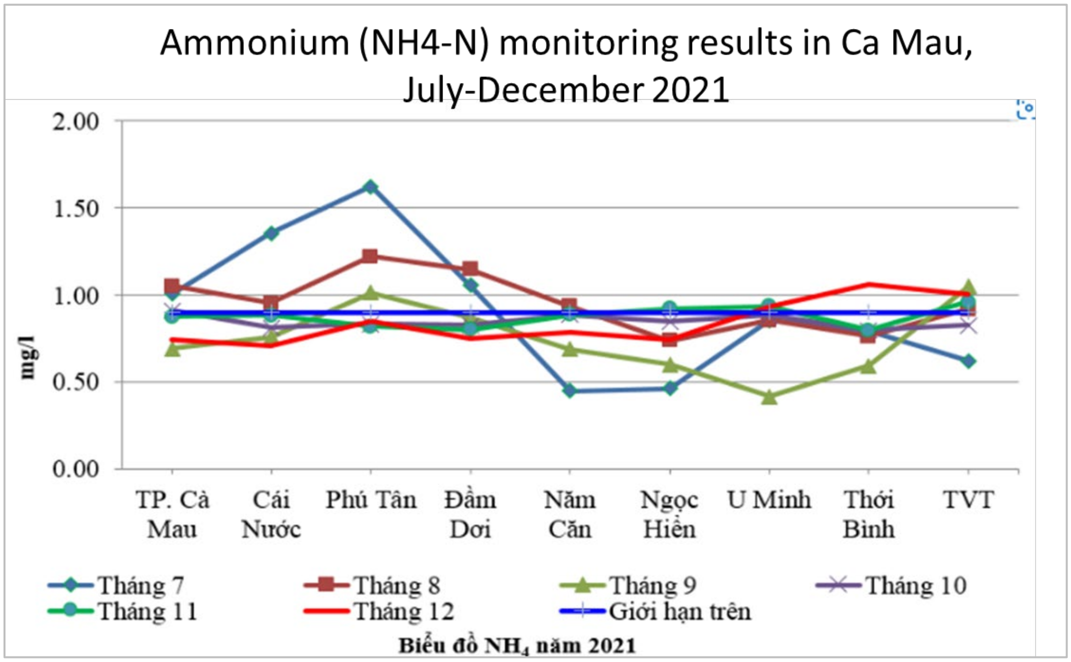

Figure 7: Example of DARD water quality monitoring results for ammonium from nine locations (along the x-axis) for the months of July to December 2021 (one line per month). The limit value for aquaculture use of 0.9 mg/l is shown by the mid-blue line, but the limit for domestic water supply purposes is 0.3 mg/l (not shown). Graph reproduced from the DARD 2021 monitoring summary report

DARD considers the reason for the elevated nitrite and ammonium levels is that some farms have not complied with the regulations on sludge disposal during the renovation of ponds and have discharged pollutants into the general water source of the area. Although there are fewer exceedances of water quality limits for aquaculture use in other parameters monitored by DARD, where limit values are also set for domestic supply purposes (phosphate, dissolved oxygen, Chemical Oxygen Demand), there are numerous or semicontinuous exceedances in the surface water monitoring results. According to DARD, the reasons are the same—discharges of pollutants from shrimp ponds. As noted above, the water quality limits for different human uses do not appear to take account of the ecosystem functionality of the water bodies, but failing to meet the requirements, particularly for the lowest category for aquatic animals in aquaculture, is considered to indicate a significant environmental impact.

Using the evidence-based assessment versus the risk-based assessment

As noted in the introduction, this Seafood Watch assessment focuses on four categories of production systems:

- Intensive systems: including semi-intensive, intensive, and super-intensive; mostly for *L. vannamei* but also for *P. monodon*
- Improved extensive: primarily for black tiger shrimp
- Shrimp-rice systems: primarily for black tiger, but some white-leg shrimp
- Shrimp-mangrove: for black tiger shrimp only.

Because of the well-established characteristics of feed and fertilizer use in integrated shrimp-mangrove systems, the effluent dynamics are considered sufficiently well understood that this system can be assessed using the evidence-based assessment. Although the example of the DARD water quality monitoring results from Cà Mau are welcome, without readily available monitoring data from other regions, or any further information that provides an understanding of the effluent impacts on ecosystem functionality, the Risk Assessment must be used for the remaining systems. Note that, though the shrimp-mangrove system is assessed separately below using the evidence-based assessment, it is also included for reference in the risk assessment tabulations for comparison to the other systems.

Shrimp-Mangrove Systems—Using the Evidence-Based Assessment

Integrated shrimp-mangrove systems are characterized by low inputs, which largely exclude both feed and fertilizers, and they rely solely on the passive influx of nutrients from tidal exchanges to feed the shrimp stock (Anh et al., 2020)(Ha et al. 2012)(Jonell and Henriksson, 2014). With little or no external feed or fertilizer inputs, the nutrient loading in these ponds is low, and mangroves act as biofilters for pond effluents in these systems (Bush et al. 2010). Under these conditions, pond effluents often contain fewer nutrients than the inflowing tidal water exchange (i.e., there is a net uptake of nutrients in ponds and removal in the form of harvested shrimp) (Anh et al. 2010)(Jonell and Henriksson 2014).

Thus, *P. monodon* in this system is considered extractive, and not associated with any significant potential for effluent impacts at the farm level or cumulatively across multiple farms. Using the evidence-based assessment option, the final score from Criterion 2—Effluent for integrated shrimp-mangrove systems is 10 out of 10.

Risk-Based Assessment

This method involves assessing the amount of waste produced by the shrimp and then the amount of that waste that is discharged from the farm. The effectiveness of the regulatory system in managing wastes from multiple farms is used to assess the potential cumulative impacts from the industry as a whole. Although phosphorous may be the main driver of effluent impacts in some environments, particularly in low salinities, this criterion uses nitrogen as a proxy indicator of waste because of the ease of calculation based on the greater availability of data for the nitrogen in the protein component of feed or as fertilizer.

Factor 2.1—Waste discharged per ton of shrimp

Factor 2.1a—Biological waste production

This section considers the nitrogen inputs in feed and fertilizer and the outputs in harvested shrimp, and therefore the initial net nitrogen waste production per ton of farmed shrimp.

Nitrogen inputs—Feed

Protein is the primary nitrogenous constituent of feed, and as discussed in Criterion 5—Feed, the average protein levels for Vietnamese shrimp feeds are estimated to be 38.3% for *L. vannamei* and 40.9% for *P. monodon*. Therefore, as protein is 16% nitrogen, 1 mt of *L. vannamei* or *P. monodon* feed contains 61.28 kg or 65.44 kg of nitrogen, respectively.

In addition to the protein content, the Feed Conversion Ratio (FCR) is the major factor determining the quantities of waste nutrients generated from feed use in aquaculture (Chatvijitkul et al., 2017a). Table 9 in Criterion 5—Feed shows a range of eFCRs[46] in intensive production systems, with an average of 1.19 mt and 1.54 mt of feed used to produce 1 mt of *L. vannamei* and *P. monodon*, respectively, in intensive systems. As discussed in Criterion 5, the extensive, rice-shrimp, and shrimp-mangrove systems are considered to be unfed based on the majority of opinions in academic literature. Thus, Dien et al. (2018) showed that feed represented 81.6% and 75.3% of the total nitrogen input into intensive systems for *L. vannamei* and *P. monodon*, respectively, compared to 0.0% of the nitrogen inputs in an (unfed) rice-shrimp system.

Nitrogen inputs—Fertilizer

The following fertilizer characteristics have been gleaned from the available literature:

- Intensive systems

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[46] eFCR is the Economic Feed Conversion Ratio, and equals the total feed input divided by the total harvest.

  - Boyd et al. (2021a, 2017) noted that only 1 farm in a survey of 30 in Vietnam used fertilizer, and previously, Hung and Quy (2013) also noted that fertilizers are rarely used in intensive farming (because the shrimp receive all their nutritional needs from the commercial feed, and fertilizer inputs would only worsen water quality). Dien et al. (2018) also noted that fertilizer may be of limited value in ponds where formulated feed is added, and suggested that fertilizer addition may be an unnecessary expense in intensive systems. Nevertheless, Dien et al. (2018) did record fertilizer use at 30 kg N/ha for *L. vannamei* and 26.1 kg N/ha for *P. monodon* in intensive ponds, equivalent to 7.7 kg N/mt and 16.8 kg N/mt of farmed shrimp respectively (calculated using the yields of 3.917 mt/ha and 1.551 kg/ha for *L. vannamei* and *P. monodon*, respectively, from Dien et al. (2018)). In these examples, fertilizer use represented a relatively minor component of the total nitrogen inputs, at 9.9% and 13.8%, respectively, for the two species. On a precautionary basis, the minor fertilizer inputs of Dien et al. (2018) are used in the scoring calculation of this assessment for intensive systems.
- Improved extensive systems
  - Older references note that improved extensive farms can use fertilizers to promote the growth of naturally occurring organisms in the pond water to accommodate slightly higher stocking densities (Bosma et al., 2014)(Ha et al., 2014)(Joffre, 2015)(Quoc, 2016), and most recently, Le et al. (2022) noted that small amounts of fertilizer may be used in these systems. Inorganic urea and NPK (nitrogen, phosphorus, and potassium) represent the two most widely used fertilizers in Vietnam (Tho et al., 2011)(Quoc, 2016), and are applied at approximately 40–60 kg/ha (Hung and Huy, 2007). Considering a typical shrimp yield of 375 kg/ha (average of 250 to 500 kg/ha from Ha and Bush (2010) and Hai et al. (2014)) and fertilizer nitrogen contents in inorganic urea of 46% N and in NPK fertilizer of 18% N (from FAO figures in Hung and Huy (2007)), it can be calculated that 42.7 kg N/mt of farmed shrimp is added. The value of 42.7 kg N/mt shrimp is therefore used in the scoring calculation of this assessment for improved extensive systems.
- Rice-shrimp systems
  - Fertilizer may be used for the rice crop (Randall et al., 2022)(Minh et al., 2018), but Dinh et al. (2018) noted that fertilizer may be added after the ponds had been prepared for the shrimp, at a rate of 27.5 kg N/mt shrimp production.[47] The rice also utilizes nutrient wastes produced by the shrimp and may thereby reduce the need for external fertilizer for the rice, and may reduce pollution (Nam et al., 2022a)(Minh et al., 2018)(Dien et al. 2019)(Dang et al., 2020)(Sammut and Sang 2020). According

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[47] 3.67 kg N/ha as fertilizer, with 133.2 kg/ha harvest for *P. monodon* shrimp = 27.5 kgN/mt shrimp in Dien et al. (2018).

    to Dinh et al. (2018), the fertilizer input represented only 8.2% of the total nitrogen input, with the remaining 91.8% coming from the incoming water supply. The value of 27.5 kg N/mt shrimp is used in the scoring calculation of this assessment for rice-shrimp systems.

- Shrimp-mangrove systems (included here for reference only)
    - There are few references that specifically refer to fertilizer regarding shrimp-mangrove systems, but this is considered to be because external fertilizer (and feed) is not used, and the shrimp feed on natural organisms within the pond and tidal water exchange (Anh et al., 2020)(Ha et al., 2012a,b)(Jonell and Henriksson, 2015).

Nitrogen outputs—harvested shrimp

The whole-body protein content for harvested shrimp is 17.8% for *L. vannamei* and 18.9% for *P. monodon* (Boyd et al., 2007). Using the same 16% nitrogen content for protein, 1 mt of shrimp contains 28.48 kg and 30.24 kg of protein for *L. vannamei* and *P. monodon*, respectively.

The above nutrient inputs and outputs can be used to calculate the nitrogen waste produced by each species in each system (Table 2). The values in bold in Table 2 for the waste production per mt of farmed shrimp are the values for Factor 2.1a—Biological Waste Production. That is, *L. vannamei* is estimated to produce 52.1 kg N per mt of shrimp in intensive systems, and zero nitrogen wastes in the rice-shrimp system. *P. monodon* is estimated to produce 87.4 kg N per mt of shrimp in intensive systems, 12.5 kg N/mt in extensive systems, and zero nitrogen wastes in rice-shrimp and shrimp-mangrove systems. As discussed in Factor 2.1b—Production System Discharge, not all this waste N is discharged from the ponds.

Table 2: Calculated nitrogen waste production according to nitrogen inputs (in feed and fertilizer) and outputs (in harvested shrimp).

		Data	
Parameter	**Units**	***L. vannamei***	***P. monodon***
Feed protein content	%	38.3	40.9
Nitrogen in feed (protein = 16% nitrogen)	Kg N per mt feed	61.3	65.4
Whole shrimp protein content	%	17.8	18.9
Intensive Systems			
eFCR		1.19	1.54
Feed nitrogen input	Kg N per mt shrimp	72.9	100.8
Fertilizer nitrogen input	Kg N per mt shrimp	7.7	16.8
Total Nitrogen INPUT	Kg N per mt shrimp	80.6	117.6
Harvested shrimp nitrogen OUTPUT	Kg N per mt shrimp	28.5	30.2
Waste production per mt of shrimp	Kg N per mt shrimp	**52.1**	**87.4**
Improved Extensive Systems			
eFCR			0.00
Feed nitrogen input	Kg N per mt shrimp		0.0
Fertilizer nitrogen input	Kg N per mt shrimp		42.7
Total Nitrogen INPUT	Kg N per mt shrimp		42.7

Harvested shrimp nitrogen OUTPUT	Kg N per mt shrimp		30.2
Waste production per mt of shrimp	Kg N per mt shrimp		**12.5**
Rice-shrimp Systems			
eFCR		0.00	0.00
Feed nitrogen input	Kg N per mt shrimp	0.0	0.0
Fertilizer nitrogen input	Kg N per mt shrimp	27.5	27.5
Total Nitrogen INPUT	Kg N per mt shrimp	27.5	27.5
Harvested shrimp nitrogen OUTPUT	Kg N per mt shrimp	28.5	30.2
Waste production per mt of shrimp	Kg N per mt shrimp	**0.0**	**0.0**
Mangrove-shrimp Systems (included here for reference only)			
eFCR			0.0
Feed nitrogen input	Kg N per mt shrimp		0.0
Fertilizer nitrogen input	Kg N per mt shrimp		0.0
Total Nitrogen INPUT	Kg N per mt shrimp		0.0
Harvested shrimp nitrogen OUTPUT	Kg N per mt shrimp		30.2
Waste production per mt of shrimp	Kg N per mt shrimp		**0.0**

Factor 2.1b—Production system discharge

Factor 2.1b estimates the proportion of the waste produced by the shrimp (Factor 2.1a) that is discharged to the environment beyond the farms. An important parameter here is the frequency and volume of water exchange between the ponds and the external environment, but because of the common use of unclear terminology, determining water discharge characteristics is challenging; for example, "water exchange" may refer to exchanges between the production ponds and the external environment, or to exchanges between production ponds and reservoirs or other treatment ponds within the farm boundary. Similarly, reservoirs or settling ponds may be used with influent water before use in production ponds or used with effluent water before discharge from the farm (or both). The term "clarifying pond" used by Tu et al. (2021) could refer to either a reservoir for influent or a settling pond for effluent. Boyd et al. (2021a, 2021b, 2017) are specific regarding the use of reservoir/settling ponds and are a useful resource.

In general, there is likely to be a large range of water management and discharge characteristics across (and within) different production systems. These vary from frequent tidal exchanges with local waterways in shrimp-mangrove or improved-extensive systems to the ability to operate multiple production cycles in intensive farms without any exchange with natural waterbodies beyond the farm. The following is an attempt to summarize the available information and to draw simple conclusions for each production system assessed.

- **Intensive Systems**
  - Water exchange: According to Nam et al. (2022b), the operation of super-intensive shrimp farms in Vietnam produces considerable volumes of wastewater and requires a large amount of daily water exchange; however, it is important to differentiate between water exchanges within the farm (via treatment ponds, etc.) and those exchanges with natural waterbodies beyond the farm. According to Nair (2015),

intensive shrimp farms in Vietnam often discharge pond effluent into the rivers and canal systems without proper treatment, and Boyd et al. (2021a) noted that water exchange remains a common practice in *L. vannamei* farming; however, Ngoc et al. (2021) noted that, although conventional shrimp farming methods require farmers to change the pond water daily, recent improved farming methods rely heavily on water treatment and allow for reuse of water and much lower water exchange. The scale of uptake of these new methods is not yet clear; for example, Nguyen and Tien (2021) reported that super-intensive *L. vannamei* farms exchanged 36% of the water 23 times per month (average 27.6% per day); intensive farms exchanged 23% of the water 3.1 times per month (2.4% per day); and semi-intensive farms exchanged 22% of the water 2.7 times per month (2% per day, or 1.9% for *P. monodon*). It is not clear how many of these water exchanges are with natural waterways beyond the farm. Somewhat in contrast, only 11 of the 30 intensive *L. vannamei* farms surveyed by Boyd et al. (2021a, 2017) exchanged water (presumed to mean with the external environment), and at a rate of 10% per day (a crude average across all 30 farms of 3.6%/day). Boyd et al. (2021a) also noted an average 10% exchange per day in semi-intensive systems. Of the farms surveyed by Boyd et al. (2021a, 2017), 90% had reservoirs (of approximately 18% of the production pond volume[48]), implying the ability to exchange water within the farm boundary (Boyd et al., 2017). For *P. monodon*, Nguyen and Tien (2021) reported that 5 out of 26 intensive farms used water exchange at an average of 8% per day (a crude average of 1.5% across the 26 farms, although it is considered here that not all these systems were intensive), and Boyd et al. (2021a) concluded that water exchange was similar in intensive farms producing either species. Tu et al. (2021) indicated that water intake was done 1.22 times per cycle on average, implying that ponds are filled at the start of the cycle and then have minor exchange during the cycle (also implying draining of the ponds at harvest if they are filled at the start of each cycle). Nguyen et al. (2019) reported that intensive farms exchanged water 7.2 times per cycle, with an estimated average of 7.8% daily exchange.[49] Overall, the crude average exchange rate of these values is 4.3% per day, and it is assumed here (regarding the scoring options in the Seafood Watch Aquaculture Standard) that the water exchange is >3% per day on average.

- Draining at harvest: In general, ponds are considered to be drained externally at harvest, unless they have high reservoir volumes and are able to contain all water within the farm (e.g., during pond drying between cycles). Boyd et al. (2021a) noted

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[48] Calculated based on area, and therefore an assumption that the depth of the reservoir is similar to that of the production ponds.

[49] Calculated on a typical production cycle of 90 days (Boyd et al., 2021) and on the basis that each water exchange was the entire production pond volume (i.e., 720% total exchange over 90 days = 7.8% per day).

that semi-intensive ponds were drained at harvest. Overall, it remains unclear as to what proportion of the water exchanges in intensive farms occurs with natural waterways beyond the farm boundary. On a precautionary basis, the figures above are assumed to be exchanges with natural waterways, and the ponds are assumed to be drained at harvest.

  - Settling ponds: Boyd et al. (2021a) reported that 67% of their surveyed *L. vannamei* farms in Vietnam had settling basins, with an average of 0.09 ha or 5.1% of the production volume.[50] Nam et al. (2022b) also considered the use of settling ponds to be a typical practice before discharge to natural water bodies from super-intensive farms. In contrast, Van Nguyen et al. (2021) reported that very few production facilities have a wastewater treatment pond to treat the water before it is pumped back out to sea. Quyen et al. (2020) considered that only 21% of farms did not treat wastewater (i.e., 79% did treat it). Overall, it is considered that, on average, settling ponds are used.
  - Sludge: A large amount of settled particulate wastes in the form of sludge is generated during each production cycle in intensive systems (Giao et al., 2021), but it is unclear how it is disposed of. In super-intensive farms, Nam et al. (2022b) show that the pond bottoms are siphoned regularly during production, which generates quite high concentrations of suspended solids in the wastewater. And, although Nam et al. showed that this water can be satisfactorily treated using settling ponds, their study did not indicate the subsequent fate of the settled solids from the settling ponds. Giao et al. (2021) implied that it is discharged, but Quyen et al. (2020) showed that approximately 50% of VietGAP-approved farms disposed of sludge correctly, with no direct discharge, yet the authors also observed illegal dumping of sludge during field trips. But, Quyen et al. (2020) also reported that 81% of non-VietGAP-approved farms practiced correct disposal of bottom sludge (by using small ponds or trenches and utilizing available land). Without conclusive references on alternative disposal, it is assumed here, on a precautionary basis, that pond sludge is discharged by intensive farms.
- **Improved Extensive Systems**
  - Water exchange: According to Le et al. (2022), water exchange in extensive farms follows the tidal systems, leading water into ponds at high tide, while water is discharged at low tide. Nguyen and Tien (2021) noted that extensive systems exchanged 48.3% of the water 10.7 times per month (17 % per day). This is also categorized as >3% exchange per day on average.

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[50] Assuming the depth of the settling pond is similar to the production pond.

  - Draining at harvest: Although no specific evidence was readily available in peer-reviewed literature, from this author's experience of visiting extensive farms in Vietnam, harvest is mainly considered to be continuous during tidal water exchanges; i.e., the ponds are not drained at harvest.
  - Settling ponds: Similarly, from this author's personal experience, it is considered to be unlikely that extensive farms use settling ponds before discharge, because these are low-input systems. The production ponds themselves are likely to act as settling basins that reduce the particulate loads of the influent water from natural waterways.
  - Sludge: Without substantial amounts of feed, the buildup of particulate wastes in extensive ponds is slower than in intensive ponds, and the removal of sludge is intermittent. From this author's personal experience, this smaller amount of sludge is typically contained within the farm boundary and used to reinforce embankments and dry areas.
- **Rice-shrimp systems**
  - Water exchange: According to Anh et al. (2020), rice-shrimp systems are typically operated tidally. Similar to improved extensive and shrimp-mangrove systems above, it has not been possible to determine a typical average daily exchange rate (for example, Tan et al. (2020) referred to "periodic" water exchanges) but it is considered to be >3%.
  - Draining at harvest: Because of the alternating nature of the rice-shrimp systems, they are considered to be drained at harvest (Dang et al., 2020). In order to reduce the salinity after the shrimp harvest (and before stocking with rice), the ponds may be flushed with freshwater to remove salt (Park et al., 2021).
  - Settling ponds: No evidence could be found for the use of settling ponds in shrimp-rice water exchanges or at harvest.
  - Sludge: With minimal amounts of feed being the typical practice, the buildup of particulate wastes in extensive ponds is slower than in intensive ponds. Though Dang et al. (2020) note that any sludge can be used as fertilizer for the subsequent rice crop, it is not known how often this is practiced. As noted above, ponds may also be flushed to reduce salinity. Therefore, on a precautionary basis, any sludge is considered to be discharged.
- **Shrimp-mangrove systems** (included here for reference only)
  - From this author's personal experience, the water and sludge characteristics of shrimp-mangrove systems are considered to be the same as improved extensive systems above.

The generalized water exchange and sludge management characteristics are applied to the Seafood Watch Aquaculture Standard, as displayed in Table 3. These values and adjustments are applied to the amount of waste nitrogen produced by the shrimp (in Factor 2.1a) and take account of the nitrogen that is broken down in the ponds or released as nitrogen gas, and thereby finally calculates the remaining nitrogen that is potentially discharged as effluent during water exchanges, harvest draining, or sludge disposal. Table 3 includes the final scores for Factor 2.1—Waste discharged per ton of shrimp.

Table 3: Calculations to determine the Factor 2.1b—Waste Discharge score. The values and adjustments determine the portion of the waste produced by the shrimp in Factor 2.1a that is potentially released from the ponds. See the Seafood Watch Aquaculture Standard for more details.

	Data	
Parameter	***L. vannamei***	***P. monodon***
Intensive systems		
Factor 2.1a Waste production	52.1 kg N/mt shrimp	87.4 kg N/mt shrimp
Average daily exchange >3%	51% discharge	51% discharge
Settling pond use adjustment	–17% discharge	–17% discharge
Sludge disposal adjustment	n/a	n/a
% of waste discharged	34%	34%
Amount discharged	17.7 kg N/mt shrimp	29.7 kg N/mt shrimp
Factor 2.1 score (0–10)	**8**	**7**
Improved extensive systems		
Factor 2.1a Waste production		12.5 kg N/mt shrimp
Average daily exchange >3%		51% discharge
Settling pond use adjustment		n/a
Sludge disposal adjustment		–0.24 discharge
% of waste discharged		27%
Amount discharged		3.4 kg N/mt shrimp
Factor 2.1 score (0–10)		**9**
Rice-shrimp systems		
Factor 2.1a Waste production	0.0 kg N/mt shrimp	0.0 kg N/mt shrimp
Average daily exchange >3%	0.51	0.51
Settling pond use adjustment	n/a	n/a
Sludge disposal adjustment	n/a	n/a
% of waste discharged	51%	51%
Amount discharged	0.0 kg N/mt shrimp	0.0 kg N/mt shrimp
Factor 2.1 score (0–10)	**10**	**10**
Shrimp-mangrove (included here for reference only)		
Factor 2.1a Waste production		0.0 kg N/mt shrimp
Average daily exchange >3%		0.51
Settling pond use adjustment		n/a
Sludge disposal adjustment		–0.24 discharge
% of waste discharged		0.0
Amount discharged		0.0
Factor 2.1 score (0–10)		**10**

Factor 2.2—Management of farm-level and cumulative impacts

Although the calculated waste discharge per metric ton of farmed shrimp (Factor 2.1 above) is relatively small, the total amount of waste produced by any one farm and by large numbers of farms in combination can be large. Joffre et al. (2018) indicated that shrimp farms in Vietnam, and particularly areas of intensive shrimp farms, cumulatively discharge heavy loads of nutrients. Thus, shrimp farm effluent can cause significant impacts and pressures on the environment if it is not well managed (Giao, 2021)(Minh et al., 2019)(Nguyen et al., 2019).

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.

It is clear from academic studies that regulations and technical standards for managing water quality in Vietnam are present (e.g., Van Nguyen et al., 2021; Joffre et al., 2018; Nguyen et al., 2019), but understanding the specific requirements and their implementation is challenging. The primary agencies are the Ministry of Agriculture and Rural Development (MARD) and the Department of Agriculture and Rural Development (DARD), the Ministry of Natural Resources and Environment (MNRE), and the Directorate of Fisheries (DoF). The key regulations are the National Technical Regulation on brackish water shrimp farms (QCVN02-19:2014/BNNPTNT), the National Technical Regulation on Surface Water Quality (QCVN 08-MT:2015/BTNMT), the 2020 Law on Environmental Protection (72/2020/QH14), the 2012 Law on Water Resources (17/2012/QH13), and the 2017 Law on Fisheries (18/2017/QH14; and their 2019 guidelines for implementation, 26/2019/ND-CP). These laws are available in Vietnamese (e.g., from Thư Viện Pháp Luật[51]) and can be satisfactorily translated online, yet they remain challenging to robustly interpret in their practical application to different types and sizes of shrimp farms in Vietnam because of the plethora of implementation guidelines documented in additional circulars, decisions, and decrees.

The overarching regulations use general language that refers to other laws for specific requirements; for example, the Law on Fisheries states (Article 20a, with minor redaction): “The wastewater treatment system and system of ponds, tanks must meet quality control requirements,” and the Law on Environmental Protection states (Article 61.3): “[M]ud and food deposited when cleaning in aquaculture ponds must be managed according to regulations on waste management.” More specific content is available in technical regulations and, regarding the key aspects of Factor 2.1 above, the National Technical Regulation on brackish water shrimp farms (QCVN02-19:2014/BNNPTNT) requires farms to have a storage/settling pond of at least 15% of the total pond area, and either a common wastewater treatment facility of the farming area or a separate wastewater treatment pond on the farm with an area of at least 10% of the total pond area. Water from wastewater treatment ponds may only be discharged into the surrounding environment if it meets the parameters in Table 4.

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[51] https://thuvienphapluat.vn/en/index.aspx

Table 4: Water quality requirements for wastewater from brackish water shrimp farms. Parameters and values reproduced from Appendix 1, Table 2, National Technical Regulation QCVN 02-19:2014/BNNPTNT Brackish Water Shrimp Farming Establishments—Conditions to Ensure Veterinary Hygiene, Environmental Protection and Food Safety.

Parameter	**Unit**	**Permissible value**
pH		5.5 to 9
Biological oxygen demand (20 °C)	mg/l	<50
Chemical oxygen demand	mg/l	<150
Floating solids	mg/l	<100
Coliforms	CFU/100ml	<5,000

More specific wastewater quality requirements that include some aspects of the receiving water body are found in the National Technical Regulations on Livestock Wastewater (QCVN 62-T:2016/BTNMT), but it is not clear if these requirements apply to shrimp farms. For reference, the regulation is based on six water quality indicators, and manages effluent based on calculations of the total discharge from any one farm and the capacity of the receiving water to assimilate the wastes (based on its flow rate or size). Without confirmation that it applies to shrimp farms, it is not considered further in this assessment.

As noted, the National Technical Regulation on Surface Water Quality (QCVN 08-MT:2015/BTNMT) includes water quality limit values for different purposes, specifically domestic, irrigation, and "traffic commissary and other purposes with low water quality requirement."[52] According to DARD's analysis of surface water monitoring results in Cà Mau described earlier in this criterion, aquaculture is included in the latter "low water quality" category.

There are also likely to be provincial variations; for example, regulations for sludge and mud from ponds in Cà Mau are available from DARD[53] (Decision No. 17/2021/QD-UBND of 2021, which updated measures from 2014 and 2016), but it is challenging to understand how these relate to national measures or those in other provinces. Although these regulations require suitable storage, treatment, or disposal of sludge to avoid discharge into rivers, there are concerns (as noted in Factor 2.2b) regarding their efficacy and enforcement.

As noted in the Introduction, DARD conducts regular environmental water quality at nine locations in Cà Mau, and although data from other regions are not readily available, Le and Le (2019) indicate that similar monitoring may take place in other regions. Although this monitoring is recognized as providing useful information, the small number of sampling locations across Cà Mau Province limit its scale.

Overall, there do appear to be regulatory measures in place in Vietnam regarding effluent wastes, although it can be challenging to understand the details in different provinces. These

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[52] Quoted text is according to a Google translation of the regulatory document.

[53] https://nongnghiepcamau.vn/ - Seafood—Aquaculture—Environmental information

measures (e.g., the limits in Table 4) are considered to apply to all wastewater throughout the production cycle, including peak discharge events such as harvest and pond cleaning, but the management system does not appear to set site-specific limits (i.e., the limits in Table 4 are in units of mg/l of pollutant in the effluent and do not relate to the total volume of effluent and therefore the total pollutant discharge). The limit values in both regulations for brackish water shrimp farms and surface waters are established for different water users (e.g., domestic users, irrigation, and aquaculture) but do not appear to be set according to the ecological principles across the variety of environments into which shrimp farms discharge wastes. Except for the surface water quality monitoring in Cà Mau, there does not appear to be a cumulative management system in place across all provinces that addresses the large scale of the industry or the interactions of shrimp farm effluents with those of other industries. Therefore, the score for Factor 2.2a is 2 out of 5.

Factor 2.2b: Enforcement of effluent management measures

The same agencies listed in Factor 2.2a (i.e., MARD, DARD, MNRE, and DoF) are considered to be associated with enforcement, but specific details on their resources or activities regarding enforcement could not readily be found.

More broadly, Van Nguyen et al. (2021) (referring to the Thừa Thiên Huế Province in central Vietnam) noted that most of the farms do not meet the required standards for managing water quality, and because of insufficient enforcement of regulations for wastewater treatment, the majority of *L. vannamei* shrimp farmers have no incentive to treat wastewater after it has been used; therefore, most of the water is discharged back into the sea untreated, creating a vicious circle of gradually decreasing quality of water that could be reused in other shrimp ponds. Joffre et al. (2018) also noted that rules for water treatment are not properly enforced by local extension services because of a lack of capacity to control all farms in areas with a high density of intensive farming, and noted only one staff member per district. Quyen et al. (2020) observed illegal sludge discharge during their field trips (in 2018 and 2019).

It must be noted that these criticisms (in Van Nguyen et al., 2021, Quyen et al., 2020, and Joffre et al., 2018) are directed at intensive farms (which generate higher waste loads per ton of shrimp); for example, Nguyen et al. (2019) also noted that the disposal of sludge and effluents from intensive farms in Northern Vietnam created pollution not only for those farms, but also for other farms nearby. The intake water of all the intensive farms and one-third of shrimp-mangrove farms in their survey had been polluted by other intensive farms. This is further evidence of limited enforcement, and Nguyen et al. (2019) noted that the water quality regulations from MARD were implemented only as advice.

The ability to draw more robust conclusions about enforcement is also hampered by the apparent lack of readily available and widespread water quality monitoring data from farms or from relevant water bodies in areas with large numbers of farms (noting the example from Cà Mau described above). Nguyen et al. (2019) noted that sludge and effluent disposal from intensive farms is not monitored stringently by any institutions. Further, despite official decrees stating the fines for various administrative violations in fisheries activities (e.g., Decree

41/2017/ND-CP of 2017), evidence of similar sanctions relating to effluent or sludge were not readily available. In the Cà Mau water quality monitoring reports, DARD considers the reason for elevated levels of various parameters is that some farms have not complied with the regulations on sludge disposal during the renovation of ponds and have discharged pollutants into the general water source of the area. This also indicates that enforcement is weak.

It must be emphasized that this assessment is not implying that all farms in Vietnam lack effective water or sludge treatment and disposal (for example, the use of settling ponds is noted in Factor 2.1a) but is simply using the examples as evidence of limited enforcement of effluent regulations. Overall, enforcement activities in Vietnam are difficult to identify, and there is little evidence of monitoring or compliance data and limited evidence of penalties for infringements. Thus, the readily available evidence indicates that enforcement is minimal, and the score for Factor 2.2b is 1 out of 5. Combined with the Factor 2.2a score of 2 out of 5, the final Factor 2.2 score is 0.8 out of 10, indicating a low confidence in the effectiveness of the management system to limit cumulative effluent impacts from the large number of shrimp farms in Vietnam.

Conclusions and Final Score

There are well-documented concerns regarding effluent pollution from shrimp farms in Vietnam because of the discharge of soluble and particulate wastes during water exchanges and harvest, and from the disposal of sludge during pond cleaning. The focus of these concerns is predominantly on intensive farms with high nutrient inputs in the form of feed. There is a regulatory system for wastewater in place in Vietnam, but documented concerns regarding weak enforcement appear to greatly reduce its effectiveness. Water quality monitoring by the Department of Agriculture and Rural Development (DARD) in Cà Mau is an encouraging example of improving management, but the results also indicate improper disposal of effluent wastes. Because of the high density of farms covering large areas, the potential for cumulative impacts from multiple farms discharging effluent and sludge wastes into shared waterbodies remains high.

In unfed shrimp-mangrove production systems, pond effluents often contain fewer nutrients than the influent tidal water exchange (i.e., there is a net uptake of nutrients in ponds and removal in the form of harvested shrimp) and *P. monodon* in this system are not considered to have a significant potential for effluent impacts at the farm level or cumulatively across multiple farms. Using the evidence-based assessment option, the final score for Criterion 2—Effluent for shrimp-mangrove systems is 10 out of 10.

For improved extensive and rice-shrimp production systems that are considered here to typically have zero or minimal feed inputs, there are still some nutrient inputs in the form of fertilizer to enhance natural food production in the ponds. The net effluent waste production per ton of shrimp in both systems is minor, but because of the regulatory uncertainty, the potential for cumulative impacts from the high density of improved extensive systems farms covering large areas (and which have slightly higher fertilizer use) is higher and remains a moderate concern. The final score for Criterion 2—Effluent for improved extensive systems is 6 out of 10, and for rice-shrimp systems is 10 out of 10 (for both species).

For intensive systems, there is commonly a high feed input (but minimal, if any, fertilizer use), and the net waste production from a farm can be substantial. It is emphasized here that not all intensive farms are considered to discharge their effluent wastes; the use of settling ponds is common and the treatment/reuse of water is increasing, but the disposal of sludge remains uncertain. Overall, the amount of waste discharged per ton of shrimp is considered to be low, but the documented pollution concerns and the low confidence in the ability of the regulatory system to limit cumulative impacts of multiple farm results in a lower final score for intensive farms in Criterion 2—Effluent of 5 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical “ecosystem services” they provide.
- 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

	L. vannamei		P. monodon	
Habitat parameters	**Value**	**Score**	**Value**	**Score**
Intensive production systems				
F3.1 Habitat conversion and function		1		1
Improved extensive production systems				
F3.1 Habitat conversion and function	Not assessed			1
Rice-shrimp production systems				
F3.1 Habitat conversion and function		7		7
Shrimp-mangrove systems				
F3.1 Habitat conversion and function	Not assessed			1
All production systems				
F3.2a Content of habitat regulations		2		2
F3.2b Enforcement of habitat regulations		3		3
F3.2 Regulatory or management effectiveness score		2.4		2.4
Intensive systems: C3 Habitat Final Score (0–10)	**1.47**		**1.47**	
Improved extensive systems: C3 Habitat Final Score (0–10)	Not assessed		**1.47**	
Rice-shrimp systems: C3 Habitat Final Score (0–10)	**5.47**		**5.47**	
Shrimp-mangrove systems: C3 Habitat Final Score (0–10)	Not assessed		**1.47**	

Brief Summary

A remarkable change in the coastal land cover regarding aquaculture began in the 1990s as shrimp farming expanded rapidly in coastal areas with the encouragement of the Vietnamese government and organizations such as the World Bank and the Asia Development Bank. Several recent academic studies analyzing satellite images provide a useful time series of land use change and show a rapid conversion of mangrove forests and agricultural land into shrimp farms, particularly in the Mekong Delta in southern Vietnam. Nevertheless, quantifying the land use change in terms of areas and timelines for different production systems is challenging, particularly for recent or ongoing conversions of high-value habitats after 1999, when the ecological value of mangrove forests was considered to be formally recognized. Though the majority of shrimp farms are shown to be located in former agricultural land, the conversion of a large proportion of Vietnam's ecologically important mangrove forest into shrimp farms, including shrimp-mangrove farms (noting prior damage to these areas from the use of defoliants by the United States during the Vietnam War), is considered to have caused a loss of ecosystem services and a loss of habitat functionality from large-scale habitat fragmentation, as well as changes in mangrove cover, diversity, ecology, access, and hydrodynamics. Recent academic studies have indicated that this has continued after 1999 and more recently (albeit at a much slower pace), and shrimp farming continues to be the most important factor affecting mangroves in Vietnam. There are some differences in the likelihood of the different production systems being located in former mangrove areas, but without an ability to robustly differentiate their respective contributions, the score for Factor 3.1 is 1 out of 10 for intensive, extensive, and shrimp-mangrove systems. The modification of rice farms for the production of rice and shrimp is not considered to result in the loss of functionality of the agricultural land, but there is a moderate concern regarding increasing soil salinity (the score for Factor 3.1 is 7 out of 10).

The Vietnamese government has clearly recognized the value of mangrove forests and their ecosystem services and has been active in their management and restoration; however, the management measures have focused on the development of shrimp-mangrove farms and efforts to reach a forest-to-pond ratio of 60%; i.e., 60% of the total farm area (which is typically allocated in small parcels to tens of thousands of individual households) must be forested. It is considered here that this ratio still results (cumulatively) in a loss of habitat functionality, and it is apparent that this ratio is often not met due to limitations in enforcement (and driven by a high price for shrimp, which encourages a larger pond area). The overall effectiveness of the management system (for all production systems) is therefore considered to be limited: the score for Factor 3.2 is 2.4 out of 10. Overall, Factors 3.1 and 3.2 combine to give a final score for Criterion 3—Habitat for rice-shrimp systems of 5.47 out of 10. For intensive, improved extensive, and shrimp-mangrove systems, the final score for Criterion 3—Habitat is 1.47 out of 10. These scores apply to both species.

Justification of Rating

Vietnam has a complex history of land use change, both before the introduction of significant aquaculture production and in recent decades. Although regions currently of importance to aquaculture such as the Mekong Delta had previously been substantially modified to support rice-based agriculture (Campbell, 2012), Phan and Stive (2022) noted that a remarkable change in the coastal land cover regarding aquaculture began in the 1990s in the Mekong Delta, first in the Cà Mau, Bạc Liêu, and Sóc Trăng Provinces, and then rapidly spreading to the coastal zones of Trà Vinh Province, Bến Tre Province, and the southern part of Kiên Giang Province. The Mekong Delta hosts approximately 90% of the shrimp farming area in Vietnam (Schuur et al., 2021)(Quyen et al., 2020), and is the focus of the majority of academic studies on land use changes of relevance to aquaculture. This region is therefore the focus of this assessment, but other parts of Vietnam are considered where possible (a map of the provinces in the Mekong Delta is provided in Figure 2).

During the industry's development, a variety of habitat types have been converted to shrimp ponds/farms, and regarding the timeframes for habitat conversion considered in the Seafood Watch Aquaculture Standard, a focus of this assessment has also been on understanding the nature of shrimp farming's land use changes before and after 1999.[54]

Annual statistics on the total aquaculture area in each province (as pond area in hectares, ha) are available from the General Statistics Office (GSO) from 1995 and shown in Figure 8 for the provinces in the Mekong Delta and the Red River Delta in Northern Vietnam. Note that this is the total aquaculture area, including all types of aquaculture (i.e., fish and shrimp), but shrimp is by far the dominant land user (e.g., Thach et al., 2021, and discussed further below).

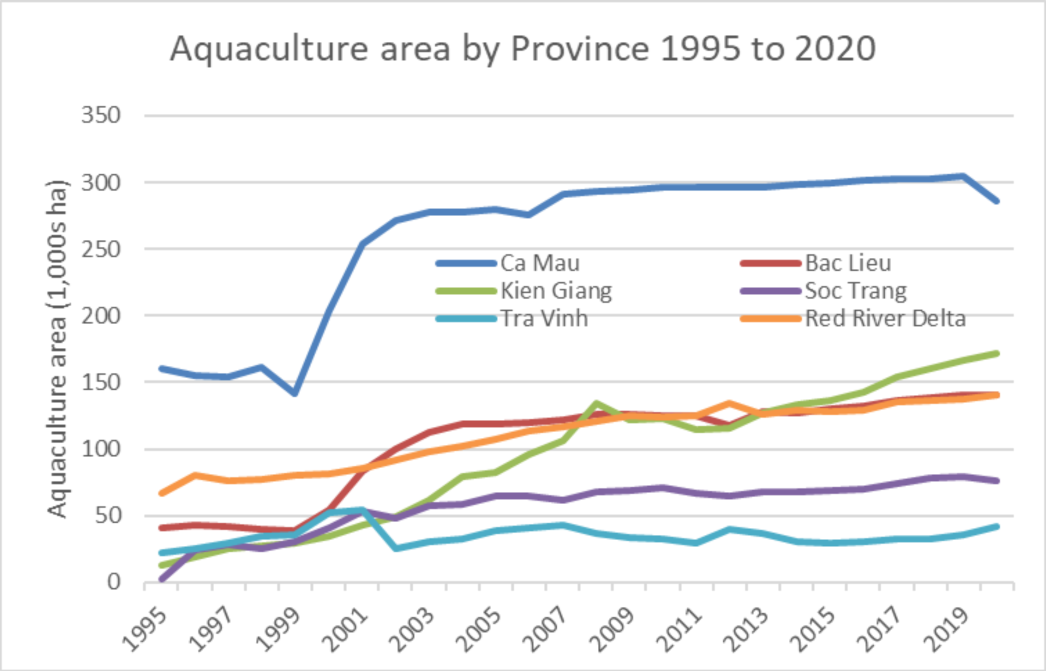

Figure 8: Aquaculture area (of ponds) by major province from 1995 to 2020. The Red River Delta is in Northern Vietnam, and the remaining provinces are in the Mekong Delta. Data from GSO.

Cà Mau Province already had approximately 160,000 ha of aquaculture in 1995, but a large increase in Cà Mau and Bạc Liêu from 1999 to approximately 2003 can be seen in Figure 8 (see Factor 3.2a for the policy reasons behind this increase). The province of Kiên Giang had a slower and later increase in aquaculture area, but all provinces (except for Trà Vinh) have had continued growth up to 2020 (the latest data available, as of July 2022). The Red River Delta in Northern Vietnam is included in Figure 8 and shows a similar gradual increase in production. It must be noted that these figures are all for pond area, so the total farm area (and therefore the habitat conversion) will be considerably larger; for example, Boyd et al. (2021a) reported an

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[54] The year 1999 is significant in the timeline of wetland conservation due to the pivotal Resolution VII.21, Enhancing the Conservation and Wise Use of Intertidal Wetlands 16, of the Contracting Parties to the Convention on Wetlands (colloquially known as the Ramsar Convention) https://www.ramsar.org.

average ratio of farm area to production pond area (i.e., the land water ratio) of 1.96 for shrimp farms in Vietnam.

The establishment of these aquaculture farms (1.13 million ha of ponds in total in 2020) required the conversion of a variety of different habitat types into ponds. For this Seafood Watch assessment, the primary challenge is to determine which types of habitats were converted to shrimp ponds and when. A detailed mapped database of mangrove farms and current land use characteristics is available for the southern region of Cà Mau[55] (and discussed further below), but for other areas of Vietnam, larger-scale assessments from academic studies are the primary source of data used here.

Factor 3.1—Habitat conversion and function

On the basis that a picture says a thousand words, this assessment has focused on recent studies using a series of remote sensing images from different years to visualize the complex land use changes in Vietnam, particularly in the Mekong Delta. Several of those images have been used here to summarize the role of aquaculture and shrimp farming.

Establishing a baseline of land use change for aquaculture in Vietnam

A time series of land use maps of the Mekong Delta from 1979 to 2015 in Liu et al. (2020) is useful to set the context of aquaculture development in Vietnam. It is important to note that these images do not differentiate different types of aquaculture, but it is noted again that shrimp is considered to be the dominant land user by far. Figure 9 shows the Mekong Delta in 1979 and 1989, and indicates that, before significant aquaculture development (i.e., in 1979), the large majority of land in the delta was already used for agriculture (yellow "planting land").

The other habitat types present before aquaculture in 1979 are the coastal mangroves (pale green in Figure 9) and other forest areas (nonmangroves: dark green). The red "wasteland" in the southern mangroves (Cà Mau Province) shows the large areas of mangroves destroyed by the United States during the Vietnam War.[56] In 1979, these areas were already being restored, and the 1989 image shows widespread recovery (albeit with a limited diversity of replanted mangrove species). In the 1980s, aquaculture began to develop in coastal areas (blue in Figure 9 in 1989), and it was estimated that 102,000 ha of mangroves were converted into shrimp farms between 1983 and 1987 (Tuan 1996, cited in Stevenson 1997).

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[55] Hệ thống quản lý, giám sát chất lượng nước nuôi trồng thủy sản, giám sát rừng tỉnh Cà Mau (aquam.com.au)

[56] The use of herbicides by the United States in the Vietnam War between 1962 and 1971 devastated approximately 105,000 ha, which made up 36% of the total mangroves in South Vietnam (Phan and Stive, 2022).

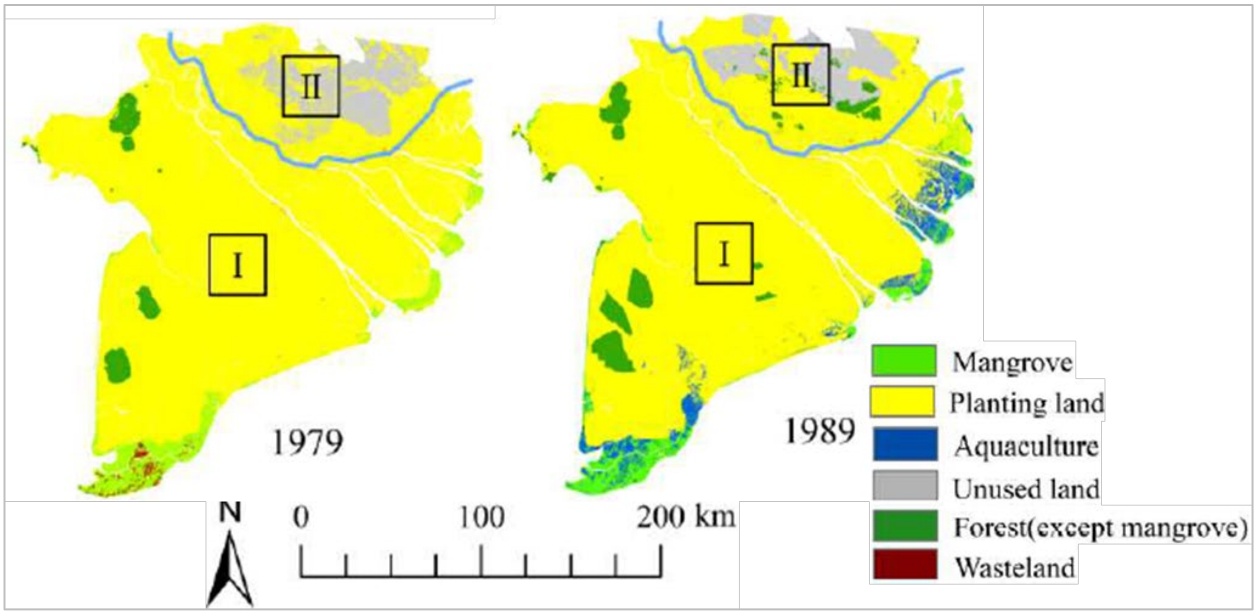

Figure 9: Land use in the Mekong Delta in 1979 and 1989. Images reproduced from Liu et al. (2020), and regions I and II refer to their study areas.

During the period 1993 to 1995, when the price of shrimp began to sharply increase, many people started occupying mangrove forest lands and digging shrimp ponds, which led to a decline in mangrove forest cover and disturbed the local ecology (Jhaveri et al., 2018). Figure 10 shows the land use in 1995 and 1998 with aquaculture rapidly expanding in coastal areas and spreading inland into agricultural areas. In 1995, the General Statistics Office (GSO) reported a total of 390,000 ha of aquaculture production in Vietnam, of which 267,000 ha (68.6%) were in the Mekong Delta.[57] By 1995, large areas of the 1979 mangroves (Figure 9) were heavily fragmented by aquaculture, but the rate of land use change in these areas appears greatly reduced from 1995 to 1998. According to the IUCN, approximately two-thirds of Vietnam's remaining mangroves had been converted to aquaculture by the year 2000 (IUCN 2013)(Van et al., 2015), and shrimp farming specifically was a major cause of mangrove loss throughout the country (Giesen et al., 2007)(Nga and Tinh 2008). Jhaveri et al. (2018) also noted that, after the active period of pond construction from 1993 to 1995, the population in mangrove areas stabilized, and over the period 1998 to 2000, the area (Cà Mau) became the focus of new mangrove plantation projects.

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[57] The next largest regional aquaculture area in 1995 was 55,000 ha (14.3%) in the Red River Delta in Northern Vietnam.

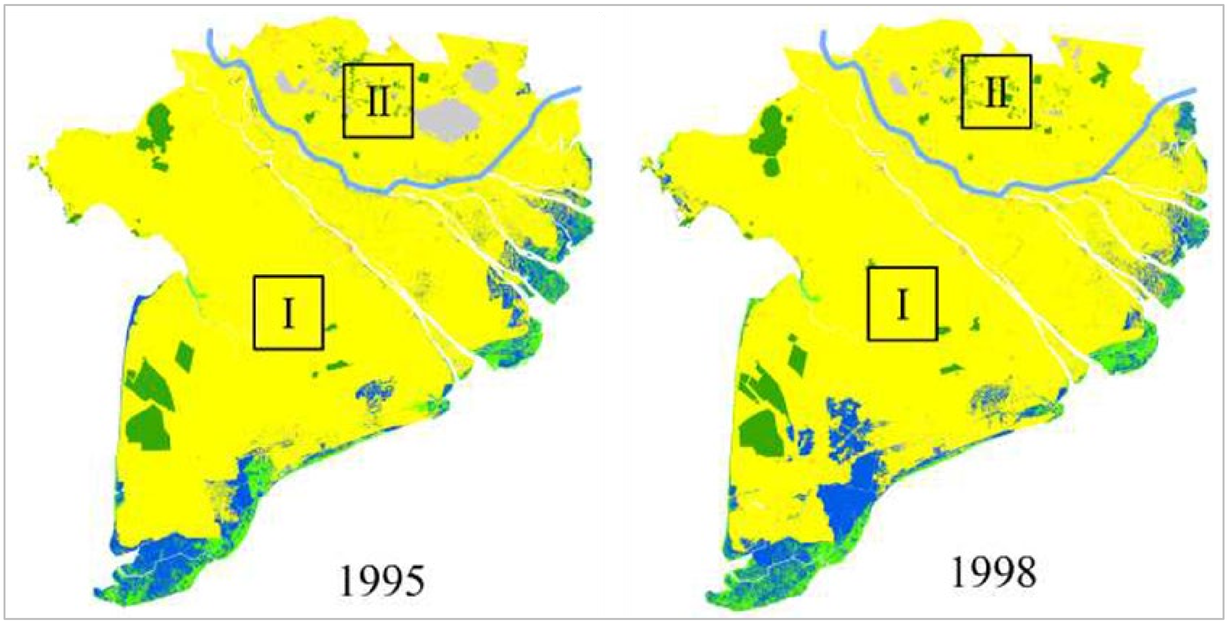

Figure 10: Land use in the Mekong Delta in 1995 and 1998. Colors are the same as in Figure 8. Images reproduced from Liu et al. (2020), and regions I and II refer to their study areas.

Figure 11 portrays the land use in 2005 and 2009 and shows that, between 1998 and 2005 (i.e., comparing Figures 10 and 11), aquaculture expanded significantly inland into former agricultural areas. In 1998, Vietnam had a total of 425,000 ha of aquaculture pond area (of which 255,500 ha, or 60.1%, was in the Mekong Delta), which increased to 1.48 million ha in 2005 (of which 1.0 million ha or 68.1% was in the Mekong Delta) (Liu et al., 2020). Between 2000 and 2001, the shrimp farming area increased by 235,000 ha, of which 232,000 were converted from rice paddies (Omoto, 2012).

In 2005, some mangrove areas showed signs of conservation efforts, particularly in the far south in Cà Mau Province; for example, the protected areas in the Cà Mau Mui National Park[58] (established in 2003) on the southwestern tip of Cà Mau can be seen, along with restoration of other coastal protection zones. The former mangrove areas (i.e., as seen in 1979) in the northeastern areas of the Mekong Delta appear to still be heavily affected by aquaculture.

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[58] https://rsis.ramsar.org/ris/2088

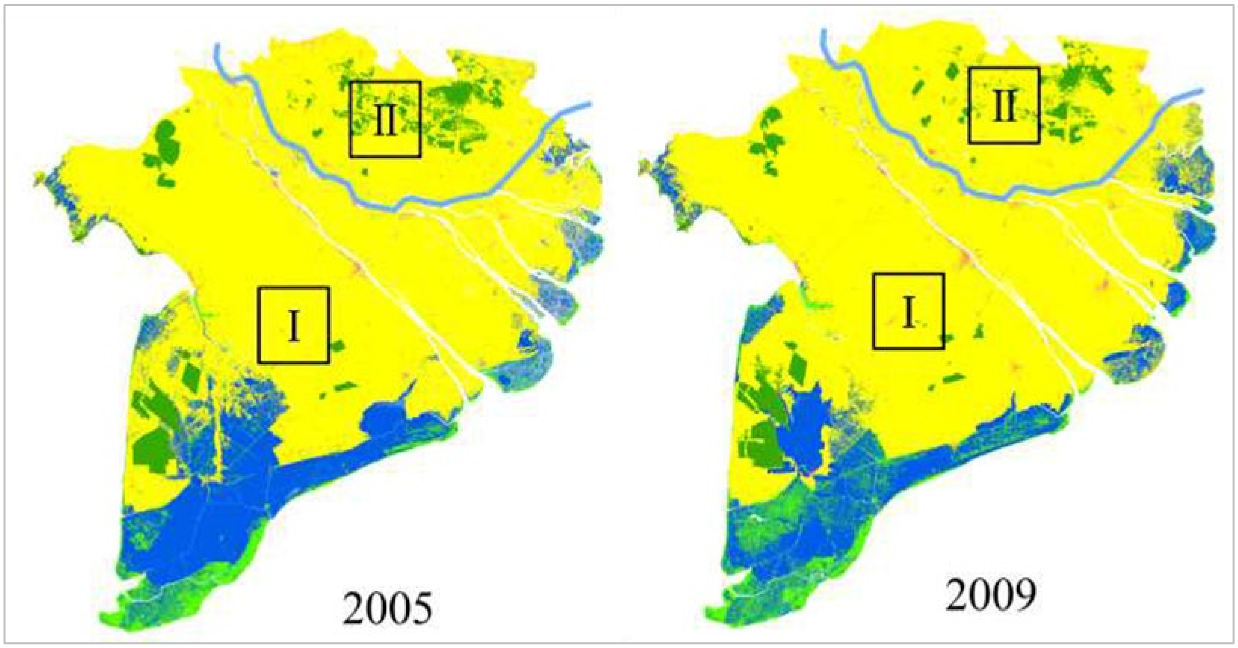

Figure 11: Land use in the Mekong Delta in 2005 and 2009. Colors are the same as in Figure 9. Images reproduced from Liu et al. (2020), and regions I and II refer to their study areas.

The most recent image from Liu et al. (2020) dates from 2015 (Figure 12) and shows a further rapid expansion of aquaculture in former agricultural areas, which was likely substantially influenced by the increasing use of rice-shrimp production systems in wet-dry seasonal cycles. Between 2005 and 2015, the total aquaculture area more than doubled from 1.48 million ha to 3.53 million ha (of which 2.47 million ha or 70.0% were in the Mekong Delta) (Liu et al., 2020). At least visually, these images show the challenge in quantifying the changes in the mangrove areas of the Mekong Delta after 1999.

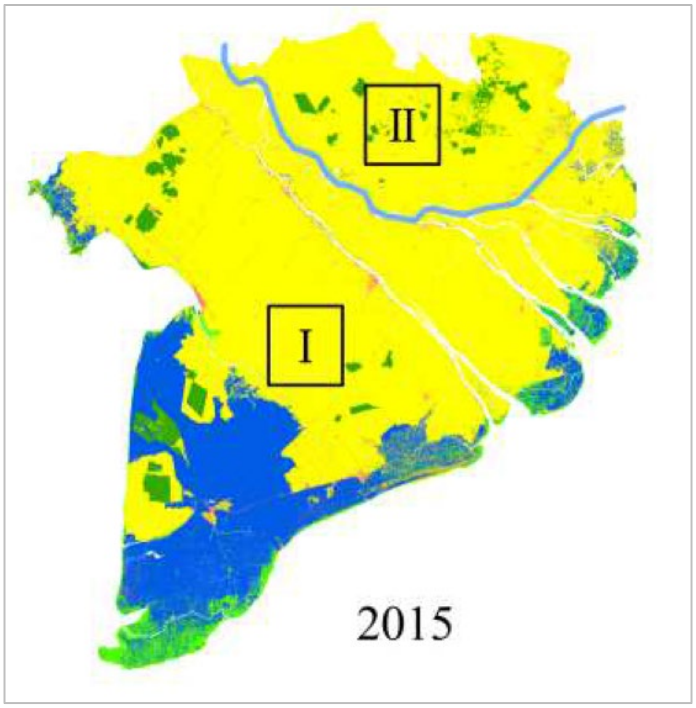

Figure 12: Land use in the Mekong Delta in 2015. Colors are the same as in Figure 9. Images reproduced from Liu et al. (2020), and regions I and II refer to their study areas.

In general support of this trajectory of land change from Liu et al. (2020), a second set of land use change maps for coastal areas of the Mekong Delta from 1975 to 2020 is available from Phan and Stive (2022). These maps (Figure 13) show a similar pattern of intense expansion of aquaculture (purple areas) into former agricultural land (yellow and brown) and mangroves (dark green).

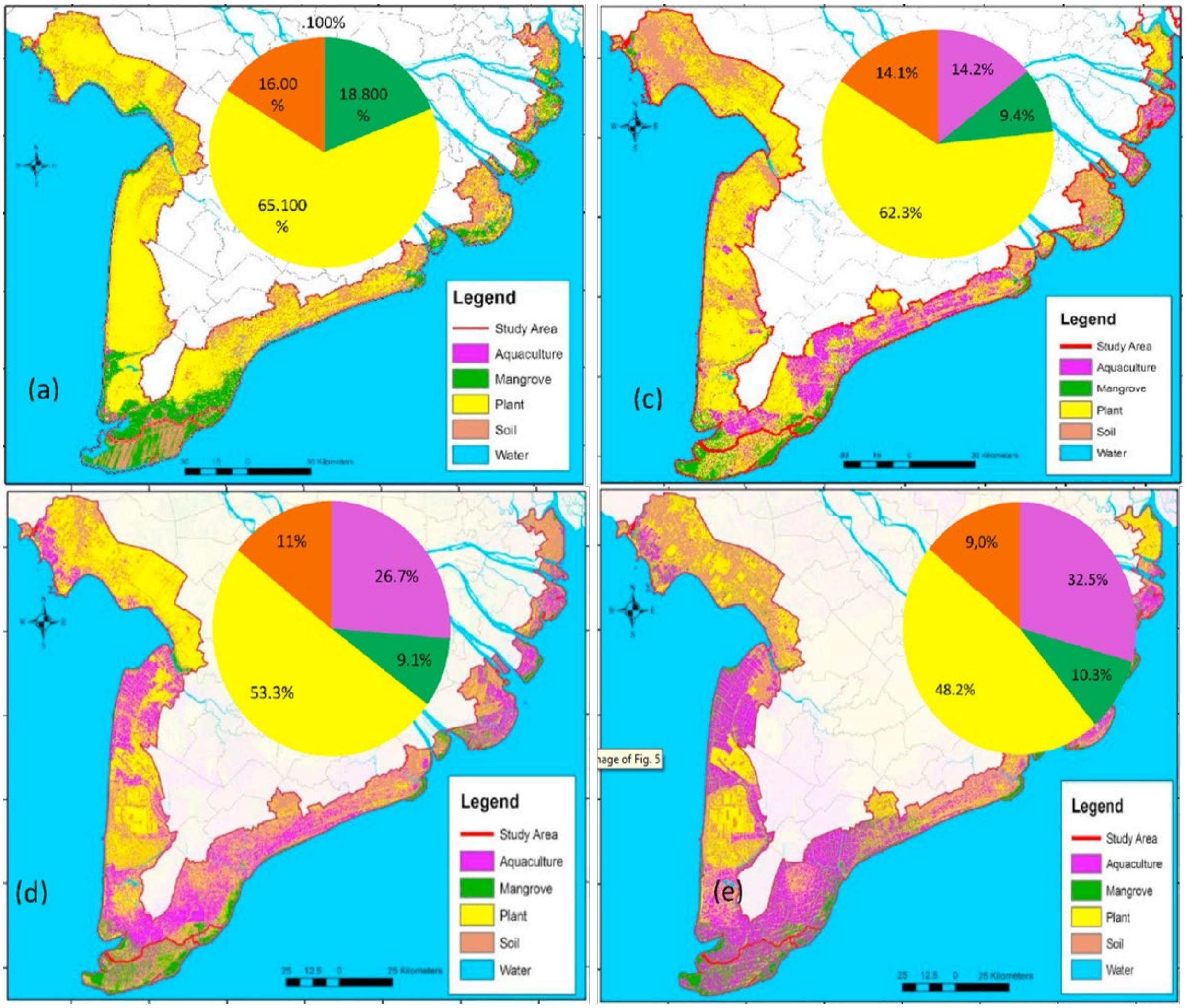

Figure 13: Land use in coastal areas of the Mekong Delta from the years (a) 1973, (c) 2000, (d) 2010 and (e) 2020. Image (b) from 1990 was not included here for space reasons. Yellow and brown colors represent agricultural land, or (for the brown areas in the far south) soil areas where mangroves were destroyed by defoliants. Images reproduced from Phan and Stive (2022).

These two sets of land use change images from the Mekong Delta show that a large amount of aquaculture was established in former agricultural areas. This would not be considered to cause any additional loss of important ecosystem services, or a loss of ecosystem functionality compared to the initial habitat change to agricultural land, so it is a low concern. Thus, the focus of this assessment is on the remaining areas of mangrove forest in the 1970s (i.e., green areas in Figures 9 and 13), and the scale and timeline of their subsequent conversion to shrimp ponds.

As noted previously, the loss of functionality of these habitats before or after 1999 is an important scoring differentiation in the Seafood Watch Aquaculture Standard. Figure 14 from Liu et al. (2020) provides further insight of the changes in the Mekong Delta before and after 1999; i.e., aquaculture's initial expansion can be seen from the 1980s to mid-1990s (during which time the mangrove area initially declined, and then increased as restoration efforts intensified). The stark increase in aquaculture area at the expense of agricultural land from 1998 to 2005 is obvious.

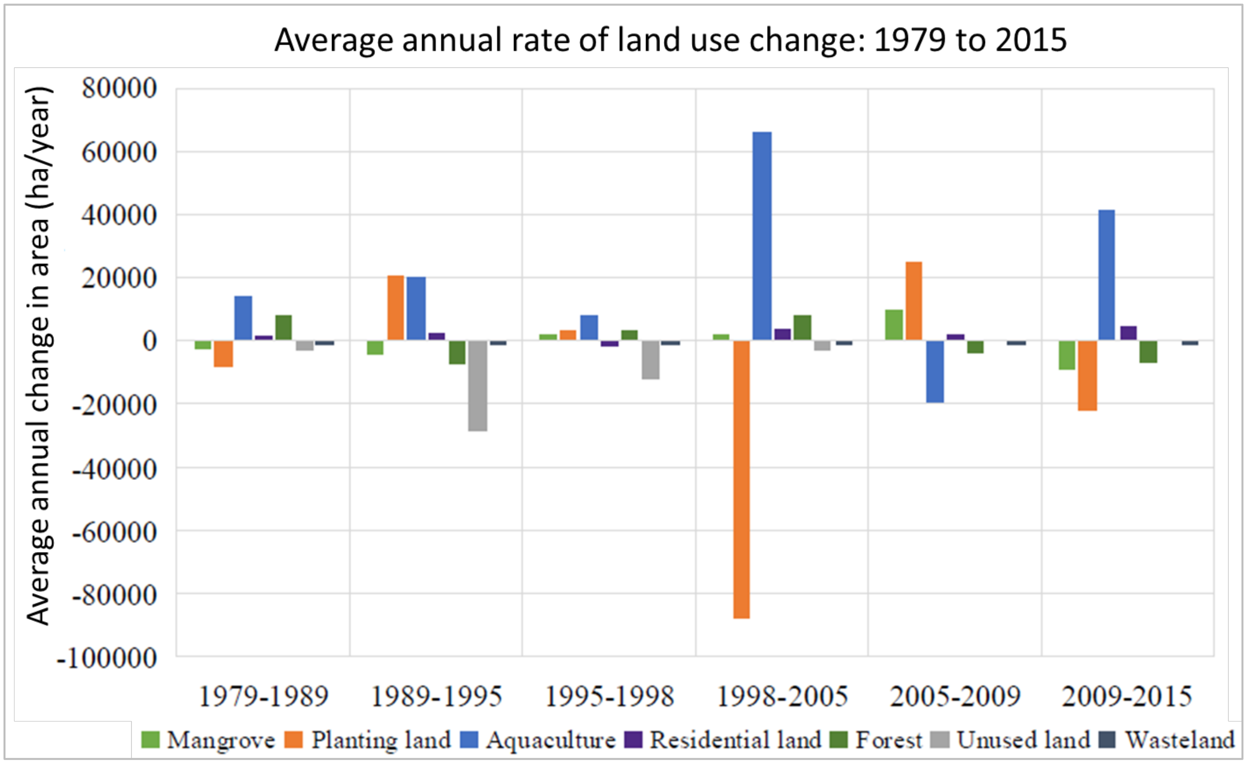

Figure 14: Average annual change in land area in the Mekong Delta from 1979 to 2015. Note that the six time periods along the x-axis are not equal. Graph reproduced from Liu et al. (2020).

The reasons for the decrease in aquaculture area from 2005 to 2009 is the conversion of extensive monoculture ponds to shrimp-mangrove ponds, in combination with increasing coverage of mangrove trees in existing shrimp-mangrove systems,[59] both of which result in an apparent decline of pond area (Liu et al., 2020). Aquaculture continued to increase in area from 2009 to 2015, apparently at the expense of agriculture (a large amount in Kiên Giang Province), but the area of mangroves also declined again during this more recent period.

<u>Scale and timeline of changes to mangrove forest cover in Vietnam</u>

Mangroves are extremely prolific ecosystems providing numerous goods and services both to the coastal environment and its residents; they are therefore robustly established as high-value habitats (Phan and Stive, 2022). Tuan (2016) noted that historically (at least before the Vietnam War and the development of aquaculture) Vietnam had 408,500 ha of mangroves in 1943, and 400,000 ha in the 1960s. As described above, Tuan (2016) reports a decline to 73,000 ha in 1990 from the war, agriculture, and aquaculture.

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[59] As discussed further below, although this increase in apparent area of mangrove trees is noted here, this does not necessarily mean that these areas imply ecologically functional mangrove ecosystems.

Regarding the current area, the GSO reports annual statistics from 2008 to 2020 on forest cover area in each province of Vietnam (both natural and planted) and the proportion of each province that is forest, and though this public reporting is welcomed, it is not possible to differentiate mangrove forests from other types of forest (nor to determine changes before and after 1999). In general, the GSO data show that the proportion of forest cover in each province is now quite low (the highest in the Mekong Delta is 18.4% in Cà Mau in 2020, and the lowest is 1.0% in Tien Giang). The average for the Mekong Delta was 4.7% in 2020. Therefore, other sources of information on mangrove forests are used here.

Veettil et al. (2018) provided a map of four mangrove forests zones in Vietnam (Figure 15): Zone 1, Northeast, with an area of 39,400 ha of mangroves; Zone 2, Northern Delta, with 7,000 ha; Zone 3, Central Coast, with 14,300 ha; and Zone 4, Mekong Delta, which has the largest and richest mangrove ecosystem in Vietnam, covering 191,800 ha of mangrove forest. The date of this map (Figure 15) is uncertain, but the total area of 252,500 ha appears to be derived from the Forest Inventory and Planning Institute of Vietnam in Hong and San (1993) and Hong (1984, 1991) and is therefore considered to be relevant to the period before aquaculture expansion.

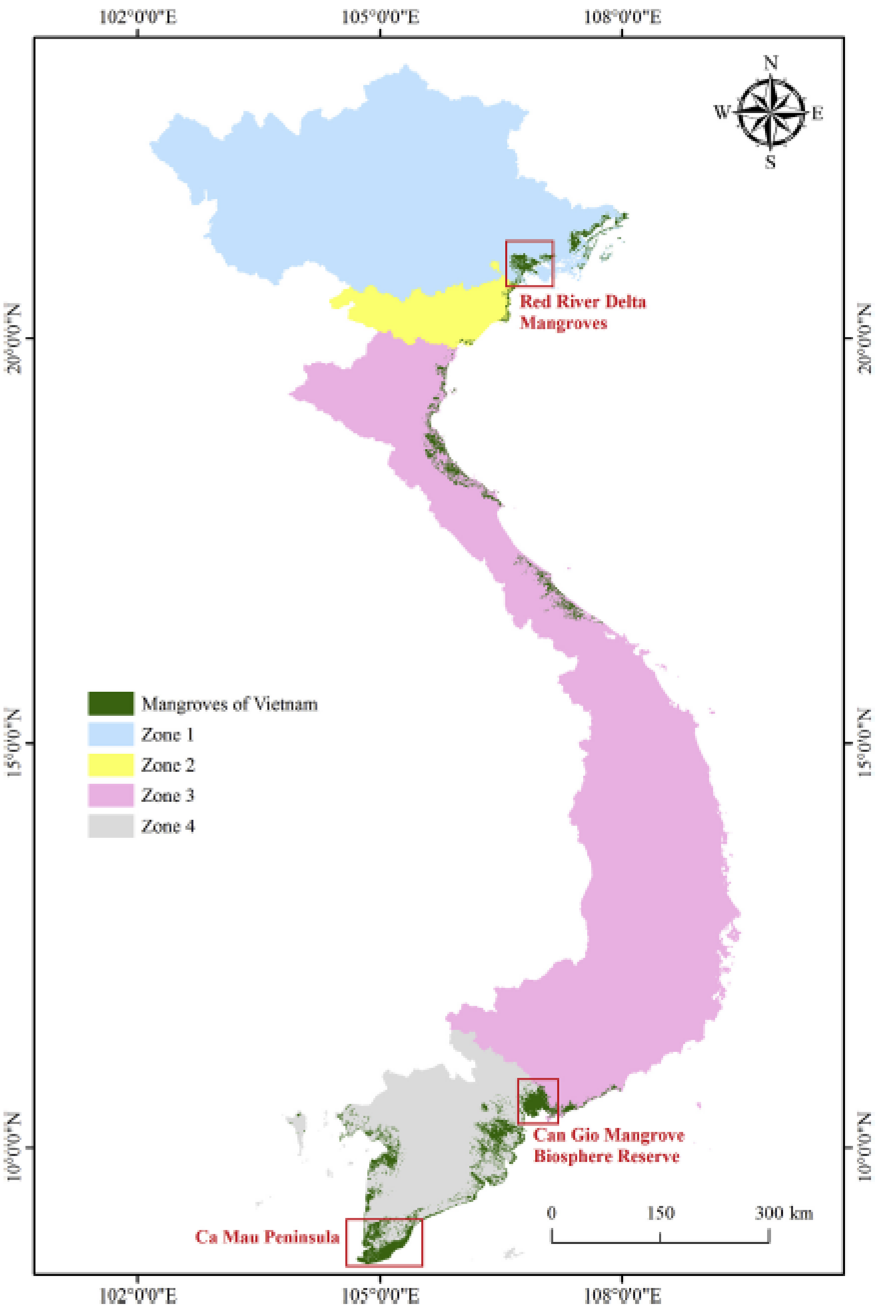

Figure 15: Map of mangrove areas in Vietnam in four zones from an uncertain year, but considered before the main development of aquaculture. Map reproduced from Veettil et al. (2018).

In the Mekong Delta, mangrove forests are primarily in the south (Cà Mau Province) and the northeastern Bến Tre and Trà Vinh Provinces, but mangroves are also present in the coastal zones of Kiên Giang, Bạc Liêu, Sóc Trăng, Tiền Giang, and Long An Provinces (Luu et al., 2021). The mangrove forest in the Mekong Delta presented two different change characteristics before and after 1995; that is, the area of mangrove was decreasing before reaching a minimum in 1995 but increased after 1995 (Liu et al., 2020). Van et al. (2015) quantified these changes in Cà Mau Province, reporting that the mangrove area was 71,435 ha in 1953, decreased to 33,083 ha in 1992, and increased again to 46,712 ha in 2011. Thuy et al. (2021) (in agreement with Van et al., 2015) illustrated the change for the Mekong Delta as a whole (Figure 16) with a rapid decline from 2.5 million ha in 1943, reaching a minimum of approximately 70,000 ha in 1995/97. Approximately half the 1943 area was gone by 1983, still before any significant expansion of aquaculture (i.e., Figure 9 shows no significant aquaculture in 1979).

Regarding the 1999 timeline, the International Union for the Conservation of Nature (IUCN) considered that the expansion of aquaculture in the 1980s and 1990s resulted in the loss of about two-thirds of Vietnam's remaining mangroves by 2000 (IUCN, 2012), and despite the increase between 1995 and 2010, Thuy et al. (2021) showed a further substantial decline in mangrove area from 2010 to a post-1943 minimum of approximately 65,000 ha in 2016.

This decline in mangrove area after 2010 is consistent with Figures 11 and 12 from Liu et al., (2020) that show a decline from 2009. Liu et al. (2020, also referring to Thu and Populus, 2007) believed that aquaculture was the most important factor affecting mangroves during that period, and despite government action to combat the decline of mangroves, the imbalance and conflict between protecting mangroves and developing aquaculture facilitated the decline of mangroves.

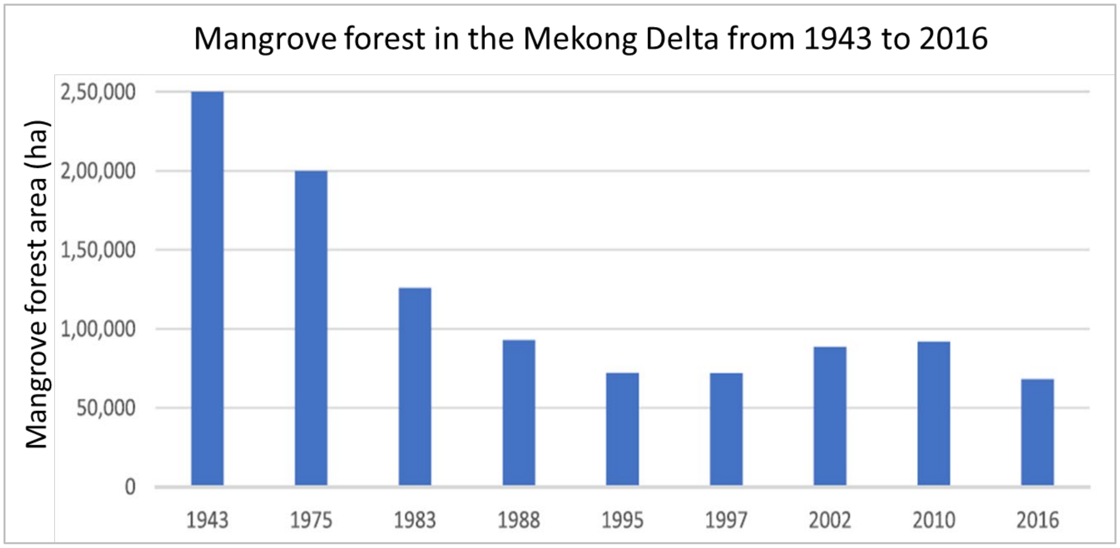

Figure 16: Mangrove forest area in the Mekong Delta from 1943 to 2016. Graph reproduced from Thuy et al. (2021).

When discussing changes to the area of mangrove forests, it is also important to note that the term "mangrove" can include naturally dense or sparse tree cover (e.g., Hong et al., 2019) or can include varying "qualities" of mangrove; for example, in restored or replanted areas where the ecological diversity of the forest is lower than in natural mangrove area (Van et al., 2015)(Schuur et al., 2021). These differentiations are often not made in academic studies (for example, in Figures 14 and 16 above). Many other factors affect mangrove forest area, such as urban development, construction of salt pans, harvesting for building materials and firewood, coastal erosion, upstream dams in the delta's rivers, and local barriers and irrigation measures

(Phan and Stive, 2022). Determining the role of aquaculture, and specifically shrimp farming, in the changing total area and the ecosystem functionality or remaining areas is challenging (Boyd et al., 2021b).

Focusing on the largest mangrove area in southern Cà Mau Province, Van et al. (2015) provides another useful example with which to establish the primary timeline of land use change to aquaculture. Figure 17 shows this region from 1953 to 2011, and the same pre-1980s lack of aquaculture seen above in Liu et al. (2020) and Phan and Stive (2020) is clear (as is the damage during the Vietnam war and the recovery). Again, this image shows a rapid and dramatic change in land use between 1979 and 1992. Whereas Van et al. (2015) attributed this to conversion of mangrove forests to mangrove-shrimp aquaculture (pale green area in Figure 17) and, to a lesser extent, to intensive shrimp monoculture (yellow areas), it is important to note that Liu et al. (2020) specified that the mode of aquaculture changed from the original single aquaculture type (extensive shrimp monoculture) to the mixed mangrove aquaculture type primarily after 1995 (also see Criterion 3.2a for the policy changes in 1994 that stimulated this change). By 2004, there was no longer intensive production in this region, and restoration of significant areas of mangrove forests can be seen in Figure 17 along most of the coastline of this area.

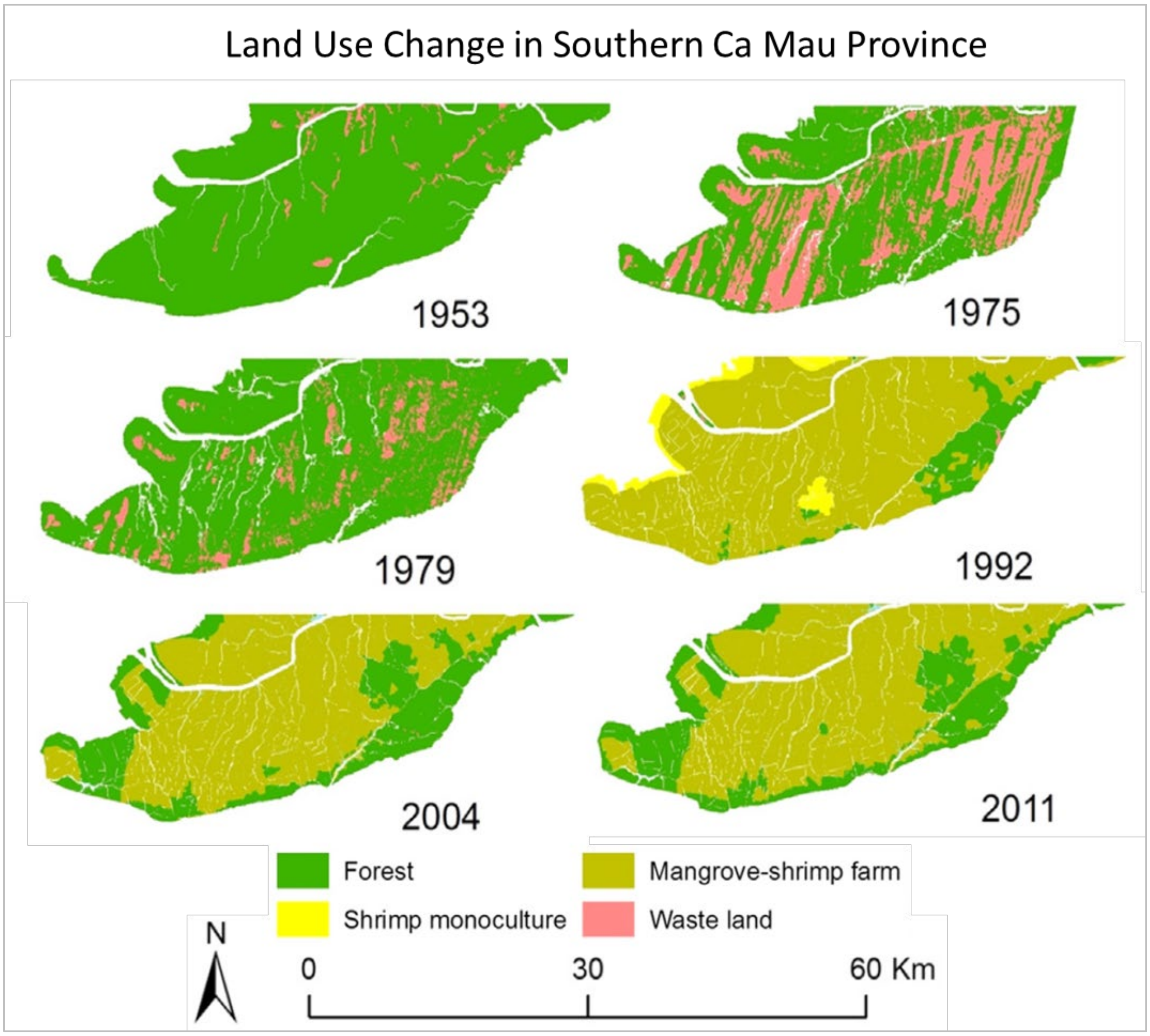

Figure 17: Land use images of the southern Cà Mau Province of Vietnam from 1953 to 2011. Images reproduced from Van et al. (2015).

The AQUAM Forest Monitoring Map of Southern Cà Mau

As is apparent in the previous figures, the main area of mangroves in the Mekong Delta is in southern Cà Mau Province. A joint Vietnamese-Australian project, AQUAM Cà Mau,[60] has established a mangrove forest monitoring project in Cà Mau Province (in addition to the water quality monitoring described in Criterion 2—Effluent). Based on satellite images, it provides detailed farm-level indications of mangrove cover and condition, in addition to defining the boundaries of different forest types (production, protective, and special use) (see Factor 3.2a for more information on these forest types). Figure 18 shows a high-level overview of southern Cà Mau and distinguishes the different forest types by color. Although some aquaculture is still permitted in special use forests (green in Figures 18 and 20, and purple in Figure 21), Figures 19 to 21 show that shrimp farms are present throughout the protective and production forests.

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[60] Forest resource management and monitoring system in Ca Mau province (aquam.com.au)

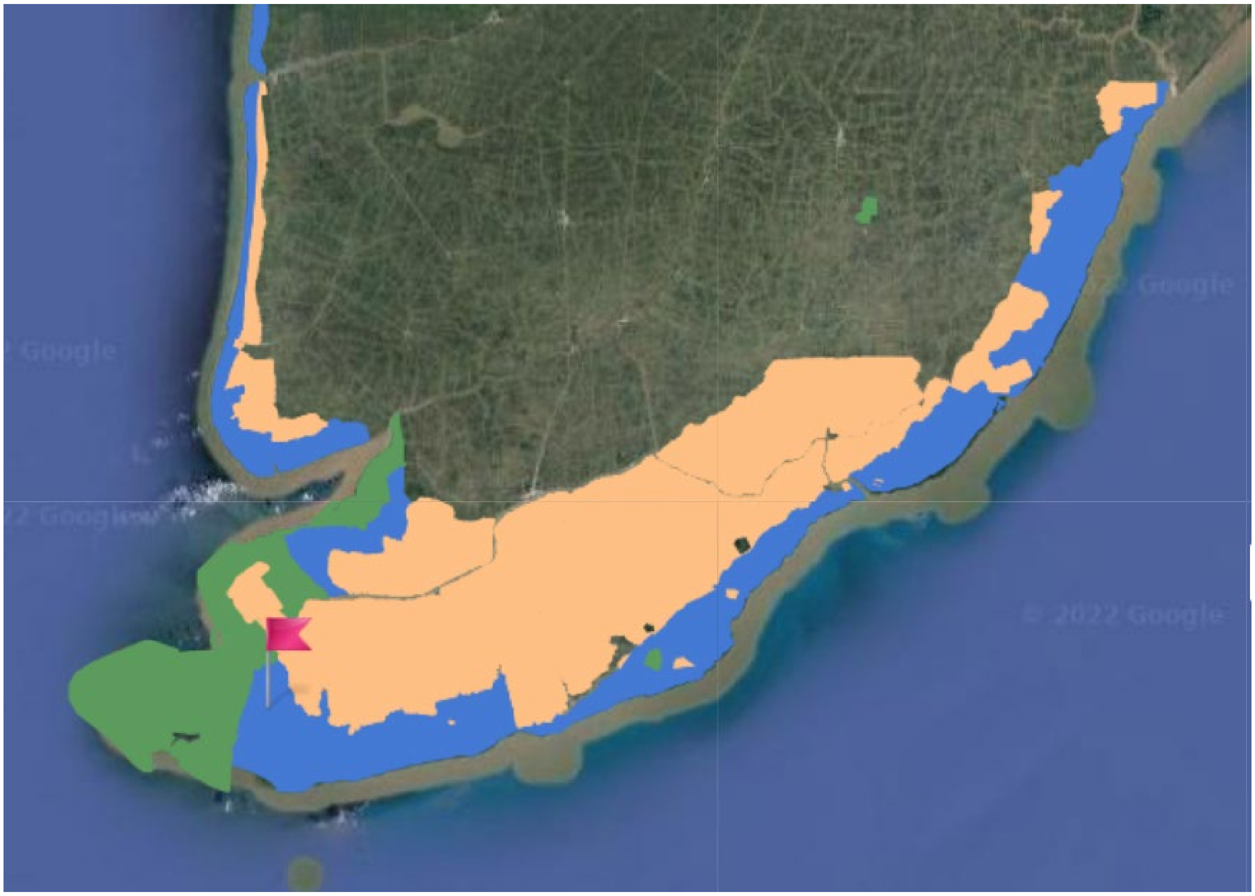


Figure 18: Screenshot of the AQUAM map layer showing the different types of forest regarding aquaculture production. Green is special use forest, blue is protection forest, and orange is production forest. The pink flag identifies the area shown in greater detail in Figures 19 to 21. Image reproduced from AQUAM Cau Mau.

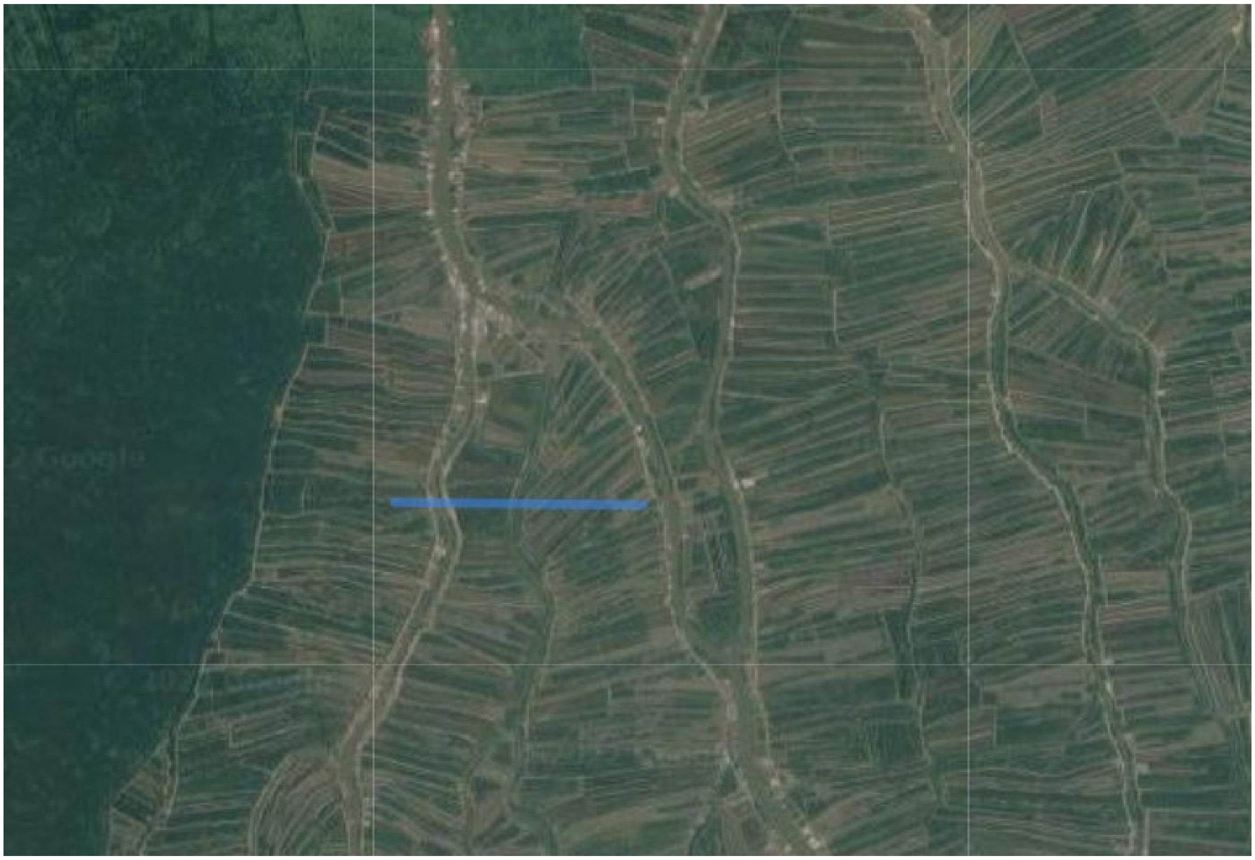
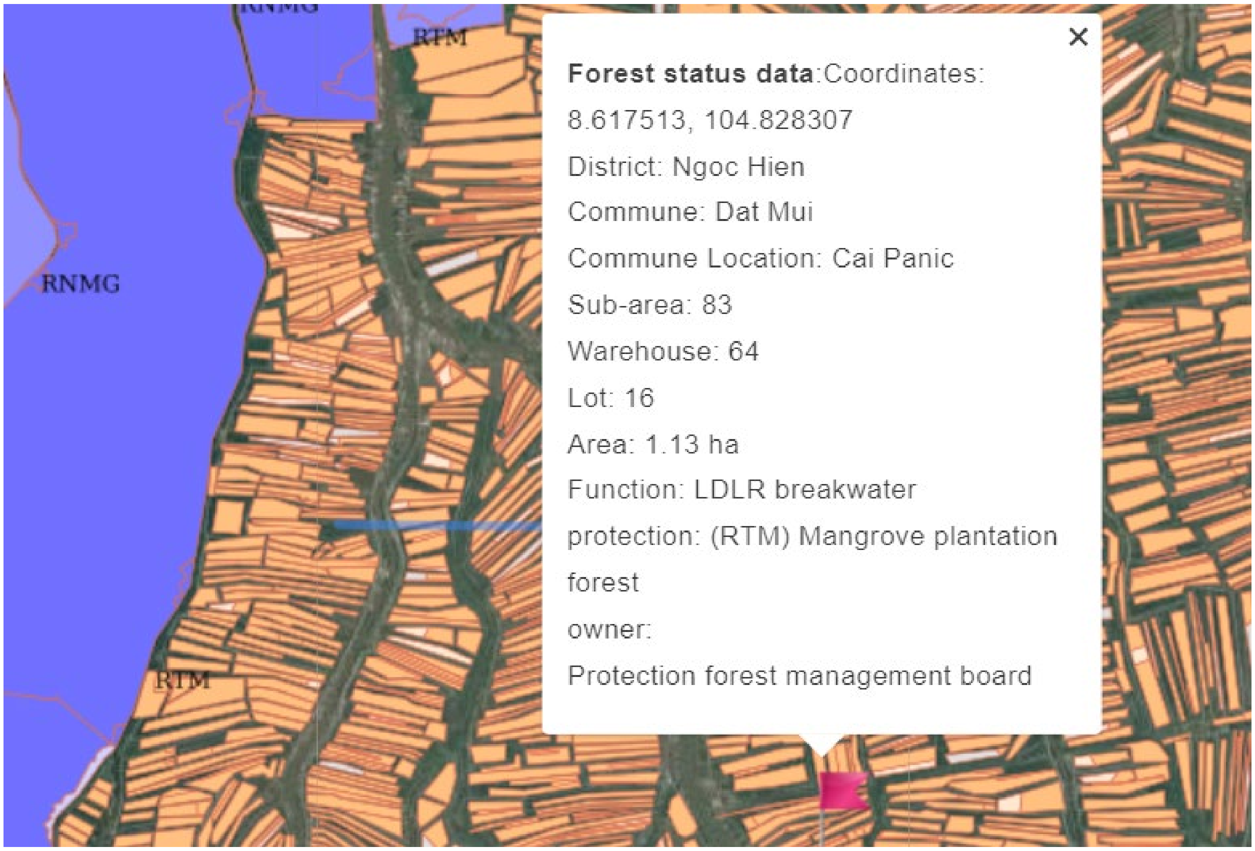


Figure 19: An example of the base layer satellite image of an area of southern Cà Mau. Hundreds of family shrimp farms can be seen in this image. The same approximate location is repeated in Figures 20 and 21. The blue bar represents 1 km (0.62 mi). Image reproduced from AQUAM Cau Mau.

Figure 20: The same area as Figure 19, showing regions classified by three different forest types. Green is special use forest, blue is protection forest, and orange is production forest. The blue bar represents 1 km (0.62 mi). Image reproduced from AQUAM Cau Mau.



Forest status data:Coordinates:
8.617513, 104.828307
District: Ngoc Hien
Commune: Dat Mui
Commune Location: Cai Panic
Sub-area: 83
Warehouse: 64
Lot: 16
Area: 1.13 ha
Function: LDLR breakwater
protection: (RTM) Mangrove plantation
forest
owner:
Protection forest management board

Figure 21: The same area as in Figures 19 and 20 showing individual sections of forest, defined by color. Purple is special use forest (with no shrimp farms in this example), orange is planted mangrove tree (RTM), while the white areas are unplanted (DTRM). The box shows the pop-ups available for every section of forest. The blue bar represents 1 km (0.62 mi). Image reproduced from AQUAM Cau Mau.

Figure 21 shows that specific information is available from the AQUAM map for every block of forest in a pop-up format. This shows the function of the forest (e.g., protection) and the specific status of that block; in this case, RTM, which means that the area is planted with mangroves. Areas that are not planted or have been recently harvested are also shown in the map layer in Figure 21 by the white color.

By comparing the 2022 image in Figure 18 with the 2011 image in Figure 17, it appears that large areas of forest (dark green areas in the lower right of the 2011 image) have apparently been allocated as production forest in Figure 18 and can be seen in satellite images (and in AQUAM) to be covered in mangrove shrimp farms. But, this example illustrates the challenge with interpreting these land use changes, because historical satellite images (from Google Earth Pro) show that the area was already covered in mangrove shrimp farms apparently before the year 2000.

<u>Additional examples of aquaculture development and land use change</u>

A further example from a different province can be seen in Bạc Liêu and Sóc Trăng Provinces in the Mekong Delta. Hong et al., (2019) showed that in 1988, aquaculture had been located within, but primarily inland of, areas of sparse mangrove forests on the open coast of Bạc Liêu

Province (dark green areas in Figure 22 and lower expanded box). Substantial areas of dense and sparse mangrove forests were also present in Sóc Trăng Province (red and yellow areas in highlighted box Figure 22 in Vĩnh Hải commune), but both provinces were dominated by agricultural land (pale green and grey).

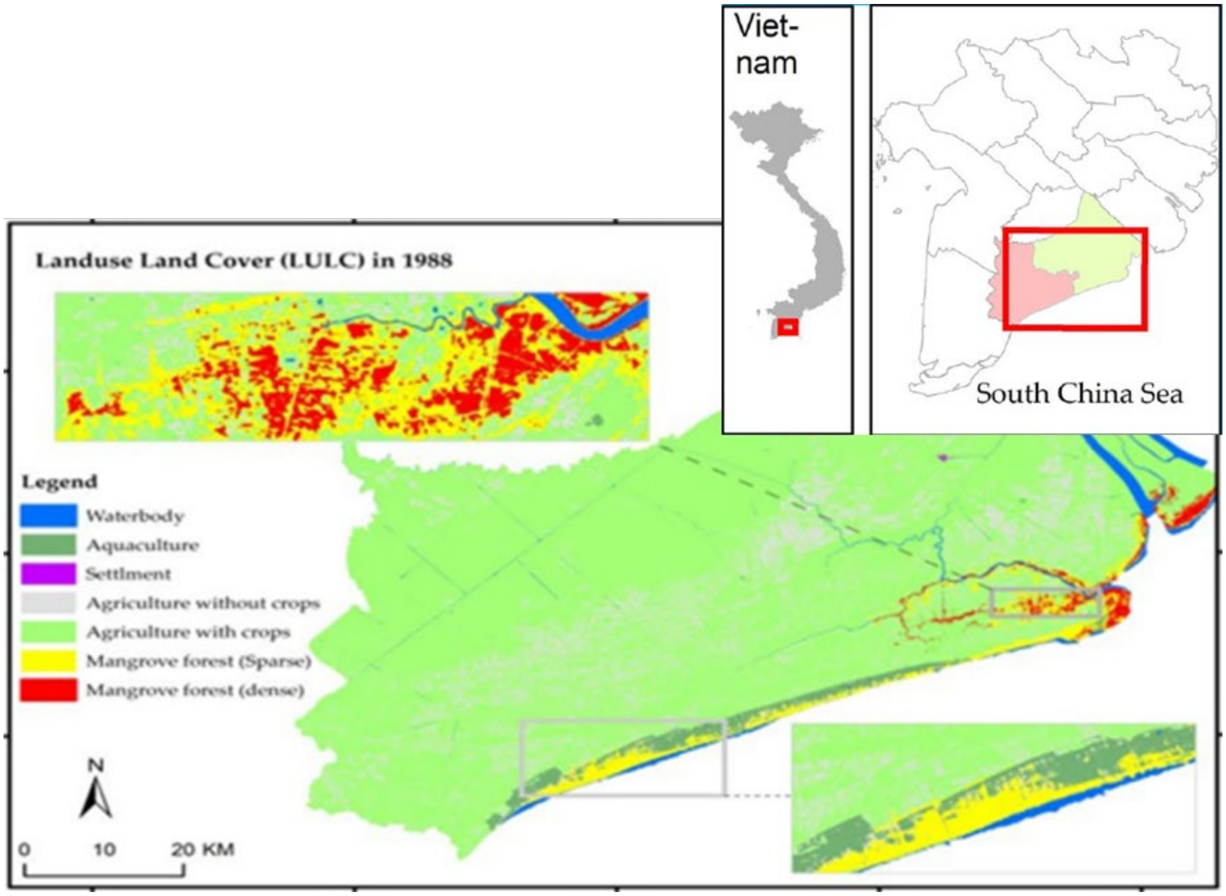


Figure 22: Land use map from 1988 for Bạc Liêu Province (pink area in inset map) and Sóc Trăng Province (yellow area in inset map). At this time, aquaculture (dark green areas) was located inland of sparse mangroves in Bạc Liêu Province. Map reproduced and adapted from Hong et al. (2019).

A decade later in 1998, Figure 23 shows that aquaculture (dark green) had expanded inland into agricultural areas but had also encroached upon the area of dense mangroves in Sóc Trăng (red areas in expanded box in Vĩnh Hải commune). Some increase in dense mangroves is seen on the exposed coast in Bạc Liêu (lower expanded box in Figure 23). After 1998, Figure 24 from 2008 shows a rapid expansion of aquaculture inland into former agricultural areas, but the area of dense mangrove forests in Vĩnh Hải commune of Sóc Trăng is now gone, replaced by aquaculture ponds. The sparse mangroves in Bạc Liêu are maintained, but the restored dense areas are no longer present. Figure 25 from 2018 shows increasing density of aquaculture ponds in Sóc Trăng and particularly Bạc Liêu; all the dense and sparse mangroves in the expanded box are gone, replace by aquaculture and to a lesser extent agriculture. The other red areas of dense mangroves in Sóc Trăng Province have reduced substantially and/or been replaced by sparse mangroves. These images clearly demonstrate that, despite the recognized ecological value of mangrove forests, the remaining areas continued to be affected by aquaculture development.

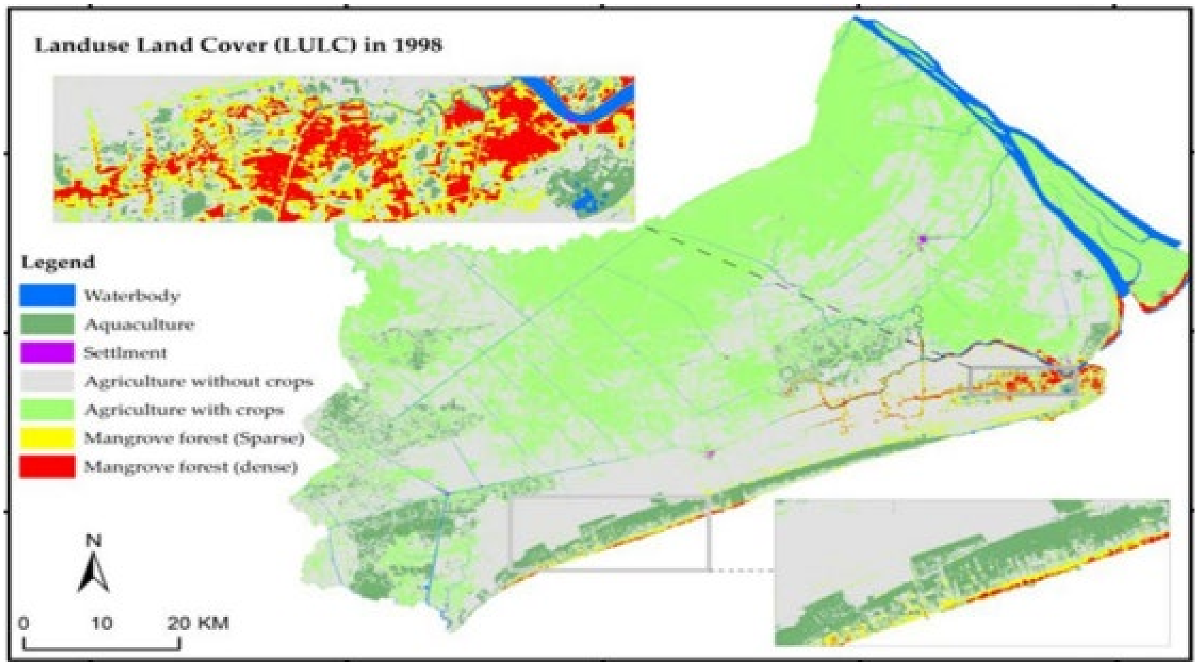


Figure 23: Land use map from 1998 for Bạc Liêu Province and Sóc Trăng Province. Map reproduced from Hong et al. (2019).

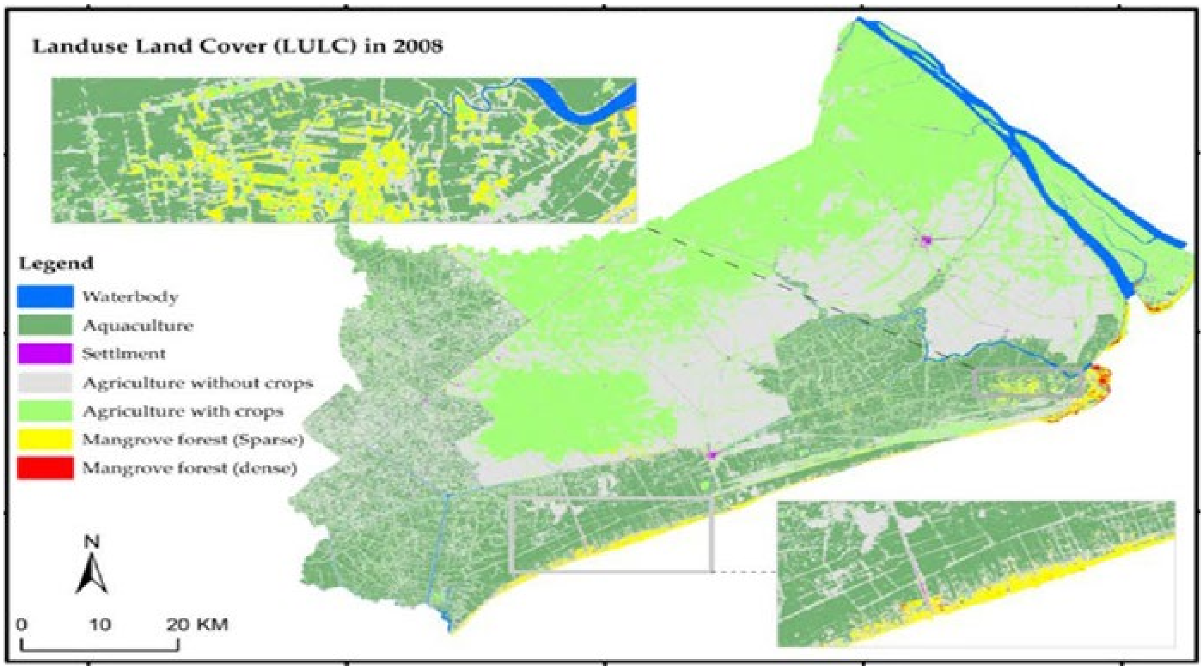


Figure 24: Land use map from 2008 for Bạc Liêu Province and Sóc Trăng Province. Map reproduced from Hong et al. (2019).

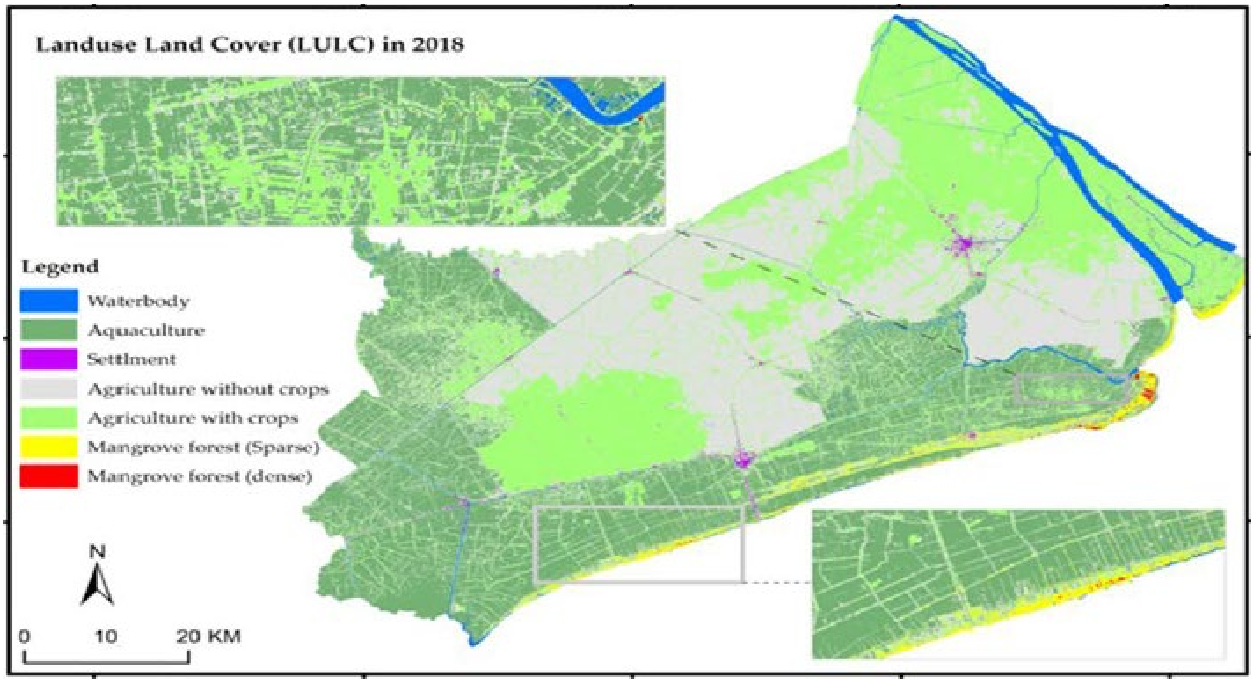


Figure 25: Land use map from 2018 for Bạc Liêu Province and Sóc Trăng Province. Map reproduced from Hong et al. (2019).

It is also interesting to note that the area of dense mangroves in Trà Vinh Province (red area in far right of Figures 22) was reduced by 1998, and largely disappeared by 2008 (Figure 24). Hong et al. (2019) largely attributed this change to an initial conversion to agricultural land (i.e., the red color changed mostly to pale green). Google Earth images from 2019 confirm minimal mangrove areas in this area, which is now extensively covered by shrimp farms (mostly extensive and shrimp-mangrove systems). It should be noted that Phan and Stive (2022) also initially attributed this loss of mangroves to agriculture (Figure 14 above), but Figures 10 to 13 from Liu et al. (2020) apparently allocate the loss to aquaculture. This difficulty in determining the correct sequence of land use changes in this area highlights the need for caution in assuming that shrimp farms currently located in former mangrove areas were the original cause of the mangrove loss and illustrates the complexity of this Seafood Watch assessment of habitat conversion.

Numerically, during the 1988 to 2018 period visualized in Figures 22 to 25, the total aquaculture area in Bạc Liêu and Sóc Trăng increased from 9,673 ha to 160,393 ha, while dense mangroves decreased from 5,495 ha to 515 ha and sparse mangroves decreased from 14,105 ha to 6,289 ha (Hong et al., 2019). The rate of mangrove loss was highest between 1988 and 1998 for sparse mangroves (yellow in Figures 13 to 25) but the rate of loss was later and more rapid for dense mangrove areas from 1998 and 2008 (red in Figures 22 to 25)—see Figure 26.

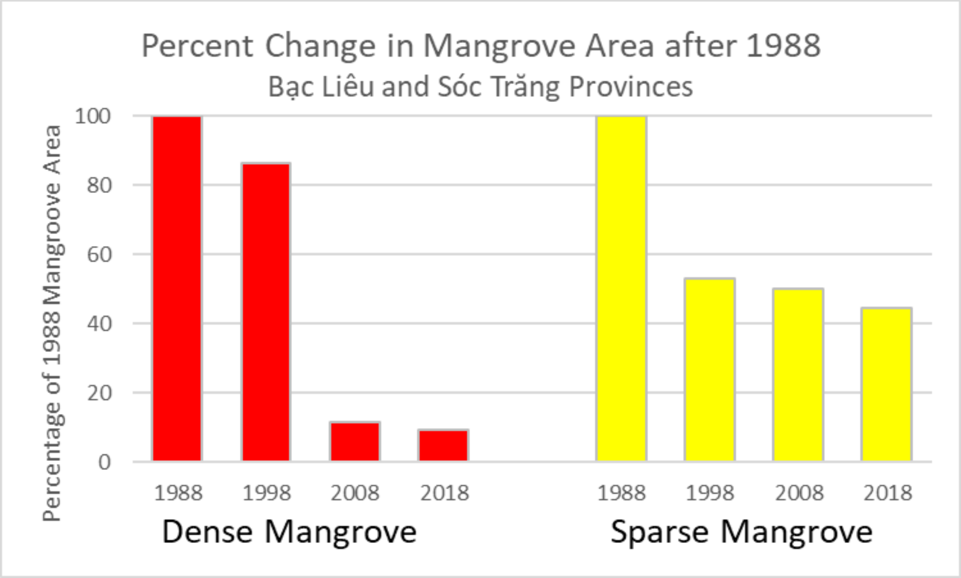


Figure 26: Rate of mangrove loss for dense and sparse forests from 1988 to 2018, expressed as a percentage of the 1988 area. Red and yellow colors correspond to the same dense and sparse mangrove areas in Figures 18 to 21. Data from Hong et al. (2019).

The total loss of mangrove area in these two provinces during this period (12,796 ha from 1988 to 2018) is equivalent to only 8.5% of the increase in aquaculture area (150,720 ha). Similarly, Hamilton and Casey (2016) noted that the total mangrove area in Vietnam of 128,791 ha in 2000 decreased 2.2% to 125,930 in 2014, compared to the shrimp farming area, which increased 29.3% (from 478,800 ha to 619,000 ha) over the same period. As noted previously, the apparently minor loss of 2.2% here is a net loss and includes increases in mangroves in restored areas. Thus, the specific loss of the remaining natural mangrove areas due to aquaculture could be higher than this figure.

As a final post-1999 example from Bến Tre Province in the Mekong Delta, Veettil et al. (2019) showed that mangrove cover (as a percentage of the total province area) declined from 8% in 2000 to 4% in 2015 (a 52.5% decline), noting the expansion of aquaculture, rice production, other crops (coconut, sugarcane, and orchards), and increased residential areas. Although Veettil et al. (2019) noted that the large increase in aquaculture area was mainly due to conversion of former agricultural land, they stated that mangrove-to-shrimp-pond conversion is still going on extensively in Bình Đại district at an “unprecedented scale.”

In summary, the expansion of aquaculture farms has been the major land use change in Vietnam in recent decades (Hong et al., 2019) and has had a severe impact on mangrove forests, particularly in the coastal regions of the Mekong Delta (Phan and Stive, 202). The timeframe is complex; Nguyen et al. (2022), Truong and Do (2018), and Minh et al. (2001) noted that the extensive expansion of aquaculture in the 1980s and 1990s resulted in the loss of about two-thirds of Vietnam’s mangroves by 2000, and Schuur et al. (2021) noted that the intrusion of aquaculture into mangrove habitats has since slowed greatly. Nevertheless, Phan and Stive (2022) note that many mangrove areas have been cleared for shrimp farming since the end of the 1990s (i.e., after 1999). The situation is considered similar in Northern Vietnam, where almost all mangroves have shrimp farms, and the rapid development of aquaculture is associated with a significantly reduced and degraded mangrove, such that aquaculture has been identified as the principal threat to mangrove systems in Northern Vietnam (Orchard et al., 2016, 2015), with a severe loss reported from 2000 to 2006 (Long et al., 2021). Therefore, although it is clear that the majority of aquaculture's expansion occurred in former agricultural land, this analysis has shown that, despite the recognized ecological value of mangrove forests by the turn of the century (e.g., as recognized by the Ramsar agreement), the remaining areas continued to be affected by aquaculture development after 1999.

Defining the role of shrimp farming in the changing mangrove forest area in Vietnam

The discussion above has established the general scale and timeline of land use change, particularly in the Mekong Delta. The analysis shows that the majority of the aquaculture expansion occurred in former agricultural areas, but also clearly shows that, although the loss of mangroves is small compared to the total increase of aquaculture area (even if the total loss of mangroves is attributed to aquaculture), aquaculture continued to expand into and replace mangrove forests after 1999. The challenge remains to determine what role shrimp aquaculture played within the overall aquaculture sector, and (particularly for the production systems assessed here) into which types of former habitat did each type of shrimp system develop and when.

According to GSO, Vietnam had a total of 736,400 ha of shrimp aquaculture in 2020, and a total aquaculture area of 1.13 million ha in the same year. Shrimp farming is therefore approximately 65% of the total aquaculture area at the country level. With the focus of shrimp farming in southern Vietnam, shrimp farming's percentages of the total aquaculture area will be higher in the Mekong Delta provinces; for example, Thach et al. (2021) provided shrimp farming areas for *P. monodon* and *L. vannamei* in 2018 that can be compared to GSO data for total aquaculture area in the same year (Table 5).

Table 5: Comparison of the production area for shrimp and the total aquaculture area in dominant provinces of the Mekong Delta in Southern Vietnam. Data for the areas of shrimp aquaculture are from Thach et al. (2021) and the data for the total aquaculture area are from GSO.

Province	Total Aquaculture (1,000 ha)	Shrimp Aquaculture			Percent Shrimp (%)
		P. monodon (1,000 ha)	*L. vannamei* (1,000 ha)	Total Shrimp (1,000 ha)	
Cà Mau	302.4	261.9	8.0	269.9	**89.3**
Kiên Giang	160.7	121.8	2.4	124.2	**77.3**
Bạc Liêu	138.9	140.3	8.5	148.8	**100.0***
Sóc Trăng	77.9	23.5	32.7	56.2	**72.1**
Bến Tre	45.4	25.8	10.4	36.2	**79.5**
Trà Vinh	32.5	25.0	7.6	32.6	**100.0***

* Because of variations in the figures from Thach et al. (2021) and the total figures from GSO, these values calculate to be greater than 100%, but are assumed to be approximately 100% here.

This shows that shrimp ponds represent between 72% and approximately 100% of the total aquaculture area in the dominant provinces of the Mekong Delta. Therefore, shrimp aquaculture can be assumed to be the dominant actor in the "aquaculture" land use changes seen in the Mekong Delta (e.g., in Figures 9 to 12), particularly in coastal areas with access to brackish water needed for shrimp aquaculture. Previous discussions have noted the complex timeline of land use change regarding aquaculture in general, and this largely applies to shrimp farms. Whereas Boyd et al. (2021b) considered that siting of shrimp farms in mangroves was done mainly in the 1980–2000 era, Phan and Stive (2022) note that, whereas agriculture, salt pan development, and the wartime use of chemicals were previously the most important threats to mangroves, for the last decades the greatest threat has been shrimp aquaculture (noting a post-2000 conversion of mangroves to shrimp farms of 2,030 ha/year between 2000 and 2010, and 1,490 ha/year between 2010 and 2020). Boyd et al. (2021b) also acknowledged that, during the timeframe of 2000 to 2014, up to 100% of the loss of mangroves could be attributed to shrimp farms, but the total area of mangrove loss represented a small increase (approximately 1%) of the increase of shrimp farms in that period.

Though there are reports of illegal cutting of mangroves for shrimp farms in Vietnam (e.g., Phan and Stive, 2022; Tran et al., 2020; Truong et al., 2018; Van et al., 2015), most reports are noted to have occurred before 1999 and there is insufficient evidence to conclude that there is a significant ongoing loss of habitat functionality from illegal habitat conversion in recent years.

Land use change by production system

Boyd et al. (2021b) noted that the concern over mangrove destruction applies to all types of shrimp farming, but also noted differences between them. Some generalities can be drawn regarding the typical locations of different production systems: for example, extensive and shrimp-mangrove farms tend to be in intertidal areas based on the characteristic of tidal water exchange (noting that, due to the low-lying nature of the Mekong Delta, the intertidal area is quite large), and rice-shrimp systems, somewhat by default, are typically located in former agricultural areas commonly further inland where seasonal freshwater/brackish water enables rice/shrimp to be grown, But, such simplistic generalities are typically unreliable.

Figure 27 from Anh et al. (2016) shows an example of 2020 land use planning for aquaculture in the Bình Đại District of Bến Tre Province.[61] Extensive *P. monodon* farms (green) are located near the coast, largely in former mangrove areas. Rice-shrimp farms (yellow) are located in the central area of the district, inland of former mangrove areas. Intensive and semi-intensive shrimp farms (orange), including areas allocated for *L. vannamei* farming (pale purple area), are located in a broader range of locations on the coast and inland, including former mangrove areas (likely previously converted from mangroves to agriculture). A small area of protective mangrove remains on the exposed coastline, and other aquaculture (mainly catfish—dark

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[61] Note this is the same district in which Veettil et al. (2019) reported that mangrove-to-shrimp-pond conversion is still going on extensively at an "unprecedented scale."

purple) is located along rivers distant from the coast. The realization of this plan and examples of each production system can easily be seen in Google Earth (also noting that the area of intensive farms has continued to expand rapidly northwest from the planned *L. vannamei* area into former agricultural land).

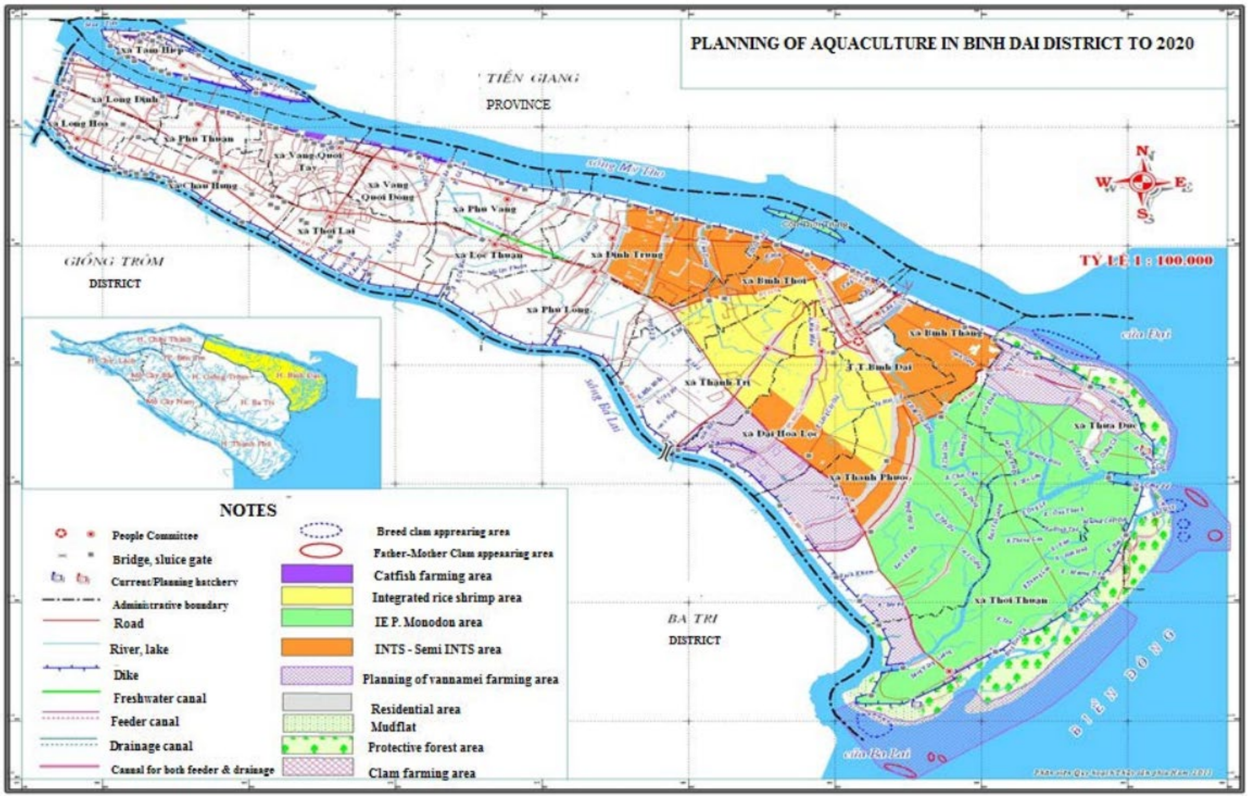

Figure 27: Example of the geographical spread of shrimp farming systems in Bình Đại District of Bến Tre Province (Mekong Delta) from a 2015 plan for the year 2020. Green areas are improved extensive farms for *P. monodon*, orange areas are intensive and semi-intensive farms, yellow areas are rice-shrimp farms, and pale purple areas are planned for *L. vannamei* farms (note these areas are now dominated by such farms). White areas are generally agricultural or urban areas. Image reproduced from Anh et al. (2016).

It is emphasized that this is an example only, and though it is likely to be similar to some other areas in the Mekong Delta, it is also possible for entirely different distributions of shrimp farming systems to be seen (for example, the extensive construction of irrigation channels in Vietnam has altered the local salinity dynamics and therefore the potential locations of agriculture and aquaculture; Phan and Stive, 2022). The following sections separate any apparent distinctions between the production systems:

- Intensive systems

  The total area of intensive farms is approximately 51,000 ha (Schuur et al., 2021), and these systems have greater flexibility in their location; i.e., they do not need to rely on tidal water exchanges but do require brackish or saline water. Boyd et al. (2021b) noted that semi-intensive and intensive shrimp farms have been constructed in mangrove areas, but mostly between 1980 and 2000, and they considered that new construction of semi-intensive and intensive shrimp farms seldom occurs in mangrove areas. Nguyen et al. (2022) noted that intensive shrimp farming began in the late 1990s but was primarily in nonmangrove areas at higher elevations, to allow ponds to dry after harvesting. In contrast, the rapid increase in intensive production, particularly after the introduction of *L. vannamei* in the early 2000s, likely increased the siting pressure, and there are examples of post-1999 conversion of mangroves, such as Hong et al. (2019) in Sóc Trăng Province (Figures 22 to 25).

- Improved extensive systems

  In combination, improved extensive monoculture and shrimp-mangrove systems dominate the total area of shrimp farms in Vietnam. For example, of the 736,000 ha total of shrimp farming area (2020 data from GSO), 675,000 ha are of extensive farms (91.7%), and they occupy 11% of the land area of the Mekong Delta (Schuur et al., 2021). Boyd et al. (2021a) estimate that 94% of shrimp farms in Vietnam by number are extensive. Both types of extensive farms are concentrated in the intertidal zone (Schuur et al., 2021), and today, most shrimp farms in mangrove areas are for extensive production (Boyd et al., 2021a). But, neither Schuur et al. (2021) nor Boyd et al. (2021b) differentiate extensive monoculture shrimp farms from shrimp-mangrove farms.

  According to Nguyen et al. (2022), the construction of extensive farms caused a significant decline in mangrove forests between 1976 and 1990, and it is clear that the conversion of mangroves to extensive monoculture farms causes a loss of ecosystem services from the mangroves and a loss of habitat functionality. Figure 8 showed that Cà Mau Province had approximately 150,000 ha of shrimp farms before 1999, of which the majority were considered to be a mix of the two extensive systems (extensive monoculture and shrimp-mangrove). After 1999, there was another rapid increase in shrimp farming area (an increase of an estimated 274,792 ha from 2000 to 2014; Boyd et al., 2021b), and though many farms are considered to have been constructed in former agricultural areas, there was a loss of the remaining mangrove areas of 2,861 ha. Uncertainties remain in other areas.

- Rice-shrimp systems

  Rice-shrimp systems covered 162,000 ha in the Mekong Delta in 2019 (Anh et al., 2020) and are (somewhat by definition) largely converted from agricultural land. They are typically located farther from the coast (and/or on slightly higher land) in areas only seasonally affected by brackish water. Although some rice-shrimp production is likely to occur in former mangrove areas, these are considered here to have typically been converted historically to agricultural land before their use for shrimp production. Thus, there is not considered to be any fundamental loss of existing ecosystem services or ecosystem functionality from the production of shrimp in rice agriculture, but that is not to say there are no impacts.

Park et al. (2021) and Dien et al. (2019) (among others) show that the salinity dynamics, particularly in the Mekong Delta, are complex, with broadly intensifying intrusion of saline water because of a variety of anthropogenic factors.[62] Park et al. (2021) note that many studies have argued that rice-shrimp culture contributes significantly to deteriorating environmental conditions as a result of the salinization of soil layers. They note that the assumption often fails to hold true that excess salts, which accumulate in the uppermost soil layers of the fields after a season of shrimp rearing, could be flushed out by the wet season rainwater. The ability to grow rice is reduced and requires the use of salt-tolerant varieties.

- Shrimp-mangrove systems

  Figure 17 (and 18) has previously shown that large areas of mangrove forests were converted to extensive shrimp-mangrove farms. Joffre et al. (2015) note that shrimp farming's expansion into mangrove areas has been primarily in the form of shrimp-mangrove systems. These systems maintain mangrove trees in the ponds at variable coverage rates dictated by government policy based on farm size and location (see Factor 3.2a), but the coverage in practice appears variable, and the species diversity is typically a monoculture of *Rhizophera apiculata* species (Van et al., 2015)(Schuur et al., 2021). Lai et al. (2022) reported that much effort has been made to replant mangroves, particularly for maintaining mangrove coverage at 30–50% of total farm area (which had been shown to provide the highest yields). Further, the trees in shrimp-mangrove systems are harvested on a 10- to 12-year cycle, albeit with the intention of replanting (Van et al., 2015).

More broadly, it is important to note that, although the shrimp-mangrove systems are perceived positively or promoted regarding their maintenance of mangrove forests within the shrimp ponds (e.g., Thuy et al., 2021), it is clear that, because of the profound changes in forest cover, species diversity, hydrodynamics, disturbance, and extensive habitat fragmentation, there is a loss of important ecosystem services and a loss of habitat functionality[63] (Liu et al., 2020)(Boyd et al., 2021b)(Schuur et al., 2021)(Tran et al., 2017).

Regarding the 1999 timeline of conversion from mangroves to shrimp-mangrove ponds, as noted previously, Cà Mau has the largest area of extensive farms and the largest area of shrimp-mangrove farms, and these were rapidly established in mangrove areas before 1999 (Figure 17), but Figures 9 to 12 from Liu et al. (2020) and Figure 13 from Phan and Stive (2022) show that substantial areas of mangroves continued to be converted after 2000, although at a lower rate than before 1999.

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[62] For example: sea level rise due to climate change, land subsidence due to extraction of groundwater, dams upstream, and changing irrigation systems. Saline intrusion is gradually increasing, but there were also large intrusion events recently in 2016 and 2020.

[63] The academic literature on mangrove forests and their ecosystem services is extensive and, given the well-established loss of ecosystem services due to their conversion to shrimp ponds, including shrimp-mangrove ponds, it is not elaborated on here.

Factor 3.1—Conclusions and scoring

Quantifying the land use change in terms of areas and timelines for different production systems is challenging. Although it is clear that large numbers of farms were constructed in former agricultural areas, there has also been widespread conversion of high-value habitats (i.e., mangrove forests) into shrimp farms in Vietnam. Although the majority of this conversion is considered to have occurred before 1999, further conversion of the remaining areas of these habitats continued (albeit at a much slower pace) after their ecological value had been fully recognized in 1999. Recent academic studies have indicated that mangroves continue to be converted to shrimp ponds (after 2010) and that aquaculture continues to be the most important factor affecting mangroves in Vietnam. There are some apparent differences between the production systems; for example, rice-shrimp farms are (somewhat by definition) considered to be modified from existing agricultural land. Despite some apparent differences between intensive, extensive, and shrimp-mangrove systems in terms of their likelihood of expansion into the remaining mangrove habitats after 1999, there is evidence that all these systems have done so and insufficient evidence to robustly distinguish them.

Regarding the scoring for Factor 3.1—Habitat Conversion and Function, the modification of rice farms for the cyclical production of rice and shrimp is not considered to result in the loss of functionality of the agricultural land, but there is a moderate concern regarding increasing soil salinity. The score for Factor 3.1 is therefore 7 out of 10. For the other production systems, the recent (post-1999) conversion of the remaining mangrove forests to shrimp ponds has resulted in a loss of ecosystem functionality of high-value habitats. Without an ability to robustly differentiate their respective contributions, the score for Factor 3.1 is 1 out of 10 for intensive, extensive, and shrimp-mangrove systems.

Factor 3.2—Farm siting regulation and management

Factor 3.2a—Content of habitat management measures

During the period of relevance to shrimp farming in Vietnam, complex changes in land use policy and management have been made. Given the lower concern regarding the conversion of agricultural land to shrimp farms, the focus here is on high-value habitats, principally mangrove forests. Therefore, this assessment focuses on the Mekong Delta region, with approximately 80% of Vietnam's mangroves (78% according to Pham et al., 2019), but also considers other areas where possible.

From 1975 to early 1990s, forest lands in Vietnam were under state-centralized forest management, enacted by State Forest Enterprises (SFEs) and other state-owned organizations under which forests and forest products were defined as "national assets" owned by the state (Thuy et al., 2021). Forest management then evolved as part of the change from a centralized economy to a household-based economy in Vietnam in the 1980s (the Doi Moi Renovation, launched in 1986; Ha et al., 2020). In order to slow the rate of deforestation across the country, under regulation 64/QD.UB in 1991 and the Land Law of 1993, the rights to use forest land were allocated to households.

This had two main forms: the land use certificate (or red book), which was a legal recognition that the state directly transfers use rights on forestland to households for 50 years, and the contract-based allocation (or green book), which was made between either forest management boards and households or state-owned forest companies and households, in which households obtain a maximum of 20 years leased tenure with more limited use rights. The red book is often associated with barren land or plantation forest, categorized as production forest, whereas the green book is allocated for special use forests, which are designated for nature conservation and protection of cultural sites for tourism, or for protection forests, which are designated to protect watersheds, prevent soil erosion, or mitigate natural disasters.

Under regulation 64/QD.UB in 1991 and the Land Law of 1993, these policies included various regulatory requirements, of which the most important was the level of mangrove coverage, but included various land use rights such as logging and the development of shrimp-mangrove ponds (Liu et al., 2020). The policies were applied under the umbrella of various regional "Master Plans" approved by the Prime Minister (Phan and Stive, 2020)(Hong et al., 2019). Under these plans, the mangrove areas in the Mekong Delta were divided into three zones: a full protection zone along some areas of the coast, and buffer and economic zones farther inland (these are now commonly referred to as special use, protection, and production forests as shown by the example in Figure 18). The requirements for mangrove cover varied by farm size; for example, under regulation 64/QD.UB in 1991, 70% tree cover was required for pond area greater than 5 ha, 60% for pond area of 3 ha to 5 ha, and 50% for pond area smaller than 3 ha. Later, according to Decision 186/2006/QD-TTg, shrimp farmers in protection and production mangrove forests must maintain at least 60% cover (Hong et al., 2019)(Boyd et al., 20021b). As noted in Factor 3.2 below, these ratios of forest cover to pond area are often not met.

These policies to promote shrimp-mangrove aquaculture were intended to protect and increase the coverage of mangroves, and with the encouragement and support of the Vietnamese government and international organizations such as the World Bank and the Asia Development Bank, these programs led to large amounts of shrimp-mangrove aquaculture in Vietnam along the coastal zone of the Mekong Delta (Boyd et al., 2021b). Although Thuy et al. (2021) and Nguyen et al. (2022) consider that this devolution policy and the promotion of shrimp-mangrove aquaculture helps conserve mangrove forests in the Mekong Delta of Vietnam, as discussed in Factor 3.1, it is now well established that the mangrove forests in areas of shrimp-mangrove farms are heavily fragmented and hydrologically impeded, and have lost critical ecosystem services and ecosystem functionality. It has therefore been proposed that benefits to coastal land use and mangrove conservation would result from removing shrimp farms from the coastal zone entirely (Boyd and McNevin, 2018).

More recently, it is clear that the importance of mangrove forests has been recognized (in Vietnam and elsewhere), and the Government of Vietnam is highly interested in improving coastal forest management (Jhaveri et al., 2018). There have been national plans such as The

National Program to Restore and Develop Coastal Mangrove Forest (2008–2015) (Boyd et al., 2021b), and there has been much activity in policy, planning, and strategy, typically involving the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE). MARD has had a long history of establishing and managing protected areas, including mangrove ecosystems, and also manages water surfaces because they are related to irrigation, fishery, and aquaculture; however, MONRE manages biodiversity within, and the land under, terrestrial and mangrove forests (Pham et al., 2019). In addition, each federal department has a provincial counterpart, namely the Department of Agriculture and Rural Development (DARD) and the Department of Nature Resources and Environment (DONRE), respectively (Pham et al., 2019).

Although these are prominent state organizations, there is institutional fragmentation, with a number of ministries and multiple state agencies covering spatial and policy planning for agriculture, rural development, natural resources management, and environment that continue to target sectors separately with low coordination levels (MDBP, 2022). As a result, it is often challenging to identify the specific regulations currently applying at national, provincial, district, or commune scales; for example, MDBP (2022) note that legislation for the agriculture and water domains (including aquaculture) remains complicated, with hundreds of scattered rules and regulations, and Jhaveri et al., (2018) noted that no single authority is responsible for ensuring that coastal management rules are harmonized within or across jurisdictions, and also noted the confusing and overlapping authority among different government agencies for managing mangrove areas (to the extent that it can result in open-access situations).

In general, the Law on Forest Protection and Development (2004) and the revised Forestry Law (No. 16/2017/QH14 of 2017) are the fundamental regulations. Boyd et al. (2021b) noted Decree No. 119/2016/ND-CP (which focuses on policies for the sustainable management, protection, and development of coastal forests to support adaptation to climate change), which will seek to prevent further conversion of coastal forests other than for reasons of national importance. Pham et al. (2019) provided a list of key policies to promote the management and development of mangrove forests, and this is shown in Appendix 1.

Fundamentally, the Law on Forest Protection and Development (2004) and the revised Forestry Law (2017) divided forests into three types according to management purposes: special use forests (national parks and protected area), protection forests (watershed, coastal, and environmental protection), and production forests (Pham et al., 2019). To varying extents, shrimp farming is permitted in all three. State boards manage special use forests and protection forests, but production forests are allocated to different actors, including private organizations and households (i.e., as part of the decentralization to household-based economies mentioned previously). Protection mangrove forests now cover the largest area (accounting for 73% of total mangrove forest area in Vietnam), followed by production forests (about 13%) and special use forests (9%) (Pham et al., 2019). According to Articles 57 and 60 of the 2017 forestry law, aquaculture is only permitted if the capability of forest protection is not affected.

Regionally, Vietnam's largest areas of mangroves in the Mekong Delta have been a focus of interest; for example, the 2013 Mekong Delta Management Plan[64] classified the Delta into three agroecological zones (Upper, Middle, and Coastal), representing the nationwide vision for long-term sustainable socioeconomic development endorsed by the central government (Park et al., 2021). The Mekong Delta Agricultural Transformation Program, in connection with the Vietnam Development Report of 2016, led to a further action plan (2019) in addition to the Comprehensive Program for Sustainable Agriculture Development (from MARD) and the ongoing Mekong Delta Integrated Regional Plan (MDBP, 2022).

Restoration of mangrove forests has been a significant activity in Vietnam, particularly since the widespread destruction during the Vietnam War. As noted previously, the overall area of mangroves is increasing, and restoration continues to be a central aspect of government policy at the national and regional level (including the Mekong Delta, as noted above) (Boyd et al., 2021b). Restoration is not discussed further here (although it is mentioned again in Factor 3.2b) but is noted as part of Vietnam's recognition of the importance of mangroves and their management.

Overall, it is clear that after the widespread loss of mangroves at the end of the last century, their importance has been recognized. Although the specifics of active regulations at varying levels of governance are challenging to understand, mangroves are a focus of land management in Vietnam, and many programs and policies have been initiated to drive mangroves' sustainable management at the national, regional, and provincial scales. Mangroves and aquaculture appear to be included in broader agricultural policies in Vietnam. Nevertheless, a challenge remains regarding the management of ecosystem functionality, particularly for shrimp-mangrove systems. Though these systems continue to be promoted as a component of maintaining mangrove cover, it is clear (as referenced previously) that these areas have lost important ecosystem services and their habitat functionality (even if some ecosystem services, such as "protection," may be maintained in some areas). Therefore, despite a broad (and arguably comprehensive) management system in place that integrates shrimp farming with other industries such as agriculture, it is considered that the management system does not account for the losses of habitat connectivity and the cumulative impacts on ecosystem services, particularly of mangrove forests. The score for Factor 3.2a is therefore 2 out of 5 and is applied to all production systems and species.

Factor 3.2b—Enforcement of habitat management measures

The primary enforcement organizations can be broadly identified as MARD and MONRE at the national level and DARD and DONRE at the provincial level, in addition to the Forest Management Boards, Commune People's Committees, and specific communities (Jhaveri et al., 2018). Thuy et al. (2021) consider that the enforcement of forest rights is assigned mainly to the Forest Management Boards and its forest rangers, but Jhaveri et al. (2018) note that this

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[64] https://mekongdeltaplan.com/

varies somewhat across different regions of Vietnam; for example, in the south (i.e., primarily the Mekong Delta), Forest Management Boards are responsible for >70% of the management and enforcement, and minor amounts are controlled by Commune People's Committees, in contrast to the north, for which approximately 30% is managed and enforced by Forest Management Boards and approximately 70% is by Commune People's Committees. Jhaveri et al. (2018) noted an enforcement worst case scenario where the confusing and overlapping authority among different government agencies for managing mangrove areas resulted in open-access situations.

Regardless of the specific enforcement body, there is a common perception in academic literature that enforcement of land use regulations in Vietnam is limited. During the early rapid expansion of shrimp farming, the high income from aquaculture encouraged farmers to expand aquaculture areas by illegally cutting mangroves (e.g., Liu et al., 2020; Phan and Stive, 2022; Tran et al., 2020; Truong et al., 2018; Van et al., 2015), which led to problems of rapid deforestation because local authorities were incapable of controlling the expanding aquaculture (Phan and Stive, 2020). Most examples of illegal deforestation are noted to have occurred before 1999, and there is insufficient evidence to conclude that there is a significant ongoing loss of habitat functionality from illegal habitat conversion in recent years.

Regarding the Forest Management Boards, which are the dominant enforcement organizations in Vietnam as a whole and particularly in the Mekong Delta, Thuy et al. (2021) reported that many concerns have been raised on the effectiveness of the forest laws and their enforcement, noting that forest rangers who are given the power to protect mangrove forests are information-constrained by a lack of human resources as well as supporting equipment. They also noted that linkages between the forest management boards and local authorities were weak and even contained conflicts.

Using the metric of mangrove coverage on farms (which typically should be 60%[65]), various studies show that this is highly variable in practice. For example, while Van et al. (2015) and Trang et al. (2022) noted that farms with 50–70% mangrove coverage were dominant, Cong and Khanh (2022) showed an average mangrove cover of 50.9%, and Thuy et al. (2021) and Truong and Do (2018) noted that the coverage was much lower, from 26% to 30%. Thuy et al. (2021) noted an average self-reported mangrove coverage of 30.0%, and satellite-image-derived coverage of 26.5%. These values apparently indicate poor enforcement. In their analysis of the number of forest rangers and their patrols, Thuy et al. (2021) concluded that, because farms are sparsely distributed and large in size, the patrolling of foresters will not be able to prevent violation of the regulatory level of mangrove coverage. Thuy et al. (2021) primarily referred to earlier sources on enforcement (e.g., Sikor and Quang, 2007; Ha et al., 2012, 2014), and their analysis of self-reporting and satellite images were from 2011 to 2016, and it is not clear if there have been substantial improvements since then. In a similar farmer survey, Nguyen et al.,

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[65] As discussed previously, this figure can vary according to farm size and according to the province, district, or commune, but 60% is considered here to be the most common requirement, and applicable in Ca Mau, which has the largest area of these farms.

(2022)[66] noted that, although the majority of farms (76%) retained >50% mangrove cover, the remaining 24% were <50% with an overall range of 20% to 70% cover (the regulatory requirements in this case in Cà Mau Province were also for 60% mangrove coverage).

Regarding compliance data as evidence of enforcement, Vietnam's General Statistics Office now publishes substantial quantities of data on aquaculture area in Vietnam (including the categorization of total aquaculture area by marine and inland shrimp culture, and the total area by province) in addition to various types of data on forest area (including new planted areas of production, protection, and specialized forests), but there is no way to relate shrimp farming to any kind of land or forest conversion characteristics. There do not appear to be any other readily available public data sources on land use changes or land use characteristics for shrimp farms in Vietnam.

Overall, it is challenging to robustly determine the current enforcement activities and their effectiveness in Vietnam. Despite many recent publications, the reliance on academic references typically results in a somewhat dated understanding; nevertheless, these sources are useful for identifying the general picture and trends. Enforcement organizations are identifiable and active, but the available evidence indicates that they have limitations in resources or activities that reduce their effectiveness. Although it is considered that enforcement is focused at the farm level (e.g., on mangrove to pond ratios in shrimp-mangrove systems), the apparent focus at the policy and planning level on total forest areas and restoration (including of production, protection, and special use forests) implies some enforcement at the cumulative level. Though specific enforcement data and transparency are limited, the recent body of academic studies do provide useful data. Therefore, the score for Factor 3.2b—Enforcement of habitat management measures is 3 out of 5.

The two scores for Factors 3.1a (Content of habitat management measures) and Factor 3.2b (Enforcement of habitat management measures) combine to give a final score for Factor 3.2—Farm siting regulation and management of 2.4 out of 10. Although the focus of habitat management measures regarding shrimp farming has been on mangrove forests, particularly shrimp-mangrove systems, because of the potential for all types of production system to be located in coastal land and former mangroves, this score applies to all the production systems (and species) assessed here.

Conclusions and Final Score

A remarkable change in the coastal land cover regarding aquaculture began in the 1990s as shrimp farming expanded rapidly in coastal areas with the encouragement of the Vietnamese Government and organizations such as the World Bank and the Asia Development Bank. Several recent academic studies analyzing satellite images provide a useful time series of land use change and show a rapid conversion of mangrove forests and agricultural land into shrimp farms, particularly in the Mekong Delta in southern Vietnam. Nevertheless, quantifying the land use change in terms of areas and timelines for different production systems is challenging,

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[66] The year in which their farm survey was conducted is not clear.

particularly regarding recent or ongoing conversions of high-value habitats after the year 1999, when the ecological value of mangrove forests was considered to be formally recognized. Although the majority of shrimp farms are shown to be located on former agricultural land, the conversion of a large proportion of Vietnam's ecologically important mangrove forest into shrimp farms, including shrimp-mangrove farms (noting prior damage to these areas from the use of defoliants by the United States during the Vietnam War), is considered to have caused a loss of ecosystem services and a loss of habitat functionality, because of large scale habitat fragmentation, and changes in mangrove cover, diversity, ecology, access, and hydrodynamics. Recent academic studies have indicated that this has continued after 1999 and more recently (albeit at a much slower pace), and shrimp farming continues to be the most important factor affecting mangroves in Vietnam. There are some differences in the likelihood of the various production systems being located in former mangrove areas, but without an ability to robustly differentiate their respective contributions, the score for Factor 3.1 is 1 out of 10 for intensive, extensive, and shrimp-mangrove systems. The modification of rice farms for the production of rice and shrimp is not considered to result in the loss of functionality of the agricultural land, but there is a moderate concern regarding increasing soil salinity (the score for Factor 3.1 is 7 out of 10).

The Vietnamese government has clearly recognized the value of mangrove forests and their ecosystem services and has been active in their management and restoration; however, the management measures have focused on the development of shrimp-mangrove farms and efforts to reach a forest-to-pond ratio of 60%, i.e., 60% of the total farm area (which is typically allocated in small parcels to tens of thousands of individual households) must be forested. It is considered here that this ratio still results (cumulatively) in a loss of habitat functionality, and it is apparent that this ratio is often not met due to limitations in enforcement (and driven by a high price for shrimp, which encourages a larger pond area). Therefore, the overall effectiveness of the management system (for all production systems) is considered to be limited, and the score for Factor 3.2 is 2.4 out of 10. Overall, Factors 3.1 and 3.2 combine to give a final score for Criterion 3—Habitat for rice-shrimp systems of 5.47 out of 10. For intensive, improved extensive, and shrimp-mangrove systems, the final score for Criterion 3—Habitat is 1.47 out of 10. These scores apply to both species.

Criterion 4: 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—*L. vannamei* and *P. monodon*

Chemical Use parameters	Score	Critical?
Intensive systems: C4 Chemical Use Score (0–10)	0	Yes
Improved extensive systems: C4 Chemical Use Score (0–10)	6	No
Rice-shrimp systems: C4 Chemical Use Score (0–10)	6	No
Shrimp-mangrove systems: C4 Chemical Use Score (0–10)	8	No

Brief Summary

Aquaculture in Vietnam, including shrimp farming, has frequently been associated with high use of antimicrobials. There are no readily available official data on their use, but multiple academic papers indicate that it has been common, primarily in intensive and semi-intensive farms. The types of antimicrobials documented include several listed as highly important and critically important to human medicine by the World Health Organization, and also some banned for use in aquaculture by the Ministry of Agriculture and Rural Development (MARD). Bacteria that are resistant to one or more of the same antimicrobials (including several that are highly and critically important to human medicine) are detected in farmed shrimp and in shrimp farms (water and sediment, etc.). Because of the common practices of water exchange and sludge disposal, shrimp farms are also associated with the detection of antimicrobials and resistant bacteria in the environment (also associated are other types of aquaculture, terrestrial livestock, and municipal sources, along with the manufacture of the pharmaceutical themselves).

The regulatory oversight of antimicrobial use in Vietnam has also been criticized due to the limited control of antimicrobials' availability, purchase, and use by farmers, but in 2017, the Vietnamese government (MARD) launched the "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)," which has the potential to substantially change the patterns of antimicrobial use and resistance in shrimp farms. With some concerns regarding the implementation of the National Action Plan, in 2021, a "Plan for Antibiotic Resistance Prevention in the Agricultural Sector in the Period of 2021–2025" was launched. To date, there have been no comprehensive results generated from either project.

The U.S. Food and Drug Administration's inspections of imported shrimp from Vietnam continue to detect residues of antimicrobials that are banned for use in aquaculture in Vietnam, with 22 import refusals in 2021. For intensive (and semi-intensive) shrimp farms, illegal and critically important antimicrobials are considered to be used in significant and unknown quantities, and antimicrobial resistance to the same chemicals has developed. The final score for Criterion 4—Chemical Use for these systems is Critical. The three remaining production systems assessed here are considered to have a demonstrably low need for chemical use, but data limitations urge some precaution. For improved extensive and rice-shrimp systems, where there is some evidence that chemicals may occasionally be used, the final score for Criterion 4—Chemical Use is 6 out of 10. For mangrove-shrimp systems, there is sufficient confidence that chemicals are used less than once per production cycle, and the final score for Criterion 4—Chemical Use is 8 out of 10. With little evidence to robustly differentiate *L. vannamei* and *P. monodon*, these scores apply to both species in the production systems in which they are assessed.

Justification of Rating

It is commonly stated in academic studies that chemical use, particularly of antimicrobials,[67] is high in Vietnamese shrimp farming and poorly regulated (Ngoc et al., 2021)(Nguyen et al., 2022)(Van Nguyen et al., 2021)(Dang et al., 2022)(Boyd, et al., 2021a)(Tan 2021)(Luu et al., 2021)(Trang et al., 2018)(Nguyen et al., 2019)(Pham et al., 2018)(Quyen et al., 2020)(Tran et al., 2021)(Suzuki et al., 2021)(Phuong et al., 2020). The intent here is to understand the *current* chemical use practices in different shrimp production systems, and there is a need for caution in the interpretation of the time frames reflected in academic studies, particularly regarding the potential for rapid changes in practices. For example, in a recent paper, Suzuki et al. (2021) noted that antimicrobial use was still common in Vietnamese shrimp farms, but their field surveys were from 4 to 6 years earlier, in 2015–17. A similar example exists with the four-country review of resource use in shrimp farms by Boyd et al. (2021a), for which the data for Vietnam were from Boyd et al. (2017).

Nevertheless, the Directorate of Fisheries recently reported (in 2021[68]) that the abuse of antibiotics and chemicals in shrimp farms has not only damaged the quality of aquaculture, but also land and water resources. As discussed further below, in 2017, the Ministry of Agriculture and Rural Development (MARD) launched the "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020) (NAP-AMU-AMR), and in 2021, the "National Action Plan on Antibiotic Resistance Prevention and Control in the Field of Agriculture in the Period of 2021–2025." It is hoped that

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[67] The term "antimicrobial" is used here, following the lead of the World Health Organization (WHO), but the term "antibiotic" is also commonly used in the literature referred to here and can be considered synonymous for the purposes of this assessment.

[68] https://tongcucthuysan.gov.vn/vi-vn/Tin-t%E1%BB%A9c/-Tin-v%E1%BA%AFn/doc-tin/016572/2021-12-13/tom-viet-nam-2021-san-luong-nuoi-tang-xuat-khau-uoc-dat-38-ty-usd

these efforts would lead to substantial recent changes in antimicrobial use, so it is important to understand the impacts that these changes may have had, and even recent peer-reviewed papers may not fully represent current chemical use practices.

Unfortunately, understanding of the most recent chemical use practices is hampered by an apparent lack of readily available public data from shrimp farming or aquaculture in general in Vietnam. (MARD and the Department of Animal Health were contacted with an information request, but a reply was not received.) Therefore (and with appropriate caution), the available academic studies are used to indicate typical chemical use practices across the production systems assessed here, with the understanding that they may not accurately reflect recent changes in practices.

Types of chemicals used

Liu et al. (2021) noted that there are approximately 13,000 veterinary medicine products licensed for used in Vietnam, of which 1,500 are licensed for use in aquaculture. FAO (2017a) states a lower number of 814 licensed products for aquaculture, of which 604 are manufactured domestically. The 2018 Circular No. 26/2018/TT-BNNPTNT[69] from the Minister of Agriculture and Rural Development provides a list of permitted and prohibited products in aquaculture feed and in production. The list of permitted products is extensive, but Table 6 lists the 25 that are prohibited.

Table 6: List of chemicals, biological products, and microproducts prohibited for using in aquafeeds and aquaculture production. Source: Circular No. 26/2018/TT-BNNPTNT; November 15, 2018 of the Minister of Agriculture and Rural Development.

	Names of chemicals, biological products, microorganisms
1	*Aristolochia* spp. and preparations thereof
2	Chloramphenicol
3	Chloroform
4	Chlorpromazine
5	Colchicine
6	Clenbuterol
7	Cypermethrin
8	Ciprofloxacin
9	Cysteamine
10	Other Nitroimidazoles
11	Deltamethrin
12	Diethylstilbestrol (DES)
13	Dapsone
14	Dimetridazole
15	Enrofloxacin
16	Ipronidazole

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[69] This list appears to be updated regularly (the previous version was from 2016). This version was downloaded from the Department of Agriculture and Rural Development in Ca Mau, in April 2022.

17	Green Malachite
18	Gentian Violet (Crystal violet)
19	Glycopeptides
20	Nitrofuran (including Furazolidone)
21	Fluoroquinolones group
22	Metronidazole
23	Trichlorfon (Dipterex)
24	Trifluralin
25	Ronidazole

In typical shrimp farming production, a variety of chemicals are expected to be used; for example, Boyd et al. (2017)[70] recorded more than 90 different types of inputs used by shrimp farmers in Vietnam, which Boyd et al. (2021a) grouped into 16 types of chemicals used for pond preparation, water treatment, and shrimp health. These include common pond preparations such as lime, various disinfectants, fertilizer, or mineral mixes (which are assessed in Criterion 2—Effluent); water treatments such as probiotics; antimicrobials, and the piscicides. Many of these chemicals are considered to be largely environmentally benign in typical use and/or are typically not discharged in their active form. According to the Seafood Watch Aquaculture Standard, the focus of this assessment is on antimicrobials and pesticides.

Species-specific differences in chemical use

With a focus on feed-based intensive systems, Boyd et al. (2021a) noted that the chemicals used in *L. vannamei* and *P. monodon* systems were quite similar. Though the two species can have some differing disease characteristics that may affect antimicrobial use (see Criterion 7—Disease), there is insufficient evidence or data with which to differentiate them in any meaningful way. Therefore, this assessment considers the chemical use to be the same for both species in the production systems in which they are both assessed (i.e., intensive and rice-shrimp systems).

Pesticides

To remove unwanted fish from ponds before stocking with shrimp, piscicides such as saponin or rotenone may be used (Boyd et al., 2021a)(Nguyen et al., 2022). These chemicals may be applied in small volumes in remaining puddles after harvest/pond draining, or before stocking. In either application, active chemicals are unlikely to be discharged from the ponds and are a low concern here.

Pesticide use in rice agriculture in Vietnam is common and pesticides may be used during the rice cycle of a rotational rice-shrimp system (Braun et al. [2019] noted that the number of rice-shrimp farmers using pesticides for rice cultivation varied from 10 to 100%), but rice-shrimp farmers are more conscious about using substances that could be harmful to shrimp (Park et al., 2021). According to Braun et al. (2019), rice-shrimp farmers not only reduce application

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[70] The data from this study in Vietnam and Thailand (for which the sampling year was not specified) was also used by Boyd et al., (2021a) in their four-country review of resource use in shrimp farms.

frequency by half compared to rice monoculture systems, they also tend to use less-toxic variations to protect their shrimp. There is likely some regional variation in rice-shrimp production; for example, Dang (2020) considered that the durability of a system (in Thanh Phu and Bình Đại communes) derived partly from the practice of no chemical pesticide or insecticide use. Any pesticide use in rice-shrimp systems is therefore considered to be primarily targeted at the rice as opposed to the shrimp, and the rice-shrimp system is generally considered to reduce pesticide use compared to rice monoculture.

Since 2014, there has been one import refusal[71] in the United States for a pesticide residue (which occurred in January 2022), and the pesticide or the source of the residue is not stated. Overall, pesticides are a lower concern in Vietnamese shrimp farms than antimicrobial use, and this assessment focuses on the latter.

Antimicrobials (antibiotics)

One of the major challenges with shrimp farming is frequent disease outbreak (Suzuki et al., (2021) but it is clear from the academic literature that antimicrobial use varies considerably between different production systems. In 2016, the Department of Animal Health (DAH) conducted a survey of antimicrobial use in shrimp farms (size, system, or species not specified) in Sóc Trăng and Bạc Liêu Provinces (FAO, 2017b). In their survey of 436 household farms, 67.9% used at least one antimicrobial (described as wide and frequent use), and antimicrobials were used without any prescription for both prevention and treatment of diseases (FAO, 2017a). There does not appear to be any readily available update to this 2017 publication from the DAH or MARD.

A review of other information on antimicrobial use in each of the four production systems assessed here is provided below:

- Antimicrobial use in intensive systems

  In general, production intensification typically increases the incidence of aquatic animal pathogens and drives antimicrobial use (Schar et al., 2020), and the impression that antimicrobial use is high in Vietnamese shrimp farms stems almost entirely from feed-based semi-intensive and intensive systems. Nevertheless, reports on the extent of antimicrobial use in these systems vary widely.

  Pham et al. (2018) reported that intensive shrimp farms rely heavily on a wide variety of antimicrobials to treat animals or prevent disease. Ngoc et al. (2021) consider that semi-intensive or intensive production depends on high antimicrobial use to reduce the risk of harvest failure. As a crude indicator of antimicrobials' importance, Nguyen et al. (2022) note that "medicine" is the second most significant cost item in intensive shrimp farming systems

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[71] For more details, see the later section in this criterion on the U.S. Food and Drug Administration's import refusals for antimicrobial residues in shrimp.

(after feed), and represents 22% of the annual budget. Similarly, Trang et al. (2018) noted that antimicrobials represented 11% of the total budget. Braun et al. (2019) and Nguyen et al. (2019) both reported that approximately 90% of intensive farmers applied antimicrobials, and Van Nguyen et al. (2021) considered that all intensive (white) shrimp farmers use aquatic medicines, with the aim of preventing rather than curing diseases. Van Nguyen et al. (2021) quote an officer of the Department of Agriculture and Rural Development (in Phong Điền district in Thừa Thiên Huế Province in central Vietnam): "Using aquatic medicines is now a habit for white shrimp farmers. White shrimp farmers believe that prevention is better than cure; so, a large number of white shrimp farmers focus on preventing diseases by using antibiotic aquatic medicines."

It is important to note that this situation is not universal in intensive systems; for example, Ngoc et al. (2021) also note that improved production methods such as multistage farming,[72] biofloc technology, and recirculating aquaculture systems (RAS) have the potential to eliminate the need for antimicrobials, but there are currently insufficient data with which to differentiate these systems and their antimicrobial use in Vietnam. There are also likely to be significant regional differences; for example, Tu et al. (2021) showed that average medicine expenses in Sóc Trăng Province were more than three times higher than in Kiên Giang Province (but this is also likely to be influenced by a higher proportion of intensive farms in Sóc Trăng, and more rice-shrimp farms in Kiên Giang).

More specifically, Nguyen et al. (2019) reported that 87.0% of intensive shrimp farmers in Northern Vietnam used antimicrobials (2017 data collection). Boyd et al. (2021a) and Quyen et al. (2020) noted that a lower percentage of farmers (33.3% and 30.5%, respectively) reported[73] the use of antimicrobials, but Quyen et al. (2020) also noted that 28.8% confirmed the use of banned antimicrobials, such as ciprofloxacin, enrofloxacin, and chloramphenicol. Quyen et al. (2020) also noted that chemicals (type not specified but assumed to include antimicrobials) were used not only for treatments, but also for disease prevention (i.e., prophylaxis) by 57.5% of intensive shrimp farm respondents. As noted previously, the DAH's baseline survey of antimicrobial use in 2016 (FAO, 2017a) showed that 67.9% of shrimp farms used at least one antimicrobial.

The FAO presentation of these results (FAO, 2017a) described the antimicrobial use as wide and frequent use. Although noting the potential for a change in use in the most recent years, this assessment uses the simple description of "wide and frequent antimicrobial use" as a starting point for intensive systems.

- Antimicrobial use in extensive systems—improved extensive and shrimp-mangrove

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[72] Involving a separate nursery phase to grow postlarvae to an intermediate juvenile size in controlled systems with higher biosecurity before stocking in grow-out ponds.

[73] Many of the studies quoted here, relied on farmer responses to interview questions, so there is some potential for inaccuracies regarding sensitive subjects such as antimicrobial use, particularly the use of banned substances.

There is little information with which to accurately estimate chemical use in extensive systems, but this is considered to be most likely due to the minimal use; for example, Quyen et al. (2022) noted that improved extensive shrimp farming involves almost no antimicrobials or chemicals. Nguyen et al. (2022) noted that shrimp-mangrove farmers may use saponin or rotenone to kill predatory fish, but no other chemicals are used, and Anh et al. (2020) noted the minimal use of chemicals in shrimp-mangrove systems is the most important feature of these systems. In contrast, Luu et al. (2021) noted (from a 2018 survey of 180 intensive and 180 extensive shrimp farmers) that there was no statistically significant difference between the number of farmers using antimicrobials (average of 24%). From visiting and interviewing many shrimp-mangrove farmers in Cà Mau Province over the last decade, this author saw no evidence of antimicrobial use in this production system.

- Antimicrobial use in rice-shrimp systems

  Braun et al. (2019) noted that the application of antimicrobials was significantly less frequent in alternating rice-shrimp production than in permanent (intensive) shrimp production, with 2.5% of rice-shrimp farmers applying them compared to 90% of intensive farms. Additional specific information on antimicrobial use in rice-shrimp systems could not be found. Although the shrimp culture phase of rotational rice-shrimp systems can operate at a variety of intensities, the stocking densities are generally low, from 1 to 15 PL/m^2, which is approximately half the lower range of semi-intensive production (Ahn et al. 2020)(Dien et al., 2019)(Dang et al., 2020)(Burford et al., 2020)(Nguyen and Tien, 2021)(Thakur et al., 2018)(Trang, et al., 2021a)(Van Nguyen, 2021). In some cases, yields in fed shrimp-rice systems can approach the lower range of semi-intensive production; e.g., approximately 1.5mt/ha (Le et al., 2022), but the average or typical rice-shrimp system is considered to operate at a low intensity, so it has an intermediate level of antimicrobial use between the intensive system and the two extensive systems assessed here.

Overall, it is clear that antimicrobial use is dominated by intensive (including semi-intensive) production systems, but reports on the extent of use (i.e., the proportion of farmers using antimicrobials) are highly variable. Further relevant information on antimicrobial use by shrimp farms in Vietnam is added below, but it should be noted that the emphasis is on intensive systems.

Types of antimicrobials and application in shrimp farms

Without specific data, it is challenging to determine the types of antimicrobials most commonly used in Vietnamese shrimp farms. As noted above, Vietnam has a high number of registered products, and Binh et al. (2018) noted that the large number of antimicrobials allowed to be used in the aquaculture industry makes it difficult to control their use and likely to increase the risk of irrational use and environmental pollution. Pham et al. (2018) noted that (intensive) shrimp farms in Vietnam rely on a wide variety of antimicrobials; on average, each farm used three different types, with 10% of the farms using up to six different products (referring to Binh et al., 2018). Ngoc et al. (2021) noted that shrimp farmers in Vietnam used more than 30 different types of antimicrobials during production. Trang et al. (2018) stated that commonly used antimicrobials include tetracycline, penicillin, and streptomycin. In a 2018 field study, Luu et al. (2021) noted that shrimp farms used 6 antimicrobial classes with 10 different antimicrobials, of which tetracycline was the most common and used by 20.6% of farms (other groups include sulfonamide, used by 3.1% of farms; aminoglycosides, 1.9%; Phenicol, 0.3%; cephalosporin, 0.3%; and quinolones, 0.3%). In the Luu et al. (2021) study, 1 shrimp farm out of 360 used enrofloxacin (a quinolone), which is banned. Dang et al. (2022) studied antimicrobial resistance (discussed further in the antimicrobial resistance section below) to nine antimicrobials that they describe as being commonly used in shrimp farming in Vietnam (doxycycline, oxytetracycline, amoxicillin, erythromycin, gentamycin, kanamycin monosulphate, neomycin, cephalexin, and sulfadiazine sodium). Unfortunately, they did not specify which types of shrimp farms their samples were obtained from. Dang et al. (2022) noted that, following an outbreak of disease (in this case, acute hepatopancreatic necrosis disease, also known as early mortality syndrome or EMS), antibiotics were used empirically for treatment, without laboratory diagnostic support and veterinary supervision.

Luu et al. (2021) reported that antimicrobials classified by the World Health Organization (WHO) as highly important or critically important for human medicine have been widely used in Vietnam aquaculture industries. Considering the antimicrobials mentioned in the previous paragraph, tetracycline, sulfonamide, phenicol,[74] cephalexin, sulfadiazine, doxycycline, and some cephalosporins (first and second generation) are listed by the WHO (2019) as highly important for human medicine, while penicillin, amoxicillin, erythromycin, neomycin, kanamycin, streptomycin, aminoglycosides, quinolones (e.g., ciprofloxacin), and some cephalosporins (third, fourth, and fifth generations) are listed as critically important. Indeed, quinolones and the later generations of cephalosporins are listed by the WHO as the highest priority critically important antimicrobials.

Again noting the potential for a recent change in antimicrobial practices by farmers or veterinarians, FAO (2017a) considered that the purchase and handling of antimicrobials by shrimp farms in Vietnam was largely uncontrolled, such that they were used without prescription for both prevention and treatment of diseases. Luu et al. (2021) reported that the majority of antimicrobial treatments were used for disease treatment (83%), while the remaining 17% was used for disease prevention. Farmers typically mix antimicrobials into feed by hand and have poor record-keeping, to the extent that they are unable to remember the types of antimicrobials used (Nguyen et al., 2019)(Luu et al., 2021). Braun et al. (2019) recorded that one farmer applied antimicrobials four times per day[75] during the entire production cycle, stopping only 5 days before the harvest. Quyen et al. (2020) also noted that shrimp farmers did not know the proper dosage, and had almost no records accounting for the usage, except for

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[74] The specific antimicrobial is not stated by Luu et al. (2021), but the group of amphenicols includes chloramphenicol, florfenicol, and thiamphenicol, and all are listed as highly important for human medicine.

[75] With the typical application of antimicrobials via feed, the antimicrobials are effectively administered at every feeding time unless nonmedicated feeds are also used in rotation.

those who were obliged to keep track of it for traceability purposes. FAO (2017a) also noted that antimicrobials are often sold with poor or nonexistent labeling.

Trang et al. (2018) noted that, as farmers switched from agricultural crops to shrimp, they often lacked adequate knowledge and experience on applying antimicrobials and used uncontrolled cocktails of antimicrobials mixed with shrimp feed. Luu et al. (2021) noted that shrimp farmers asked various people for advice on antimicrobial use, not many of which appear likely to give reliable information, including the veterinary drug stores (31%), neighbors (28%), veterinary drug companies (22%), feed companies (18%), private veterinarians (3%), local veterinarians (1%), and others (5%). As noted in the following section, these weaknesses are all foci of the developing Vietnamese regulations and particularly the NAP-AMU-AMR.

Vietnamese Regulations on Antimicrobial Use and the NAP-AMU-AMR

As noted above, the available evidence indicates that antimicrobial use in Vietnam has been poorly regulated, with little control over availability, labeling, prescriptions, purchasing, handling, frequency and quantity of use, record-keeping, and reporting. The regulatory system is complex, with overlapping responsibilities from three ministries: the Ministry of Agriculture and Rural Development (MARD), the Ministry of Health, and the Ministry of Industry and Trade. Joffre et al. (2018) and Van Nguyen et al. (2021) noted that the prioritization on high production output often makes farmers ignore existing regulatory limits of using medicine. Until recently, sanctions against such administrative violations have been weak (Joffre et al., 2018). Tan (2021) also noted that noncompliance with regulations is a major concern in Vietnam.

The objectives and outcomes of the 2017 “National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)” (NAP-AMU-AMR) in addition to the 2013 “National Action Plan on Combatting Drug Resistance from 2013 to 2020” closely reflect these concerns. Hue (2021)[76] and FAO (2017a) provide useful reviews of the NAP-AMU-AMR in terms of the objectives and the activities taken. In brief, the overall objective is to mitigate the risk of antimicrobial resistance in public health through controlling the antimicrobial usage in livestock production and aquaculture in Vietnam.

According to Hue (2021), there has been much progress on these activities, and regarding regulations, the following have been recent changes:

- Decree 90/2017/ND-CP—Penalties for Administrative Violations Against Regulations on Veterinary Medicine
- Decree No. 35/2016/ND-CP—On Guidelines for the Law of Veterinary Medicine
- Circular No. 13/2016/TT-BNNPTNT—On Veterinary Drug Management
- Circular No.12/2020/TT-BNNPTNT—On Veterinary Drug Management and Prescription
- Decree 39/2017/ND-CP—Providing the Regulatory Framework for Animal Feeds and Aqua Feeds

Hue (2021) also reported the following regulatory outcomes:

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[76] Dr. Le Thi Hue is from Vietnam’s Department of Animal Health

- The use of antimicrobials for treatment and prevention requires prescription
- There are 24 agents prohibited for use in aquaculture
- Do not allow using antibiotics in aquaculture feed[77]*
- Do not allow selling of raw antimicrobial materials directly to farmers

Nevertheless, according to Decision No. 3609/QD-BNN-TY of August 2021, there are still many activities in the NAP-AMU-AMR that have not been implemented or were inadequately implemented due to the short implementation time or limited budget. In addition, the activities were carried out heterogeneously, in isolation, or the results of the implementation were not shared, so there is currently no comprehensive scientific report on antimicrobial resistance in livestock and aquaculture in Vietnam to provide effective measures to control and prevent antimicrobial resistance. As a result, the MARD has developed the “Plan for Antibiotic Resistance Prevention in the Agricultural Sector in the Period of 2021–2025” to continue the task of preventing antimicrobial resistance in agriculture (Decision No. 3609/QD-BNN-TY). Its goals are (note that the original term “antibiotic” used in the Decision is maintained here):

1. To improve the policy and law enforcement mechanisms on antibiotic and antibiotic resistance management
2. To complete the system and organize the monitoring of antibiotic resistance and the use of antibiotics in livestock, aquaculture, and cultivation
3. To perfect and implement good practices in animal husbandry, aquaculture, and cultivation to minimize infection and spread of drug-resistant microorganisms in the agricultural production process
4. To raise awareness about the use of antibiotics and antibiotic resistance for managers, technical staff, professional workers in the field of agriculture and food, farmers, and consumers
5. To strengthen interdisciplinary cooperation, international cooperation in the research and use of antibiotics, prevention and combat of antibiotic resistance in a one-health approach.

Luu et al. (2021) noted that, from January 2018, it was prohibited to add antimicrobials in animal feed for growth stimulation (Circular No. 06/2016/TT-BNNPTNT of 2016), and Joffre et al. (2018) noted that the revision of the Penalties for Administrative Violations Against Regulations on Veterinary Medicine (Decree 90/2017/ND-CP) means that fines that were previously not considered large enough in comparison to the potential financial benefits of selling or using banned products now fall under the Criminal Procedure Code and entail jail time. As a result, Joffre et al. (2018) expect this type of sanction to induce a change in the behavior of previous offenders.

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[77] From a translation of Decree 39/2017/ND-CP on animal and aquaculture feeds, it appears that the avoidance of antimicrobials in aquaculture (and animal) feeds is an underlying principle or goal, rather than a stipulated regulatory requirement.

Unfortunately, even though all these activities are welcomed and might be expected to reduce antimicrobial use in shrimp farms and improve practices, without robust data collection and availability, it remains impossible to know if these activities have had a significant impact on antimicrobial use in Vietnam.

Antimicrobial residues in shrimp and the United States Import Refusals

Since 2013, the Department of Animal Health (MARD) has carried out monitoring of antimicrobial residues in shrimp products at 199 main aquaculture areas of 37 provinces in Vietnam, with detections varying from 0.3% (i.e., 6 out of 1,692 samples in 2016, and the latest data available) to 1.18% in 2014 (FAO, 2017b), but further details on the types of antimicrobials or the levels of detection were not readily available. Given the concerns regarding microbial residues in exported products, it is considered that testing is widespread in Vietnam, and this is confirmed by anecdotal reports (e.g., in Sóc Trăng[78]), but the results are typically piecemeal and inconclusive, and as stated in Decision No. 3609/QD-BNN-TY of August 2021, there is no comprehensive scientific report on antimicrobial use or resistance in livestock and aquaculture in Vietnam.

One enduring indicator of antimicrobial use is the U.S. Food and Drug Administration's Import Program[79] and their Import Refusal Reports.[80] The FDA's Food Compliance Program Guidance Manual (Program 7304.018)[81] lists the wide range of antimicrobials, pesticides, and other chemicals that are analyzed for residues in imported seafood at the U.S. border. Nitrofuran and chloramphenicol are assessed as individual drug classes, while sulfonamides, trimethoprim, fluoroquinolones, and quinolones are assessed as multiclass residues. In addition, the FDA also refuses imported seafood due to residues of "New Animal Drugs" (code 2860),[82] which include the antimicrobials fluoroquinolone and nitrofuran and two triphenylmethane dyes: gentian violet and malachite green (which are used as fungicides and parasiticides; Zhou et al., 2019). Nitrofuran and chloramphenicol have been banned in Vietnam since 2005 (Nguyen et al., 2016), and the two dyes have been banned since at least[83] 2009 (Decree 15/2009/TT-BNN). Fluoroquinolone has been banned since 2016 (see Table 6 above).

Figure 28 shows the results for imports in the category of "Shrimp and Prawns, Aquaculture Harvested" from Vietnam from January 2014 to the end of March 2022. Although detections of New Animal Drugs have declined since 2014, there has been a recent peak of 12 import refusals in 2021, in addition to 10 refusals for nitrofuran. From January 2017 to the end of March 2022,

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[78] Soc Trang focuses on controlling residues of antibiotic chemicals in seafood production and business (dcs.vn)

[79] https://www.fda.gov/food/food-imports-exports/seafood-imports-and-exports

[80] https://www.accessdata.fda.gov/scripts/ImportRefusals/index.cfm

[81] Available at https://www.fda.gov/media/71452/download

[82] In the United States, the use of malachite green, nitrofurans, fluoroquinolones, or gentian violet as drugs in food-producing animals would require an approved new animal drug application under Section 512 of the Federal Food, Drug, and Cosmetic Act (FFDCA). See https://www.accessdata.fda.gov/cms_ia/importalert_33.html

[83] An initial list of banned chemicals for use in aquaculture was released in 2005 but could not be readily obtained.

there have been 36 refusals for New Animal Drugs, 12 for Nitrofuran, and 7 for chloramphenicol, for a total of 55 import refusals due to the detection of chemicals banned for use in shrimp in Vietnam. Data on the number of samples and therefore the percentage of positive detections (from which a comparison to the MARD data from 2013 to 2016 could be made) were not readily available and would likely be affected by the strategic sampling strategy of the FDA inspection program.

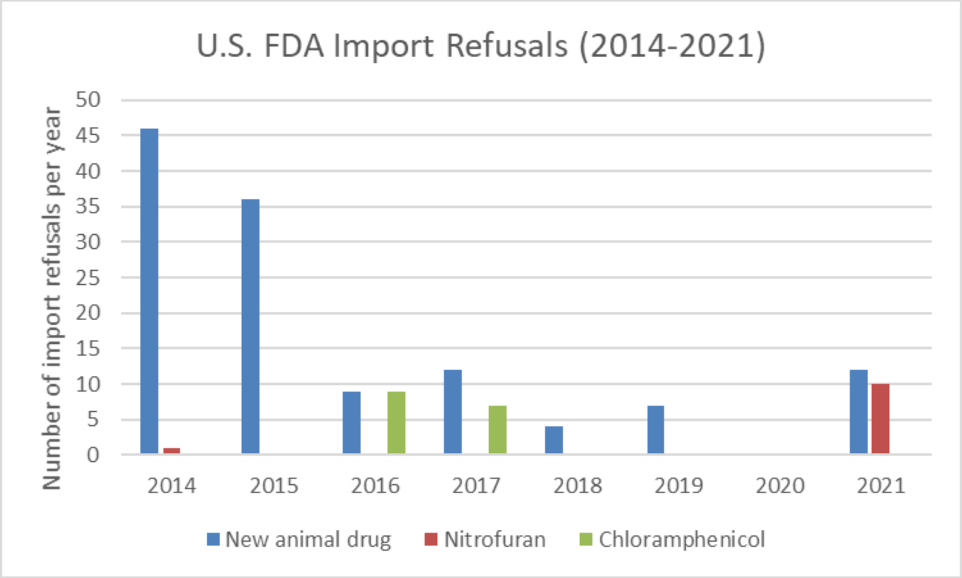

Figure 28: U.S. FDA import refusals for farmed shrimp and prawns from Vietnam from 2014 to end of March 2022.

It is also of interest to note that, while shrimp from Vietnam had the third highest rejection rate in the United States from 2012 to 2021 (behind India and Malaysia), it had the second highest rate in the European Union (also behind India), but the highest in Japan.[84]

In separate studies of imported shrimp, Davis et al. (2021) found no antimicrobial residues in three samples of Vietnamese shrimp in U.S. retail locations. In contrast, Khan and Lively (2020) found that 86% of their seven Vietnamese shrimp samples in the United States had residues of nitrofurantoin, 28.6% tested positive for fluoroquinolone, and 14% (i.e., one of their seven samples) tested positive for malachite green. As noted above, these are all banned for use in aquaculture in Vietnam.

Although it cannot be expected that the activities associated with the 2017–2020 NAP-AMU-AMR would lead to immediate reductions and improvements in antimicrobial use and legality, without specific antimicrobial use data from Vietnam showing otherwise, the FDA import refusals indicate that, at a minimum, it is highly likely that illegal antimicrobial use is continuing in shrimp farms in Vietnam.

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[84] Southern Shrimp Alliance Releases Updated Databases of Refused Shipments of Antibiotic-Contaminated Shrimp Imports in EU, Japan, and U.S. through 2021 - Southern Shrimp Alliance

Antimicrobial Resistance

Compared with antimicrobial use in terrestrial food animal production, the application of antimicrobials in aquaculture provides a potentially wider environmental exposure pathway for drug distribution through water and sediment (Schuur et al., 2020)(Binh et al., 2018), and it is now widely documented that antimicrobial resistance (AMR) genes and resistant bacteria are transported from the aquatic environment to the terrestrial environment and may risk adverse effects on human and animal health (Hossain et al., 2022). The apparent reliance on a variety of antimicrobials to treat or prevent disease outbreak in shrimp farms results in a high potential for the emergence of resistance to multiple drugs (Pham et al., 2018).

Prolonged usage of antimicrobials induces continuous selective pressure on bacterial communities, even at well below minimum inhibitory concentrations, and increases horizontal transfer of mobile genetic components of resistance (Watts et al., 2017). The potential for the development of AMR is considered to be closely related to the scale and frequency of antimicrobial use, so (as discussed above) the primary concern here is in relation to semi-intensive and intensive farms.

Thornbur et al. (2019) noted that the risk of AMR is compounded by the high levels of antimicrobial pollution in the environment surrounding shrimp aquaculture facilities, with growing evidence of the role of farms themselves in this pollution through the release of water and pond sediments, such that inflowing local water sources can also be heavily polluted with antimicrobial compounds and resistant bacteria. But, it must also be emphasized that antimicrobial use in other aquatic species, terrestrial livestock, and human health, along with the manufacture of the pharmaceuticals themselves, can also be responsible for the presence of antimicrobial resistance in the environment, including in shrimp ponds via their influent water (Binh et al., 2018).

Nevertheless, Binh et al. (2018) noted that aquaculture (including fish) was the dominant documented source of several antimicrobials in the environment in Vietnam, including the quinolones enrofloxacin, oxolinic acid, and norfloxacin, the sulfonamide sulfamethoxazole, and trimethoprim (as discussed above, these are banned for aquacultural use in Vietnam and/or listed by the WHO as highly or critically important for human medicine).

Despite the size and international nature of the shrimp industry, there is little information on AMR in shrimp farming environments (Thornbur et al., 2019); although this is largely the case in Vietnam, there are some illuminating studies that are briefly discussed below (bearing in mind the caveat above regarding the variety of sources of antimicrobials and antimicrobial resistant bacteria in the environment).

Dang et al. (2022) evaluated 58 isolates of *Vibrio parahaemolyticus* (the bacteria associated with acute hepatopancreatic necrosis disease [AHPND], also known as early mortality syndrome [EMS]) from shrimp in farms on the eastern coast of the Mekong Delta. Dang et al. noted that, when the disease occurred, antibiotics were used empirically for treatment without laboratory diagnostic support and veterinary supervision, so the susceptibility of the bacterial isolates to nine commonly used antimicrobials was assessed. The authors' results (Figure 29) showed that the isolates were highly resistant (i.e., not susceptible or sensitive) to multiple antimicrobials, such that resistance to only one microbial was relatively rare. Figure 29 shows that all the isolates were resistant to amoxicillin and cephalexin, with a further 94.7% and 87.7% of isolates resistant to sulfadiazine sodium and erythromycin, respectively.

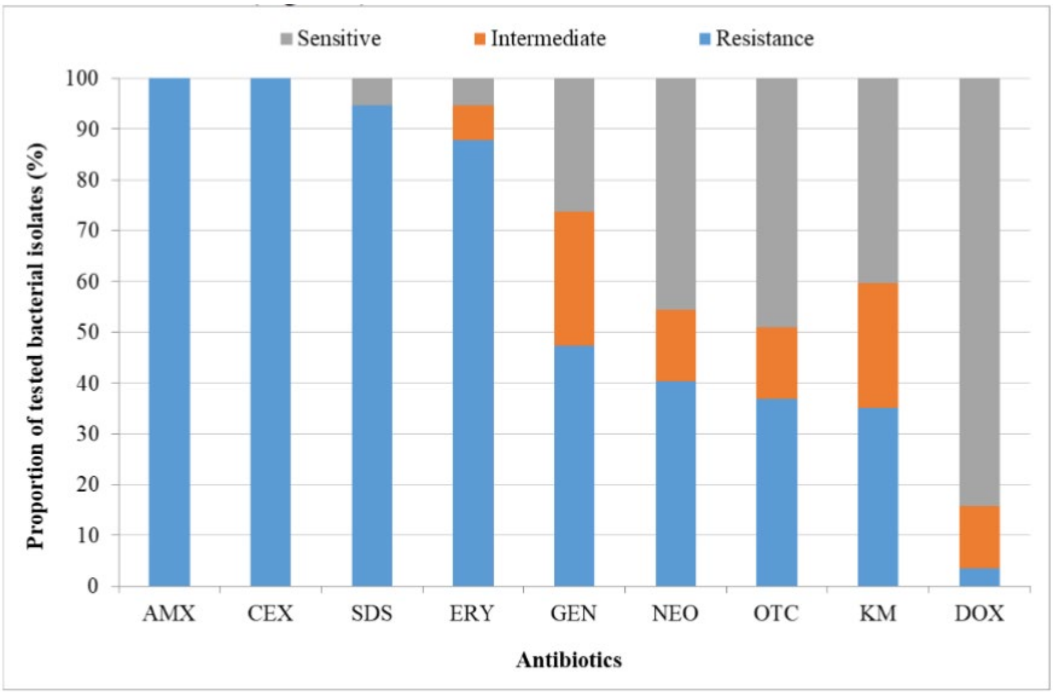

Figure 29: Pattern of antimicrobial resistance among *Vibrio parahaemolyticus* strains isolated from shrimp farms in the eastern Mekong Delta. Note the term "antibiotic" is considered synonymous with "antimicrobial" in this context. Legend: amoxicillin (AMX), cephalexin (CEX), sulfadiazine sodium (SDS), erythromycin (ERY), gentamycin (GEN), neomycin (NEO), oxytetracycline (OTC), kanamycin monosulphate (KM), doxycycline (DOX). Graph reproduced from Dang et al. (2022).

It is important to note again that amoxicillin, erythromycin, neomycin, and kanamycin are classified by the World Health Organization (WHO) as critically important for human medicine. Also, oxytetracycline, cephalexin, sulfadiazine, and doxycycline are classified as highly important for human medicine.

An analysis of antimicrobial multiresistant bacteria and resistance genes in the water and sediment effluent of an intensive shrimp farm by Pham et al. (2018) showed that bacteria with multiresistant traits were isolated, conferring multidrug resistance capacity. In total, 41 resistance genes targeting 9 antimicrobial groups were identified, including those associated with resistance to chloramphenicol and fluoroquinolone—both banned in Vietnam since 2005 (Nguyen et al., 2016). Pham et al. (2018) considered that their results clearly indicated that multiresistant bacteria present in intensive shrimp cultures may disseminate in the natural environment.

Three studies of resistant bacteria in shrimp from retail locations in Vietnam (Yen et al., 2020; Huynh et al., 2019; Tra et al., 2016) showed high levels of resistance in *Vibrio* and salmonella bacteria, with high percentages >80% of *Vibrio* samples against ampicillin (listed as critically important to human medicine by the WHO). Tra et al. (2016) also reported a moderate rate (18.5%) for sulfamethoxazole/trimethoprim (listed as highly important by the WHO). Nearly 60% of salmonella isolates in Yen et al. (2020) were resistant to multiple antimicrobials, including critically important quinolones (14.4–47.8%), and third- and fourth-generation cephalosporins.

Considering the temporal variations in resistance, high incidences or resistance were detected in the early 2000s (e.g., in 2003 samples by Le et al., 2006, quoted in Nguyen et al., 2016), but again it is challenging to understand the recent impacts of the 2017 NAP-AMU-AMR on the occurrence of antimicrobial resistance without readily available monitoring data.

According to Hue (2021), monitoring for antimicrobial resistance regarding shrimp farms has been limited, with no apparent new data since the pilot tests in 2016 referred to above. The FAO has a project in Vietnam (TCP/RAS/3702) from 2019 to July 2021 with the objective: "To enhance knowledge, significantly strengthen overall capacity and regulatory framework at different levels for effective monitoring and mitigation of AMR risk associated with production of 2–3 key aquaculture commodities in the target countries," but there do not appear to be any readily available reports and other evidence of outcomes to date.

Hue (2021) noted a number of challenges to the implementation of the NAP-AMU-AMR:

- AMR surveillance has been limited and has not been carried out regularly
- Lack of equipment for surveillance of antimicrobial resistance
- Lack of qualified personnel to work in laboratories for AMR
- Limited funds for residue and AMR surveillance
- To enforce prescription drug regulations [sic]
- No policy on prudent use of AM
- Gaps in the database in AMU
- Cooperation mechanisms between relevant ministries (MOH, MARD, MOIT, MONRE) are weak.
- There has not been a linkage between the antimicrobial surveillance systems in health care and agriculture.

The 2021 "Plan for Antibiotic Resistance Prevention in the Agricultural Sector in the Period of 2021–2025" has a comprehensive monitoring and sampling plan for a wide variety of pathogens and antimicrobials, and it is hoped that the results of these activities will be made publicly available.

Conclusions and Final Scores

Aquaculture in Vietnam, including shrimp farming, has frequently been associated with high use of antimicrobials. There are no readily available official data on their use, but multiple academic papers indicate that it has been common, primarily in intensive and semi-intensive farms. The types of antimicrobials documented include several listed as highly important and critically important to human medicine by the World Health Organization, and also some banned for use in aquaculture by the Ministry of Agriculture and Rural Development (MARD). Bacteria that are resistant to one or more of the same antimicrobials (including several that are highly and critically important to human medicine) are detected in farmed shrimp and in shrimp farms (water and sediment, etc.). Because of the common practices of water exchange and sludge disposal, shrimp farms are also associated with the detection of antimicrobials and resistant bacteria in the environment (also associated are other types of aquaculture, terrestrial livestock, and municipal sources, along with the manufacture of the pharmaceutical themselves).

The regulatory oversight of antimicrobial use in Vietnam has also been criticized due to the limited control of their availability, purchase, and use by farmers, but in 2017, the Vietnamese government (MARD) launched the "National Action Plan for the Control of Antimicrobial Use and Antimicrobial Resistance in Livestock Production and Aquaculture (2017–2020)," which has the potential to substantially change the patterns of antimicrobial use and resistance in shrimp farms. With some concerns regarding the implementation of the National Action Plan, in 2021, a "Plan for Antibiotic Resistance Prevention in the Agricultural Sector in the Period of 2021–2025" was launched. To date, there have been no comprehensive results generated from either project.

The U.S. Food and Drug Administration's inspections of imported shrimp from Vietnam continue to detect residues of antimicrobials that are banned for use in aquaculture in Vietnam, with 22 import refusals in 2021. For intensive (and semi-intensive) shrimp farms, illegal and critically important antimicrobials are considered to be used in significant and unknown quantities, and antimicrobial resistance to the same chemicals has developed. The final score for Criterion 4—Chemical Use for these systems is Critical. The three remaining production systems assessed here are considered to have a demonstrably low need for chemical use, but data limitations urge some precaution. For improved extensive and rice-shrimp systems, where there is some evidence that chemicals may occasionally be used, the final score for Criterion 4—Chemical Use is 6 out of 10. For mangrove-shrimp systems, there is sufficient confidence that chemicals are used less than once per production cycle, so the final score for Criterion 4—Chemical Use is 8 out of 10. With little evidence to robustly differentiate *L. vannamei* and *P. monodon*, these scores apply to both species in the production systems in which they are assessed.

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—intensive systems

	L. vannamei		*P. monodon*	
Feed parameters	**Value**	**Score**	**Value**	**Score**
Intensive Systems				
F5.1a Forage Fish Efficiency Ratio (FFER)	0.48		1.09	
F5.1b Source fishery sustainability score	1.2		1.2	
F5.1 Wild fish use score		2.4		1.6
F5.2a Protein IN (kg/100 kg fish harvested)	455.8		629.9	
F5.2b Protein OUT (kg/100 kg fish harvested)	178.0		189.0	
F5.2 Net Protein Gain or Loss (%)	–60.9	3	–70.0	2
F5.3 Species-specific kg CO_2-eq kg^{-1} seafood protein	9.60	7	11.22	7
C5 Feed Final Score (0–10)		**3.68**		**3.05**
Critical?	No	Yellow	No	Red

Criterion 5 Summary—improved extensive, rice-shrimp, shrimp-mangrove systems

Note: these systems are considered to be unfed.	*L. vannamei*		*P. monodon*	
C5 Feed Final Score (0–10)	**10.0**		**10.0**	
Critical?	No	Green	No	Green

Brief Summary

Intensive systems have a complete reliance on formulated feed. In contrast, some feed may be used in extensive and rice-shrimp farms and may occasionally be significant, but the bulk of academic studies indicate that shrimp rely primarily on natural organisms in the ponds (particularly in shrimp-mangrove systems) and external feed use is typically zero or minimal. Thus, feed use is not assessed for extensive, rice-shrimp and shrimp-mangrove systems, and the final score for Criterion 5—Feed for both species in these systems is 10 out of 10. Academic studies provide examples of typical feed ingredients with which a general feed formulation can be approximated for each species, but it is noted that data availability for *P. monodon* is particularly poor. Data on the use of fishmeal and fish oil from by-products were provided anonymously from one large feed company. Using the available data, intensive systems are calculated to have a Forage Fish Efficiency Ratio (FFER) of 0.29 and 0.51 for *L. vannamei* and *P. monodon*, respectively (the higher value for *P. monodon* resulting from a greater inclusion level of marine ingredients and a higher feed conversion ratio). With substantial quantities of fishmeal and fish oil coming from unknown species or unknown fisheries (34.9% of the fishmeal and fish oil comes from mixed-fish fisheries in Vietnam, and just over half the total comes from known species but unknown fisheries), the sustainability score for marine ingredients is low (1.11 out of 10 for whole fish sources, and 2.83 out of 10 for by-product sources). Thus, the Wild Fish Use scores for *L. vannamei* and *P. monodon* in intensive systems are 2.35 out of 10 and 1.6 out of 10. respectively.

With estimated average feed protein contents of 38.3% and 40.9% for *L. vannamei* and *P. monodon* feeds, respectively, there is a substantial net protein loss in intensive systems of 60.9% and 70.0% for *L. vannamei* and *P. monodon*, respectively, and scores for Factor 5.2—Net Protein Gain or Loss of 3 out of 10 and 2 out of 10, respectively. The Feed Footprint (Factor 5.3), which is assessed as the feed-related global warming potential of 1 kg farmed shrimp protein, is 9.60 kg CO_2-eq kg^{-1} and 11.22 kg CO_2-eq kg^{-1} for *L. vannamei* and *P. monodon*, respectively, in the feed-dependent systems (scores of 7 out of 10 for both species). When the scores are combined, the final score for Criterion 5—Feed in intensive systems is 3.68 out of 10 for *L. vannamei* and 3.05 out of 10 for *P. monodon*, using the available data.

Justification of Rating

The total feed used in Vietnamese shrimp farms in 2021 was approximately 900,000 mt, of which 70–80% was used for *L. vannamei* and 20–30% for *P. monodon* (Merican, 2021a), but the extent of external formulated feed varies profoundly between the different production systems in Vietnam. For example, according to Nguyen et al. (2022), feed accounted for 53% of the total operating costs of intensive systems, while Lucien-Brun (2021) considered that it was even higher, at 67% of total operating costs.

The large majority of academic studies indicate that feed use is minimal or zero in extensive systems (i.e., improved extensive, rice-shrimp, and shrimp-mangrove); for example, Boyd et al. (2021b), Schuur et al. (2022), Davis et al. (2021), Anh et al. (2020), Burford et al. (2020), Samut and Sang (2020), Dien (2019), Leigh et al. (2020), Jonell and Henriksson (2014), and Ha et al. (2020). Nevertheless, some studies do indicate that feed is occasionally or casually used, such as Vo et al. (2021), Le et al. (2022), and Hai et al. (2020b), but the amount is minimal.[85] For example, Nguyen et al., (2022) estimated that feed accounted for 7% of the total operating

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[85] As noted in the introduction, each production system operates in practice on a spectrum of intensities. In some cases, stocking densities in extensive or rice-shrimp systems may be higher and daily feed may be added, with yields reaching the range of semi-intensive production at 1,500 kg/ha (Hai et al., 2020). This is considered here to be an exception, and would be covered by the intensive system assessment, which includes fed systems operating at higher stocking densities.

costs in extensive systems, and 2% in shrimp-mangrove (noting that, because of the low overall operating costs in intensive and extensive systems, the 7% and 2% values imply quite minor feed use on average). Following the indications in the majority of studies that feed use is zero or minimal in extensive systems (for example, Leigh et al. (2020) note that unfed and minimally fed rice-shrimp systems are dominant), the score for Criterion 5—Feed is 10 out of 10 for extensive, rice-shrimp, and shrimp-mangrove systems, and the remainder of this assessment applies to intensive systems only (which covers the spectrum of semi-intensive to super-intensive production).

There are several feed companies active in Vietnam; for example, CP Vietnam, Grobest, Sheng Long, Uni-President, Cargill, Biomar-Tongwei, and Skretting, of which the first four are considered to supply nearly 80% of shrimp feed (Merican, 2020). According to their websites, each company has a broad range of shrimp feeds for both shrimp species. The specific ingredients and their inclusion levels in each feed are seldom readily available because feed producers consider this information proprietary (Boyd et al., 2021a), and feed formulations may vary from batch to batch depending on the price and availability of ingredients. The feed companies listed have basic information about their feeds on their websites (i.e., a basic list of ingredients[86] and a simple breakdown of the nutrient composition, such as protein and fat content). Each company was contacted with a request for further information, and data on fishmeal and fish oil sources (species and country of origin) and their classification as whole fish or by-product sources was provided anonymously by one major feed manufacturer (pers. comm., Anon, November 21, 2022).

The government's Decree 39/2017/ND-CP of 2017 provides the Regulatory Framework for Animal Feeds and Aqua Feeds and lists the responsibilities of feed producers and importers, mainly regarding registration, product quality, inspection, and testing. Circular 08/2013/TT-BNNPTN of 2013 lists the permissible feeds, feed ingredients, and additives for aquaculture in Vietnam. Although some parts of these regulations relate to antimicrobial use (see Criterion 4—Chemical Use), there does not appear to be anything directly relevant to this assessment of Criterion 5—Feed.

In addition to the proprietary nature of feed formulations, Boyd et al. (2021a) noted a sparsity of feed data for *P. monodon*, and this was quite apparent in the search conducted here. Although the basic lists of primary ingredients available from feed companies were highly similar, the availability of full feed formulations in academic or grey literature was limited to those for *L. vannamei*. Table 7 shows the recent complete or partial formulations for *L. vannamei* in various academic studies[87] from Vietnam (note that none of these formulations differentiated fishmeal or fish oil from whole fish or by-product sources). The feeding trials in the studies referred to here stocked postlarvae or juveniles, and ran for at least 8 weeks (up to

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[86] All the feed companies have many different types of shrimp feed, but typically list the same basic ingredients: fishmeal, fish oil, squid meal, wheat flour, and soybean meal, in addition to various minor ingredients including soybean lecithin, cholesterol, amino acids, vitamins, and minerals.

[87] Academic studies often use multiple feed formulations to test different ingredient types. In each case, only the basic or control feed (which is typically modeled on a commercial feed) was used here.

20 weeks). The feeds used are therefore considered representative of substantial periods of commercial grow-out production cycles (i.e., they are not specific feed formulations for quite small shrimp that would not represent the typical formulations used for the bulk of the growth of shrimp in commercial production).

Table 7: Recent feed formulation data (or partial data for key ingredients) for *L. vannamei* in Vietnam from 10 academic and grey literature studies from 2018 to 2022 (A–J; see footnotes for references). All values are percent inclusions of the total feed. Ingredients in bold are listed in general feed company information.

Ingredient		**Recent feed formulations for *L. vannamei***									
	A	B	C	D	E	F	G	H	I	J	Average
Fishmeal[a]	30.0	27.0	8.0	15.0	27.7	15.0	24.0	18.2	27.0	24.0	**21.6**
Fish oil[a]	2.0	1.5	1.0	1.2	2.5	1.7	2.0	3.0	2.1	2.5	**2.0**
Fish hydrolysates			2.0	2.0							2.0
Squid liver meal	5.0	4.0	6.0	5.0		4.0					**4.8**
Shrimp head meal						4.0					4.0
Krill meal				2.0						8.0	5.0
Soybean meal	28.0	27.0	25.0	34.2	25.9	30.0	20.0		26.1	30.5	**27.4**
Wheat meal	24.9	30.3	31.9	26.3	24.8	20.0	27.2		34.0	29.0	**27.6**
Rice meal					17.1	10.0					13.6
Wheat gluten	4.1			1.0		2.0			5.0		**3.0**
Soybean lecithin		2.0	1.5	1.7		1.5	1.5		2.0	1.0	1.6
Corn protein meal						5.0					5.0
Peanut meal							10.0				10.0
Canola oil									1.3		1.3
Soybean oil				1.0							1.0
Poultry/meat meal		3.0	20.3	5.0			5.0				8.3
Other[b]	6.0	5.2	4.3	5.6	2.0	6.8	10.3		2.5	5.0	**5.3**
Total	100	100	100	100	100	100	100		100	100	n/a

References: A = Nguyen et al. (2018); B = Moniruzzaman et al. (2019); C = Novriadi and Tan (2021); D = Jintasataporn (2022); E = Lucien-Brun (2021); F = Lin et al. (2021); G = Kuhlwein, (2021); H = Boyd et al. (2021a); I = McLean et al. (2021); J = Kesselring et al. (2020).

[a] These are total fishmeal and fish oil values. The use of by-product fishmeal and oil is discussed in Factor 5.1 below.

[b] Typically includes vitamins and minerals, cholesterol, amino acids, and processing agents such as oil carriers and antioxidants.

Although many ingredients are listed in Table 7, the specific ingredients listed by the feed companies (i.e., those in bold) were used as the reference to create a simplified formulation for *L. vannamei* in Table 8. For *P. monodon*, recent total inclusion levels for fishmeal and fish oil (28.9% and 3.0%, respectively) were available from Boyd et al. (2021a), but the inclusion levels of other ingredients were generally not available. Using the same ingredient list specified by the feed companies (i.e., in bold in Table 8), arbitrary equal modifications were made to reduce the two largest ingredients (soy and wheat) to compensate for the higher fishmeal and fish oil content specified for *P. monodon* by Boyd et al. (2021a). Table 8 shows the two simplified and estimated formulations used here. Again, the use of fishmeal or fish oil from whole fish versus by-product is not differentiated here.

Table 8: Estimated feed formulations for *L. vannamei* and *P. monodon* based on the examples in Table 7, the available values for fishmeal and fish oil for *P. monodon*, and the basic ingredients listed by the feed companies. All values are percent inclusions of the total feed.

	Inclusion level (%)	
Ingredient	***L. vannamei***	***P. monodon***
Fishmeal[a]	21.6	28.9
Fish oil[a]	2.0	3.0
Squid liver meal	4.8	4.8
Soybean meal	27.4	23.3
Wheat	27.6	23.4
Wheat gluten[b]	3.0	3.0
Poultry by-product meal[b]	8.3	8.3
Other[c]	5.3	5.3
Total	100.0	100.0

[a] Values are for total fishmeal and fish oil. The proportion coming from by-product sources is discussed in Factor 5.1 below.

[b] Wheat gluten and poultry meals were not listed by the feed companies as basic ingredients, but occurred in multiple formulations in Table 7, so they were included here.

[c] Typically includes vitamins and minerals, cholesterol, amino acids, and processing agents such as oil carriers and antioxidants.

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.

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., do 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. It is acknowledged that the eFCR varies between production facilities and production cycles for a variety of reasons (Chatvijitkul et al., 2017), but average values for each production system are used here.

The estimated 900,000 mt total feed use (Merican, 2021a) and the 987,500 mt total harvest of shrimp in 2021 (GSO, 2021b) give an overall eFCR of 0.91, but as noted above, feed use varies considerably by production system and species. There are several recent eFCR values available for commercial production of *L. vannamei* in Vietnam, but Boyd et al. (2021a) note a sparsity of data from *P. monodon.* Table 9 shows the recent values for intensive systems available in the academic literature (note that, while many other studies mention feed, these references have been selected because they stated a specific eFCR value or provided the production and feed use values from which an eFCR value could be calculated directly). The averages of these values are used here; i.e., 1.19 and 1.54 for *L. vannamei* and *P. monodon*, respectively, in intensive systems.

Table 9: Recent eFCR values for intensive production systems in Vietnam for *L. vannamei* and *P. monodon*.

	Species	
Reference	***L. vannamei***	***P. monodon***
Tu et al. (2021)	1.14 to 1.19	No data
Vo et al. (2021)	1.23	No data
Nguyen et al. (2019)	1.17	No data
Le et al. (2022)	1.22	No data
Nguyen et al. (2021)	1.20	No data
Thakur et al. (2018)	1.29	No data
Vanh et al. (2016)	1.19 to 1.28	No data
Thach et al. (2021)	0.79	No data
Dien et al. (2018)	1.08	1.44
Boyd et al. (2021a)	1.36	1.47
Boyd et al. (2017)	1.0 to 2.0; average 1.33	0.8 to 2.0; average 1.71
Quyen et al. (2020)	1.20	
Average eFCR	**1.19**	**1.54**

The range of eFCRs in Table 9 reflect a wide range of production intensities (e.g., stocking densities, feeding practices, and yields per hectare) that may commonly be referred to as semi-intensive, intensive, and super-intensive. Although it is possible that the lowest intensity on this spectrum may have a better (lower) eFCR as the result of some natural feed production in the ponds, Folorunso et al. (2021) showed that the ratio of semi-intensive to intensive yield of 9.56[88] was highly similar to the ratio of feed inputs between the systems, which was 10, thus indicating similar eFCR values. Therefore, the grouping of semi-intensive production with intensive and super-intensive is considered justified here.

Regarding the use of by-product sources of fishmeal and fish oil, as discussed in Factor 5.1b below, the sources of fishmeal and fish oil used in Vietnam are complex, and typically poorly documented. Information on the use of by-product aquatic ingredients was provided by one major feed company, and these values were compared to the resource use analysis of Boyd et

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[88] That is, the yield of the intensive system in kg shrimp/ha was 9.56 times higher than that of semi-intensive systems.

al. (2021a) (for five countries including Vietnam), which refers to Boyd and McNevin (2018), Chatvijitkul et al. (2017b), and Naylor et al. (2021). The feed company data indicated that 74.2% of the fishmeal and fish oil came from by-product sources, of which 53.2% was from wild fish and 21.1% was from aquaculture by-products (mostly pangasius—*hypothalamus* sp.—with a small amount from farmed salmon—*Salmo salar*). The remaining 25.8% of the total fishmeal and fish oil came from whole fish, for which sources are discussed in Factor 5.1b below.

The resource use analysis of Boyd et al. (2021a) also showed that the use of by-product sources was substantial and quite similar to the feed company data. For example, whereas the estimated inclusion of fishmeal is 21.6% (in Table 8), Boyd et al. (2021a) showed that 5% was from whole fish; i.e., 76.9% of fishmeal came from by-products (compared to 74.2% in the feed company data). The information in Boyd et al. (2021a) was less clear for fish oil (apparently indicating no use of by-product sources). For *P. monodon* feeds, therefore, with some expected similarities between feeds for both species, the 74.2% use of by-products from the feed company is used for all feeds assessed here.

Table 10 shows the calculated inclusion levels and the resulting FFER values associated with the eFCR and fishmeal/fish oil inclusion rates. The standard yield values (i.e., the amount of fishmeal and fish oil obtained per unit of whole fish, from Tacon and Metian [2008]) have been used.

Table 10: Fishmeal and fish oil inclusion levels from whole fish and by-product sources, eFCR values, and calculated FFER values for *L. vannamei* and *P. monodon* in intensive systems.

	Species	
Parameter	***L. vannamei***	***P. monodon***
Fishmeal inclusion level (total)	21.6%	28.9%
Fishmeal inclusion level (whole fish)	5.6%	7.5%
Fishmeal inclusion level (by-product)	16.0%	21.4%
Squid meal (by product)	4.8%	4.8%
Fishmeal yield	22.5%	22.5%
Fish oil inclusion level (total)	2.0%	3.0%
Fish oil inclusion level from whole fish	0.5%	0.8%
Fish oil inclusion level from by-product	1.5%	2.2%
Fish oil yield	5.0%	5.0%
Economic Feed Conversion Ratio	**1.19**	**1.54**
FFER fishmeal	0.30	0.51
FFER fish oil	0.12	0.24
Assessed FFER	**0.29**	**0.51**

From first principles, these values mean that, in feed-dependent intensive systems, 0.29 mt of wild fish are required to provide sufficient fishmeal to produce 1 mt of farmed *L. vannamei*, and because of the higher fishmeal inclusion and higher eFCR, 0.51 mt of wild fish are required to produce sufficient fish meal to produce 1 mt of farmed *P. monodon*.

Factor 5.1b—Source fishery sustainability

According to Holmyard (2019) and Leadbitter (2019), fishmeal (and presumably fish oil) in Vietnam may originate from:

- Fish caught in domestic fisheries and used as whole fish
- Fish caught outside territorial waters and used as whole fish
- Fish imported as whole fish (wild or farmed) for processing, with the processing waste made into fishmeal
- Locally produced farmed fish that are processed, with the processing waste made into fishmeal
- Fish that have exceeded their shelf life at local retail outlets.

In a review of Southeast Asian trawl fisheries, focusing on Thailand and Vietnam, Leadbitter (2019) emphasized the poor documentation of fisheries in Vietnam and the fragmented nature of information about fishmeal and oil production.

In 2021, Vietnam produced 301,000 mt of fishmeal, imported 150,000 mt, and exported 180,000 mt; and in the same year, Vietnam produced 175,000 mt of fish oil, imported 17,000 mt, and exported 84,000 mt (IFFO, 2021). Of the local production, some is from wild fisheries, and some is made from the by-products of Vietnam's large farmed pangasius[89] industry (1.5 million mt in 2020, according to Vietnam's General Statistics Office). Regarding the imports, there is considerable variability in the countries exporting fishmeal to Vietnam; for example, Figure 30 shows substantial differences in the main source countries in 2020 and the first half of 2021 (using data from IFFO, 2021).

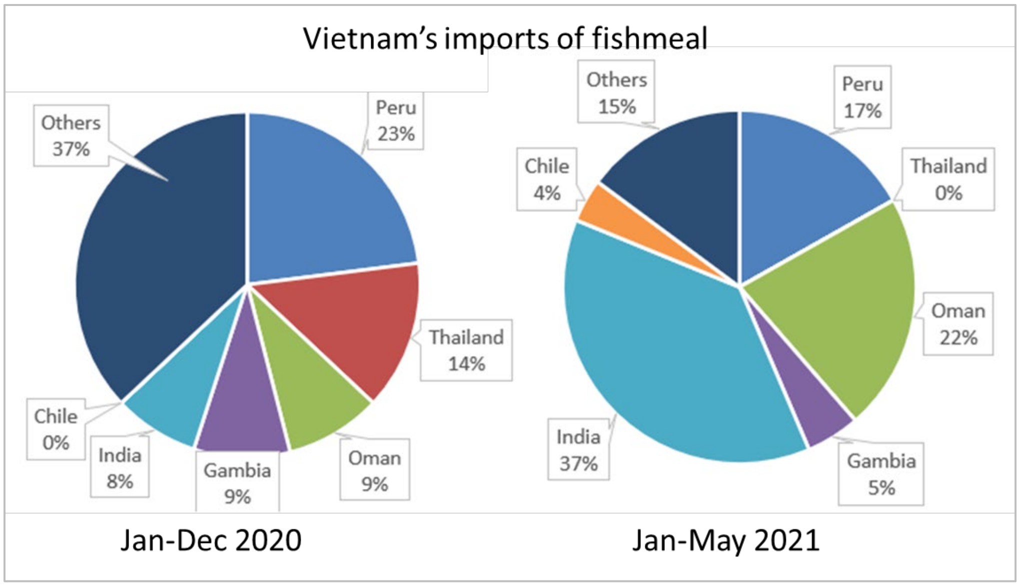

Figure 30: Vietnam's import of fishmeal from January to December 2020 (left) and January to May 2021 (right). The fisheries or species in each country were not specified. Data from IFFO (2021).

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[89] Farmed pangasius catfish (*Pangasius bocourti* and *Pangasius hypophthalmus*) have low yield values that result in 60–70% of the total harvest weight being nonfillet by-products, which can be processed into fishmeal and fish oil (Hien et al., 2022).

Regarding fish oil, IFFO (2021) noted that 55% to 65% of the oil imported into Vietnam in 2020 (17,000 mt total) was salmon oil from Norway or Chile, presumed here to be from farmed salmon by-products. A further 20% to 25% was from sardines in Japan, Oman, Pakistan, and Thailand.

The information provided anonymously by a large feed company in Vietnam highlights the complex nature of the domestic production and imports of fishmeal and fish oil in Vietnam. In the breakdown of the sources used (from January 2019 to January 2022), just over half the total fishmeal and fish oil (50.9%) came from known species/fishery combinations. Therefore, just under half the fishmeal and fish oil came from either known species but unknown fisheries, or unknown species and fisheries. Still, the country of origin was known for >95% of the fishmeal and fish oil (67.5% from Vietnam). It should be noted that 18.8% of the total fishmeal and fish oil came from aquaculture by-product sources (rather than wild fisheries) that are not assessed here for their sustainability score. The majority of the unknown sources was “mixed fish” from Vietnam (sometimes referred to as “trash” fish), which made up 34.9% of the total fishmeal and fish oil. Given the general uncertainty in the overall sources of fishmeal and fish oil in Vietnam (described previously), the specific information from the feed company (albeit from only one company) is used here to calculate the Seafood Watch Source Fishery Sustainability score.

Within the total wild-caught fish meal and fish oil used by the feed company, 5.3% came from fisheries certified to the Marine Stewardship Council[90] (or in a Fishery Improvement Project toward certification) and 30.7% came from fisheries certified to the IFFO RS scheme.[91] These score 6 out of 10 and 4 out of 10, respectively. Unknown sources of fishmeal and fish oil score 0 out of 10 for the Source Fishery Sustainability score, but it is important to understand if significant amounts might come from “critical” fisheries according to the Seafood Watch Aquaculture Standard. Regarding the feed company data, this relates to the 34.9% of the total fishmeal and fish oil that comes from the “mixed fish” fishery in Vietnam.

Regarding the potential for these fisheries to be illegal, unregulated, or unreported (IUU) fisheries, Leadbitter (2019) and Holmyard (2019) noted that estimating the scale of IUU fishing is extremely difficult. According to the IUU Fishing Index,[92] Vietnam scored 2.33 out of 5 in 2021 (where 5 is the worst performance), which is an improvement from 3.16 in 2019. Vietnam ranked 56th out of 152 countries, but 15th out of 20 countries in Asia. The Index notes that Vietnam is vulnerable to IUU fishing (score 4.11 out of 5), has a moderate prevalence of IUU fishing (score 2.43 out of 5, based on a European Union “yellow card” warning issued in 2017,[93] an FAO identification of IUU fishing, and mentions of IUU fishing in media reports), and has made a moderate/good response to the problem (score of 2.0 out of 5). Although the Vulnerability score has not changed from 2019 to 2021, the Prevalence score has improved

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[90] https://www.msc.org/en-us

[91] https://globalmarinecommodities.org/en/iffo-rs/

[92] https://iuufishingindex.net/profile/vietnam

[93] At the time of writing (July 2022), the EU “yellow card” is still active.

from 3.29 to 2.43, and the Response score has also improved from 3.25 to 2.0. The IUU Index states that it provides a measure of the risk of IUU fishing in and by different countries and cannot be used as the basis for computing the incidence of IUU fishing in individual countries or the perpetration of IUU fishing by given fleets. It appears that Vietnam is taking this issue seriously, and VASEP describes the country's action campaign to combat IUU fishing, including the 70-page White Book on Combating IUU Fishing in Vietnam.[94]

Leadbitter (2019) and Holmyard (2019) noted the general risks regarding bycatch of trawl fisheries in SE Asia: as well as undersized/juvenile fish, at-risk species such as turtles, stingrays, and sharks are also taken as feed fish. This concern regarding bycatch, other ecosystem impacts, or other unacceptable practices is noted, but because of the "unknown" nature of the specific "mixed fish" fisheries in the feed company data, it is impossible to quantify. Therefore, although it is considered likely that some of the mixed fish come from demonstrably unsustainable fisheries and there is a risk that some may be IUU, there is insufficient evidence with which to conclude that these sources represent a "critical" concern according to the Seafood Watch Aquaculture Standard. The Source Fishery Sustainability score is therefore 0 out of 10 for the 34.9% of fishmeal and fish oil that come from "mixed fish" in Vietnam.

Considering the other wild-caught ingredients from named species in the feed company data—yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), anchoveta (*Engraulis ringens*), Humboldt squid (*Dosidicus gigas*), South American pilchard (*Sardinops sagax*), and Antarctic krill (*Euphausia superba*)—the weighted average Source Fishery Sustainability score for the whole fish sources (mixed fish, anchoveta, pilchard, and krill) is 1.11 out of 10. For the wild-caught by-product sources (yellowfin tuna, skipjack tuna, Humboldt squid), the weighted average Source Fishery Sustainability score is 2.83 out of 10.

According to the FFER value of 0.29 for *L. vannamei* and 0.51 for *P. monodon*, the score for Factor 5.1—Wild Fish Use is 2.35 out of 10 and 1.60 out of 10 for *L. vannamei* and *P. monodon*, respectively. For reference, the unfed systems would have an FFER value of zero, and a Wild Fish Use score of 10 out of 10.

Factor 5.2—Net protein gain or loss

An analysis of the basic composition information available online for approximately 60 different feeds from the 5 leading feed companies (listed previously) shows a range of total crude protein content from 37% to 45%. The variations generally relate to the farmed species (i.e., the protein content is typically slightly higher for *P. monodon* than *L. vannamei*), feed size (i.e., the protein content is typically higher for smaller feed sizes for small shrimp compared to those for larger shrimp nearing harvest), and the nature/quality of the feed (i.e., specialty feeds for high growth rates or for times of stress, etc. typically have higher protein levels). This range is similar to the 36% to 42% in Tu et al. (2021) for shrimp feeds in Vietnam.

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[94] Combat IUU Fishing (vasep.com.vn)

Considering the higher relative weight gains of larger shrimp, an average of the three largest size categories of each feed for each farmed species was used here to determine an average feed protein content of 40.9% for *P. monodon* and 38.3% for *L. vannamei*. These values are similar to those in some academic studies (e.g., 38.4% in Jintasataporn, 2022), but higher than general values of 35% or 34% in Boyd et al. (2021a) or (2021b), respectively. Using whole-body protein contents for harvested shrimp of 17.8% for *L. vannamei* and 18.9% for *P. monodon* (Boyd et al., 2007), and the eFCR values from above, the following net protein gains or losses can be calculated for each species and production system (Table 11).

Table 11: Values used to calculate net protein gain or loss in intensive shrimp farms.

Parameter	Species	
	L. vannamei	***P. monodon***
Protein content of feed (%)	38.3	40.9
Protein content of whole harvested shrimp (%)	17.8	18.9
Economic Feed Conversion Ratio	1.19	1.54
Total protein INPUT per mt of farmed shrimp (kg)	455.8	629.9
Total protein OUTPUT per mt of farmed shrimp (kg)	178.0	189.0
Net protein gain or loss (%)	**–60.9% loss**	**–70.0% loss**
Seafood Watch Score (0–10)	**3**	**2**

These values show that the reliance on external feed in intensive systems results in a substantial net loss of protein from the feed ingredients to farmed shrimp. This loss is greater for *P. monodon* (a loss of 70.0% of protein and a Factor 5.2 score of 2 out of 10), with the higher feed protein content and higher eFCR, than for *L. vannamei* (a loss of 60.9% and a Factor 5.2 score of 3 out of 10). For reference, the unfed production systems (or those that use minor amounts of feed) would result in a net gain of protein and a score of 10 out of 10 for Factor 5.2.

Factor 5.3—Feed Footprint

Factor 5.3 approximates the embedded global warming potential (kg CO_2-eq including land use change [LUC]) of the feed ingredients required to grow 1 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[95] to estimate the global warming potential of 1 metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood (Table 12). If an individual crop, animal, and/or alternative ingredient is not found in the GFLI database, the aggregated value(s) for the category has been used. The detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Table 12 shows the ingredient categories selected from the GFLI database according to the above methodology for ingredients of unknown origins. Because of the licensing agreement, the specific values for each ingredient from the GFLI database are not reproduced here, but the calculated value per mt of feed for each ingredient is shown.

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

Table 12: Global warming potential values (including land use change) in kg CO_2-eq per mt of feed ingredients and of complete feed for intensive shrimp farms. GWP values from the GFLI database.

Feed Ingredient	GWP (incl. LUC) Category	***L. vannamei***		***P. monodon***	
		Inclusion %	kg CO_2-eq/ mt feed	Inclusion %	kg CO_2-eq/ mt feed
Fishmeal	Fishmeal, from fishmeal and fish oil production, at plant/GLO Economic S	21.6	201.21	28.9	269.21
Fish oil	Fish oil, from fishmeal and fish oil production, at plant/GLO Economic S	2.0	18.63	3.0	27.95
Squid liver meal*	As fish meal above	4.8	31.31	4.8	31.31
Soybean meal	Soybean expeller, from crushing (pressing), at plant/GLO Economic S	27.4	702.43	23.3	597.33
Wheat flour	Wheat flour, from dry milling, at plant/GLO Economic S	27.6	204.07	23.4	173.02
Wheat gluten	Wheat gluten meal, from wet milling, at plant/GLO Economic S	3.0	113.77	3.0	113.77
Poultry meal	Animal meal, poultry, from dry rendering, at plant/RER Economic S	8.3	102.38	8.3	102.38
Other	Total minerals, additives, vitamins, at plant/RER Economic S	5.3	62.34	5.3	62.34
Total kg CO_2-eq/ mt feed			**1,436.16**		**1,377.31**

* GFLI does not provide a listing for squid meal, so it was assessed as fishmeal.

As can be seen in Table 12, the estimated embedded global warming potential of 1 mt of a typical Vietnamese *L. vannamei* feed is 1,436.16 kg CO_2-eq. Considering a whole-harvest shrimp protein content of 17.8% for *L. vannamei* and an eFCR of 1.19, it is estimated that the feed-related global warming potential of 1 kg farmed *L. vannamei* protein is 9.60 kg CO_2-eq. This results in a score of 7 out of 10 for Factor 5.3—Feed Footprint. For *P. monodon*, the estimated embedded global warming potential of 1 mt of a typical Vietnamese *P. monodon* feed is 1,377.31 kg CO_2-eq. Considering a whole-harvest shrimp protein content of 18.9% and an eFCR of 1.54, it is estimated that the feed-related global warming potential of 1 kg farmed *L. vannamei* protein is 11.22 kg CO_2-eq. This also results in a score of 7 out of 10 for Factor 5.3—Feed Footprint.

Conclusions and Final Score

Intensive systems have a complete reliance on formulated feed. In contrast, some feed may be used in extensive and rice-shrimp farms and may occasionally be significant, but the bulk of academic studies indicate that shrimp rely primarily on natural organisms in the ponds (particularly in shrimp-mangrove systems) and external feed use is typically zero or minimal. As a result, feed use is not assessed for extensive, rice-shrimp, and shrimp-mangrove systems, and the final score for Criterion 5—Feed for both species in these systems is 10 out of 10. Academic studies provide examples of typical feed ingredients with which a general feed formulation can be approximated for each species in feed-dependent systems, but it is noted that data availability for *P. monodon* is particularly poor. Data on the use of fishmeal and fish oil from by-products were provided anonymously from one large feed company. Using the available data, intensive systems are calculated to have a Forage Fish Efficiency Ratio (FFER) of 0.29 and 0.51 for *L. vannamei* and *P. monodon*, respectively (the higher value for *P. monodon* resulting from a greater inclusion level of marine ingredients and a higher feed conversion ratio). With substantial quantities of fishmeal and fish oil coming from unknown species or unknown fisheries (34.9% of the fishmeal and fish oil comes from mixed-fish fisheries in Vietnam and just over half the total comes from known species but unknown fisheries), the sustainability score for marine ingredients is low (1.11 out of 10 for whole fish sources, and 2.83 out of 10 for by-product sources). Thus, the Wild Fish Use scores for *L. vannamei* and *P. monodon* in intensive systems are 2.35 out of 10 and 1.6 out of 10, respectively.

With estimated average feed protein contents of 38.3% and 40.9% for *L. vannamei* and *P. monodon* feeds, respectively, there is a substantial net protein loss in intensive systems of 60.9% and 70.0% for *L. vannamei* and *P. monodon*, respectively, and scores for Factor 5.2—Net Protein Gain or Loss of 3 out of 10 and 2 out of 10, respectively. The Feed Footprint (Factor 5.3), which is assessed as the feed-related global warming potential of 1 kg farmed shrimp protein, is 9.60 kg CO_2-eq kg^{-1} and 11.22 kg CO_2-eq kg^{-1} for *L. vannamei* and *P. monodon*, respectively, in the feed-dependent systems (scores of 7 out of 10 for both species). When the scores are combined, the final score for Criterion 5—Feed in intensive systems is 3.68 out of 10 for *L. vannamei* and 3.05 out of 10 for *P. monodon*, using the available data.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- 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—All production systems

	L. vannamei		***P. monodon***	
Escape parameters	**Value**	**Score**	**Value**	**Score**
F6.1 System escape risk	1		1	
F6.1 Recapture adjustment	0		0	
F6.1 Final escape risk score		1		1
F6.2 Competitive and genetic interactions		6		7
C6 Escape Final Score (0–10)		**3**		**4**
Critical?	No	Red		Yellow

Brief Summary

Farmed shrimp can escape from ponds in various ways, including during water exchanges, harvesting, and pond cleaning, from hatcheries, and during transport, and although there are no specific data, the dominant cause of large-scale escapes is considered to be flooding. The Mekong Delta, by its hydrographic nature, is prone to flooding, and the loss of large areas of farms during heavy rains has been reported. The region is also highly vulnerable to further flooding from sea level rise, increasingly severe weather, and land subsidence. The escape risk is therefore high (a score of 1 out of 10 for Factor 6.1). *L. vannamei* is nonnative in Vietnam but there is no evidence of the species establishing viable populations anywhere in the world, so it is concluded that *L. vannamei* is likely to be present in the wild in Vietnam though not established, and highly unlikely to establish viable populations (a score of 6 out of 10 for Factor 6.2). *P. monodon* in farms come from a combination of wild-caught (70%) and farm-raised domesticated broodstocks (30%). Those from wild-caught broodstocks have minimal genetic differentiation or risk of competitive interactions if they were to escape. Similarly, although domesticated farm-raised stocks have been shown to be genetically distinct and to have selected characteristics such as higher growth rates, the genetic diversity of wild *P. monodon* populations means that there is limited potential for competitive or genetic impacts if these stocks were to escape into the wild. This results in a weighted score of 7 out of 10 for Factor 6.2 for *P. monodon*. The final scores for Criterion 6—Escapes are 3 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*, and apply to all production systems.

Justification of Rating

Factor 6.1—Escape risk

It is to be expected that shrimp farmers will take comprehensive measures to reduce the risk of escape of their stocks, yet farmed shrimp can escape from ponds in various ways, including during water exchanges, harvests, and pond cleaning, as a result of floods, from hatcheries, during transport, and by intentional releases (De Silva et al., 2021 and references therein). There are apparently no readily available data on escape events or on escape quantities (either in numbers or weight) in Vietnam.

Regarding water exchanges, figures for exchange frequencies and volumes in different production systems are highly variable but are considered on average to be >3% per day (see Criterion 2—Effluent). It is not always clear whether exchanges occur with the external environment beyond the farm or with reservoirs and treatment ponds on the farm site, and this has a considerable bearing on the escape risk. Nevertheless, it is anticipated that, although best practices are likely used regarding the use of single or multiple screens or other capture devices during water exchanges or harvest, these are inevitably imperfect and prone to human error.

Cristoplos et al. (2017) noted that shrimp farmers in Vietnam have experienced recurrent losses when unpredictable and extreme weather events such as unusually heavy rains or storms have flooded ponds, enabling shrimp to escape; for example, Typhoon Damrey in 2017 destroyed about 1,475 ha of shrimp ponds, resulting in the loss of 2,949 mt of shrimp (Folorunso et al., 2021) and other examples can be found such as Typhoo Wutip in 2013 (Cristoplos et al., 2017). Because of its low elevation, the Mekong Delta is fundamentally prone to flooding, but its hydrology has also been substantially altered by extensive dikes and sluice gates to control and supply water for the different needs of agriculture and aquaculture crops in different areas (Tran et al., 2019)(Le et al., 2018), so understanding the flood risks to shrimp ponds is challenging.

Di Giusto et al. (2021) consider that the Mekong Delta faces a dire combined threat from climate change (increasingly volatile weather, sea level rise, storm surge) and land subsidence (exacerbated by groundwater extraction for shrimp farming), which is already exacerbating flooding intensity and extending the flooding season. Nevertheless, although particularly severe floods were reported in 2020,[96] the frequency of substantial shrimp escape events (from flooding or any other reason) remains uncertain. The scale of any losses from hatcheries or from deliberate releases is even more uncertain.

Although *L. vannamei* has been detected in the wild beyond its native range in several countries (the United States, Thailand, Venezuela, Brazil, Puerto Rico, Mexico, the Philippines, and India; De Silva et al., 2021 and references therein)(CIBA, 2019), there is no evidence of this species being caught or otherwise detected in significant numbers in the wild in Vietnam; however, this

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[96] https://www.cnn.com/2020/10/21/asia/vietnam-floods-weather-intl-hnk/index.html

may be due to limited sampling and/or reporting of its occurrence. In the event of an escape event, there is no evidence or data on any recapture efforts or their success, and no recapture adjustment is applied here.

Overall, there is little evidence with which to robustly assess the escape risk of shrimp from farms in Vietnam, and there appears to be limited monitoring of escaped shrimp in the wild. The production systems appear inherently vulnerable to large escape events or trickle losses, and also the farm locations in low-lying river deltas are vulnerable to flooding events. Thus, it is considered that there is a high risk that farmed shrimp will enter the wild as a result of escapes from shrimp farms, and the score for Factor 6.1—Escape Risk is 1 out of 10.

Factor 6.2—Competitive and genetic interactions

L. vannamei

L. vannamei is nonnative to Vietnam and was first legally introduced into Vietnam from Taiwan in 2001 (De Silva et al., 2021). Only 10 years later, Liao and Chien (2011) considered *L. vannamei* to be the world's most widely cultured alien crustacean, and it now accounts for approximately 60% of Vietnamese shrimp aquaculture by weight. As noted in Factor 6.1, *L. vannamei* shrimp has been detected in the wild in several countries beyond its native range, but little is known about its ecological impacts; for example, De Silva et al. (2021) note that whether it will become predator or prey (or pathogen carrier) remains to be studied. The presence of *L. vannamei* in the wild may present competitive ecological risks for Vietnam's native shrimp species, including the commercially relevant *P. monodon*, though genetic risks are considered negligible, given the lack of other *Litopenaeus* species in Vietnam and the significant failures in interspecific hybridizations of penaeid shrimps (Perez-Velazquez et al., 2010)(Ulate and Alfaro-Montoya, 2010).

Regarding ecological impacts, the primary risks involve competition for food, predation, and acting as pathogen reservoirs (the latter is discussed in Criterion 7—Disease). Although no research specific to Vietnam could be found, academic studies have 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). In addition, in laboratory studies, researchers found 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 has confirmed this previous result, with the species appearing to be nonselective in its prey choice and faster in identifying and consuming food, despite size class differences (Chanavich et al., 2016).

But in this same study, the competitive advantage of *L. vannamei* compared to *P. monodon* was mostly lost when the ratio of *L. vannamei* to *P. monodon* was 1:2 or 1:3, indicating that the competitive risks of *L. vannamei* escapes may be density-dependent (Chanavich et al., 2016). In addition, when paired with a common and widespread native crab, *Charybdis affinis*, in food competition contests, not only did the crab win every time, 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). Overall, it is likely that *L. vannamei* is able to survive in Vietnamese waterways, given its wide range of tolerance to environmental conditions (salinity, pH, temperature, etc.) and its ability to find and consume food in the wild in environments (Chanavich et al., 2016)(Panutrakul et al., 2010)(Senanan et al., 2010). Regarding reproduction, although Senanan et al. (2010) found evidence of gonadal development in captured escapees (in Thailand), they also stated that it is "premature to conclude that the persistence of *L. vannamei* [in Thailand] is because of natural reproduction."

Analyzed together, this research is inconclusive regarding the true impact of escapees in the wild, and even if, to date, there is no indication of established populations, the consequences of the massive translocation of this species remain uncertain (Fernández de Alaiza García Madrigal et al., 2018). Recent studies continue this uncertainty; for example, using the Aquatic Species Invasiveness Screening Kit (AS-ISK), Ruykys et al. (2021) conducted a risk assessment of 30 nonnative species in Vietnam and concluded that *L. vannamei* was a high risk of becoming invasive in Vietnam, and a slightly higher risk when climate change aspects were included. In contrast, Yen (2021) but did not attribute any specific impacts to its presence in Vietnam as an alien species or include it in a list of the most important invasive alien species in Vietnam.

Overall, a review of literature surrounding this topic revealed that there is no evidence of nonnative *L. vannamei* establishing viable populations anywhere in the world, and it is concluded that *L. vannamei* is likely to be present in the wild in Vietnam, though not established and highly unlikely to establish viable populations. Thus, the final score for Factor 6.2—Competitive and genetic interactions is 6 out of 10.

P. monodon

For native species, the impact risk of competitive and genetic interactions in the environment due to escapes is driven partly by the phenotypic traits of farm stock, so an examination of the source of stock (in the form of broodstock) is required. As discussed in Criterion 8X—Source of Stock, a combination of farm-raised and wild-caught *P. monodon* broodstocks is currently used in Vietnam. These are discussed separately here:

- Farm-raised broodstock

It has been the intention of *P. monodon* breeding programs to use genetically diverse founder broodstocks to eliminate inbreeding effects, ensure sustainable seed supply, and facilitate genetic upgrading for selective breeding (Wong et al., 2021). In their summary of domestication efforts in Thailand, McIntosh and Jeerajit (2021) noted that founder populations had been collected from around the Pacific (including Fiji, Western Australia, the Andaman Sea, and the east coast of Africa). Similarly, the Moana Marine Biotech facility in Vietnam claims the broadest geographical selection of founder stock for any shrimp breeding program in the world.[97] McIntosh and Jeerajit (2021) then note that the Thai program now has at least eighth-generation domesticated broodstocks, with selection for growth, stress and disease resistance, and high survival. The Moana program has fourteen generations at its base in Hawaii. McIntosh and Jeerajit (2021) noted that the growth rate of domesticated *P. monodon* had increased by 35% since 2014, but it is uncertain if this would confer any competitive advantages to domesticated *P. monodon* in the wild.

Perhaps not surprisingly, the analysis of population structure and genetic diversity in *P. monodon* broodstocks collected from the wild and from aquaculture sites by Wong et al. (2021) revealed that the domesticated populations were unequivocally diverged from the wild-caught populations, with clear genetic differentiation between the wild and domesticated broodstocks. Nevertheless, Wong et al. (2021) showed that wild *P. monodon* populations in the Indo-Pacific region have high within-population genetic variation, which is considered to limit the risk of genetic impact from escaping farmed cohorts (compared to, for example, the many discrete populations of wild Atlantic salmon into which escaping farmed salmon have been associated with genetic introgression; Grefsrud et al., 2021a,b).

In summary, for farm-raised *P. monodon* broodstock, there is clear genetic differentiation and evidence of selected characteristics such as increased growth rate, but given the diverse genetic structure of wild populations, the potential for genetic introgression is uncertain (and there is no evidence of such). Similarly, although some competition, predation, disturbance, or other impacts to wild species may occur, they are not currently considered likely to affect the population status of the wild species. The score for Factor 6.2—Competitive and genetic interactions for farm-raised *P. monodon* is 4 out of 10.

- Wild-caught broodstock

Postlarvae from wild-caught broodstock are first-generation hatchery raised and exhibit high genetic similarity to wild conspecifics, so the likelihood of genetic impacts if they were to escape and interbreed with wild populations is quite low, particularly noting the findings of Wong et al. (2021) on the high genetic diversity in wild *P. monodon* populations. Regarding competition, there is no information available to quantify the potential impacts; information about resource availability and regional stock statuses of *P. monodon* in Vietnam would be useful for estimating the potential competitive effects of escaped shrimp, but no such information could be found. Overall, wild-caught *P. monodon* broodstock is unlikely to present significant competitive or genetic risks to wild populations, given its native status and high genetic similarity to wild conspecifics, and the score for Factor 6.2—Competitive and genetic interactions is 8 out of 10.

Combining the Factor 6.2 score for both sources of *P. monodon* broodstock

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[97] http://www.moananinhthuan.com/en/tai-sao-moana-doc-dao/

Because there is little possibility for seafood buyers or consumers to determine the source of *P. monodon* broodstock, a single score for Factor 6.2 must be generated. In Criterion 8X, it is estimated that approximately 70% of *P. monodon* broodstock are wild-caught and 30% are farm-raised, therefore (based on the scores of 8 and 4 for wild-caught and farm-raised broodstocks, respectively), the weighted final score for Factor 6.2 is 7 out of 10.

Conclusions and Final Score

Farmed shrimp can escape from ponds in various ways, including during water exchanges, harvesting, and pond cleaning, from hatcheries, and during transport, and although there are no specific data, the dominant cause of large-scale escapes is considered to be flooding. The Mekong Delta, by its hydrographic nature, is prone to flooding, and the loss of large areas of farms during heavy rains has been reported. The region is also highly vulnerable to further flooding from sea level rise, increasingly severe weather, and land subsidence. The escape risk is therefore high (a score of 1 out of 10 for Factor 6.1). *L. vannamei* is nonnative to Vietnam but there is no evidence of it establishing viable populations anywhere in the world, and it is concluded that *L. vannamei* is likely to be present in the wild in Vietnam, though not established and highly unlikely to establish viable populations (a score of 6 out of 10 for Factor 6.2). *P. monodon* in farms come from a combination of wild-caught (70%) and farm-raised domesticated broodstocks (30%). Those from wild-caught broodstocks have minimal genetic differentiation or risk of competitive interactions if they were to escape. Similarly, although domesticated farm-raised stocks have been shown to be genetically distinct and to have selected characteristics such as higher growth rates, the genetic diversity of wild *P. monodon* populations means that there is limited potential for competitive or genetic impacts if these stocks were to escape into the wild. This results in a weighted score of 7 out of 10 for Factor 6.2 for *P. monodon*. The final scores for Criterion 6—Escapes are 3 out of 10 for *L. vannamei* and 4 out of 10 for *P. monodon*, and apply to all production systems.

Criterion 7: Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- 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—*L. vannamei* and *P. monodon*

Risk-Based Assessment

Pathogen and parasite parameters	**Score**	**Critical?**
Intensive systems: C7 Disease Score (0–10)	4	No
Improved extensive systems: C7 Disease Score (0–10)	6	No
Rice-shrimp systems: C7 Disease Score (0–10)	6	No
Shrimp-mangrove systems: C7 Disease Score (0–10)	6	No

Brief Summary

Shrimp farming in Vietnam has been plagued with several severe viral disease epidemics, and these and other diseases caused by bacteria, parasites, and protozoans are dominant concerns for farmers. Although biosecurity characteristics and practices are considered likely to be highly variable among production systems and individual farms, it is clear that pathogens are commonly discharged from farms in wastewater, sediment, and sludge, and enter neighboring farms in influent waters. The development of specific pathogen-free (SPF) breeding lines and postlarvae has been important in mitigating some of the pathogens of highest concern, but shrimp continue to be vulnerable to infection during grow-out in all but the most contained and biosecure facilities. Intensive production systems with high stocking densities are typically considered more vulnerable to disease outbreaks (supported by reports of higher antimicrobial use in these systems), but with more common use of water treatment and recirculation, they have the potential for greater biosecurity compared to the low stocking densities but simpler practices of extensive and shrimp-mangrove systems in the thousands of small family farms in Vietnam. Although there are regulations relating to fish and shrimp health and biosecurity in aquaculture in Vietnam, academic studies indicate that there are limited resources for enforcement, and farmers may still choose to dump infected water or not report disease outbreaks to neighboring farms or the authorities. Despite clear evidence of the discharge of pathogens from farms and the presence of many of the same pathogens in the environment and wild shrimp (e.g., in wild broodstock), it remains challenging to determine what impacts, if any, these pathogens have on wild shrimp. Without clear data or evidence with which to understand the impacts of farm pathogens on wild shrimp, the risk-based assessment has been used. Although all systems are considered at least partly open to the introduction and discharge of pathogens, the greater risk of disease in intensive systems results in a final numerical score for Criterion 7—Disease of 4 out of 10 for intensive systems. With lower density and less likelihood of pathogen amplification, the score for extensive, shrimp-rice, and shrimp-mangrove systems is 6 out of 10. Without clearly different risk characteristics between the two species of farmed shrimp, the score applies to both *L. vannamei* and *P. monodon*.

Justification of Rating

Disease on farms

It is widely reported that diseases associated with bacteria, viruses, parasites, and protozoans (and their prevention, detection, treatment, and the resulting economic losses) are a focal point of shrimp farming in Vietnam (Arulmoorthy et al., 2020). Shrimp farming globally has been plagued with several severe viral disease epidemics (Boyd et al., 2021a), and in a study of stakeholder perceptions toward sustainable shrimp aquaculture in Vietnam by Xuan et al., (2021), disease outbreaks were the dominant concern (Figure 31).

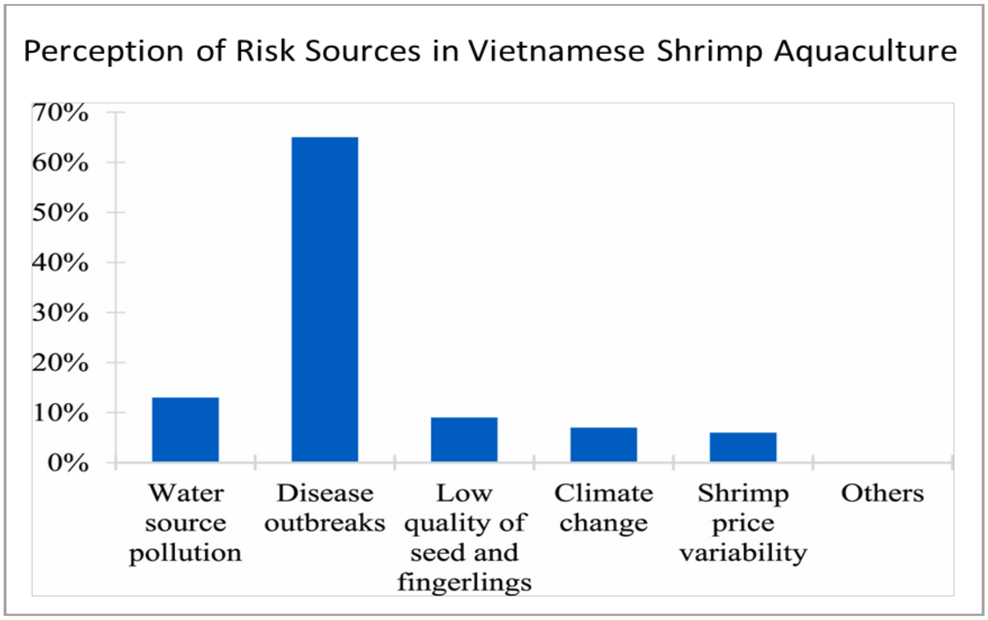

Figure 31: Perceptions of risk sources in Vietnamese shrimp aquaculture. Image reproduced from Xuan et al., (2021).

Water source pollution and disease outbreaks have similarly been reported as the two main reasons for high crop failure rates in Vietnam in recent years (Xuan et al., 2021, referencing DAH, 2017), and Nguyen et al. (2020) consider that disease outbreaks have been the primary cause of shrimp production loss in Vietnam during the last two decades. Nevertheless, it is also important to point out that both diseases and their countermeasures are highly variable, and even though some modern farms have quite high biosecurity, it is clear that this is not the case across the thousands of family farms in Vietnam. The apparently regular use of antimicrobials in intensive farms (see Criterion 4—Chemical Use) supports the common perception that disease outbreaks are likely to be more common there than in lower intensity systems (extensive, rice-shrimp, and shrimp-mangrove).

Despite the accepted challenge of disease, there are few publicly available data sources on their detection or impact on shrimp farms in Vietnam. In 2018, Vietnam launched the Animal Health Information System (VAHIS)[98] but it does not appear to be publicly accessible. The World Organization for Animal Health (WOAH; formerly OIE) reports detections of a small number of pathogens listed in their Aquatic Animal Health Code in quarterly and annual country-level reports.[99] The latest annual report for Vietnam[100] (issued January 2022) shows that white spot syndrome virus (WSSV) and acute hepatopancreatic necrosis disease (AHPND) were detected in both *L. vannamei* and *P. monodon* in every month of 2021 but were limited to "some small-scale farms with low biosecurity control." The remaining five pathogens listed by OIE have never been detected in Vietnam, so this data source, though useful, does not provide data on the range of other pathogens associated with disease in shrimp farms.

It is clear from the general literature that a variety of pathogens that cause (potentially high) mortality to shrimp are common in shrimp farms in Vietnam, but for the sake of brevity, the specific bacterial or viral pathogens are not elaborated upon here. (This information is readily available elsewhere; for example, Arulmoorthy et al., (2020) provide a comprehensive review of viral diseases[101] in cultured Penaeid shrimp.) The focus instead is on the sources and amplification of pathogens in farms, and the transmission dynamics of the farming systems regarding the risk to wild shrimp.

Pathogens can enter farms in influent water (during pond filling or water exchanges) or with postlarvae/juveniles stocked into the ponds, as well as by many other potential routes, including workers or equipment, wildlife, or feed. Pathogens in influent waters are commonly a circular challenge, and Khiem et al. (2022) consider that, once a pond becomes infected, it is difficult to prevent spread of the disease to nearby shrimp farming areas. For example, wastewater (plus sediment and sludge) from shrimp farms is often discarded directly into the same water body that serves as source water for other farms, which can lead to severe and persistent disease outbreaks and economic losses to the farmers (Ngoc et al., 2021)(Nguyen et al., 2020)(Xuan et al., 2021). Although treatment (e.g., disinfection) of both influent and effluent water is increasingly common (e.g., Boyd et al. [2021a]), it is not clear how often it is done in practice.

Regarding postlarvae/juveniles for stocking, according to Emerenciano et al. (2022), the use of specific pathogen-free (SPF) broodstock has provided the central pillar to mitigate disease risk for those pathogens that posed the greatest disease risk to shrimp farming. Indeed, the initial driver for domestication was the industry's need for commercial broodstock free of certain

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[98] https://vahis.vn/home/login.aspx

[99] Regional Aquatic Animal Disease Report - OIE - Asia (woah.org)

[100] Regional Aquatic Animal Disease Report from 2021 - OIE - Asia (woah.org)

[101] Viral diseases are the major problem to the shrimp aquafarmers, which cause severe economic loss globally (Arulmoorthy et al., 2020).

pathogens commonly found in the wild sources. As such, specific disease risks could be mitigated, if not wholly removed, by breeding companies developing SPF domesticated breeding lines maintained in highly biosecure facilities. Nevertheless, although SPF lines provide an ideal starting health status for farming, these stocks are still vulnerable to pathogen infection once in the ponds, and Emerenciano et al. (2022) consider that it is increasingly challenging to maintain pathogen freedom through the production tiers from broodstock through hatcheries and the grow-out cycle in ponds.

Disease management

An overview of the animal health system in Vietnam is shown in Figure 32, and it is clear that there are substantial measures in place, but their efficacy remains uncertain, particularly regarding ongoing disease challenges.

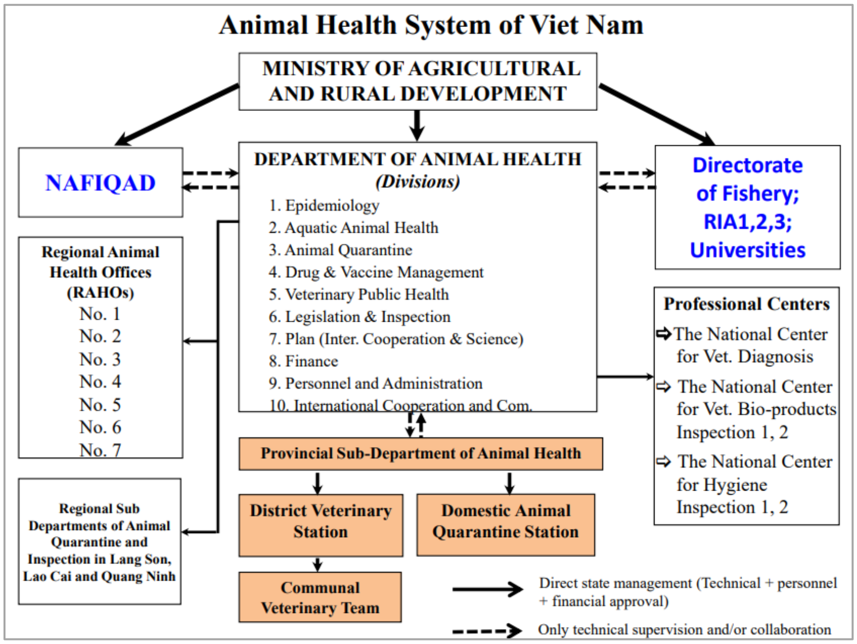

Figure 32: Overview of the animal health system in Vietnam. NAFIQAD—National Agro-Forestry-Fisheries Quality Assurance Department; RIA—Research Institute for Aquaculture. Image reproduced from FAO (2017a).

According to the regulations on the prevention and combatting of aquatic animal epidemics (Circular 17/2014/TT-BNNPTNT of 2014), and specifically regarding the discharge of pathogens in water or sludge, it is the responsibility of shrimp farmers to:

- Ensure that their aquaculture system is designed in a way to ensure hygiene, ease of disinfection, and efficiency of combatting disease
- Have a waste and wastewater treatment area; when aquatic animals contract disease, the water must be processed in a way to ensure that it is totally free from disease before discharge to the environment.

Joffre et al. (2018) noted that, although these rules exist for water treatment and disease control, they are not properly enforced by local extension services because of a lack of capacity compared to the number of farms. In the event of a disease outbreak, farmers must report to the local Department of Agriculture and Rural Development (DARD) for diagnostics, to decide on treatment. Quyen et al. (2020) noted that, when a disease is reported, the authorities took water samples regularly for diagnosis and announced the results widely to help farmers monitor and adjust their actions; however, Joffre et al. (2018) noted that complying with this rule to report disease outbreaks increases farmers' operational costs (and farmers might lose the benefit of an early harvest in the event of mass mortality in the pond); therefore, farmers rarely report diseases to DARD.

Similarly, Van Nguyen et al. (2021) noted that few shrimp farmers would actually contact the various government officers when they identified diseases in shrimp ponds, and would bear in mind that the government involvement would be a time-consuming process without clear benefit. Thus, rather than involving third parties, farmers tend to hide the disease or try to deal with it themselves; hence, there were few warnings of disease, and farmers were discharging contaminated water and spreading the pathogen(s) (Van Nguyen et al., 2021)(Quyen et al., 2020). Joffre et al. (2018) also noted that the administration is not inclined to fine a farmer who is already struck by a disease in their pond and already facing financial issues.

Since July 2021, DARD in Cà Mau has conducted weekly water quality monitoring in waterways at nine locations across the province (see Criterion 2—Effluent), and the sampling parameters include total *Vibrio* bacteria and *Vibrio parahaemolyticus* in colony forming units (CFU) per ml of water. With a water quality limit "suitable for aquaculture" of 1 x 10^3 CFU/ml, of total V*ibrio*, the results for 2021 show a range of values from <1 to 7.9 × 10^3 CFU/ml. Although the 2021 report notes a small number of observation points that exceeded the limits, it considered that the reason may be that some households have not complied with the regulations on pond/lagoon sludge and have discharged pollutants into the general water source of the area, leading to increased microbial density.

Joffre et al. (2018) note that inefficient quality control for postlarvae (PLs) is apparent, with non–disease-free PLs present on the market; in the Mekong Delta, the authors estimated that the infection rate was around 54%, and that only 38.5% of the PLs were tested for disease by hatcheries and PL suppliers before stocking. As a result, farmers do not trust the certification of disease-free PLs, which is supposed to guarantee the quality of the product for buyers. Joffre et al. did note that the regulatory framework for the control of PL quality and the operation of hatcheries is well designed (with standard procedures, control stations at provincial and district level, and a dedicated department within provincial DARDs), but they considered that the underlying reason for the gap between existing rules and their enforcement lay in limited infrastructure, in addition to limited knowledge and capacity in the responsible departments in DARD. Joffre et al. (2018) referenced Hai et al. (2016), and it is uncertain if this situation has changed since 2016, but Joffre et al. considered that a major investment to upgrade the capacity of the institutions in charge of quality control was needed.

Impacts to wild shrimp

Khiem et al. (2022) noted that, once a pond becomes infected, it is difficult to prevent the spread of the disease to nearby shrimp farming areas. This demonstrates the transmission of viable pathogens via shared water resources, and therefore the potential transmission to wild shrimp, but in contrast to the amount of information available regarding disease pathology on farms, there is limited research or evidence to indicate whether shrimp farms in Vietnam are exerting negative disease pressures on wild populations of shrimp and other crustaceans. Nor is there evidence to suggest that they are not. A particular challenge is to understand the differences in the pathogen dynamics in the various shrimp farming systems (with highly variable shrimp stocking densities, water quality, and other stressors, etc.) compared to the dynamics of the same pathogens in wild shrimp.

Most of the relevant diseases are caused by the opportunistic microorganisms that are part of the microflora and fauna of the penaeid shrimp (Arulmoorthy et al., 2020), and pathogens such as white spot syndrome virus (WSSV) and yellow head virus (YHV) are endemic in most shrimp producing countries, including Vietnam, with quite broad host ranges (Zwart et al., 2010)(Dhar et al, 2022). Studies on the detection of various pathogens in wild shrimp are often associated with the search for pathogen-free sources of wild *P. monodon* broodstocks and show the common detection of various pathogens associated with diseases in shrimp farms; e.g., Anshary et al. (2017) in Indonesia, Orosco et al. (2017) in the Philippines, Hamano et al. (2017) in Thailand, Dutta et al. (2015) in India, and Arbon et al. (2022) in Australia. There is no implication in these studies of a concern for the wild shrimp populations from the detection of these pathogens.

The only demonstrated impact to wild shrimp is from the 1990s, when an IHHNV outbreak resulted in significant losses in both farms and wild fisheries for the blue shrimp (*P. stylirostris*) in Mexico (Lightner, 2011). As noted previously, shrimp farming has been plagued with several severe viral disease epidemics, and Lee et al. (2022) note that new viral diseases occur rapidly. Existing diseases can evolve into new types; therefore, there is apparently an ever-present risk that pathogens evolving in shrimp farms could potentially be transmitted to wild shrimp. Nevertheless, it is also important to note that the increased sensitivity of advanced molecular techniques can cause difficulty in interpreting the biological significance of such detections in wild organisms. For example, detections of “new” (unknown or known but discovered in a different geographic location or fish host) potentially infectious agents can be misinterpreted, because molecular detection is not proof of agent viability within or on host tissues (Meyers and Hickey, 2022). Further investigation is required regarding the agent’s ability to replicate and to provide evidence that the agent causes substantial risk of disease to exposed wild populations (Meyers and Hickey, 2022). Therefore, the risk of impacts to wild populations (compared to those in farms) from pathogens commonly found in shrimp farms continues to be uncertain.

Differences across species and production systems

There are many aspects of the different production systems and their management that relate to their biosecurity and/or vulnerability to disease. Although the high stocking densities of intensive farms are widely acknowledged to have a higher risk of pathogen amplification and clinical disease outbreaks than the low densities of extensive or shrimp-mangrove farms (e.g., Schar et al. [2020]), the latter have higher water exchanges and are less likely to treat water before use (Nguyen and Tien, 2021)—both aspects that may increase the disease transmission risk. It is likely that some super-intensive recirculation systems have a minimal connection to wild populations in daily operations yet may have uncertainties regarding sludge disposal (Quyen et al., 2020). Intensive farms typically have the ability to dry the pond substrates between cycles, and are perhaps more likely to use high-quality SPF postlarvae than extensive farms do (Nguyen et al., 2022); rice-shrimp systems effectively have extended fallow periods as the crops alternate. As noted in Criterion 4—Chemical Use, antimicrobial use is higher in intensive systems. Overall, the typically low production intensities of the "extensive" systems (i.e., improved extensive, rice-shrimp, and shrimp-mangrove) are considered to have a substantially lower risk of clinical disease outbreaks than intensive systems.

For the two species, the differing disease characteristics and patterns of epidemics along with the varying availabilities of SPF postlarvae have been defining aspects of the evolution of the shrimp farming industry in Vietnam and elsewhere. Although SPF lines of *L. vannamei* have greater availability, other factors still control the risk of disease outbreaks on farms, regardless of the species. Although there are native *P. monodon* in Vietnam and no *L. vannamei*, the variable host ranges of many pathogens mean that there is no robust reason to distinguish the two species here regarding their risk of disease transmission to wild shrimp.

Conclusions and Final Score

Shrimp farming in Vietnam has been plagued with several severe viral disease epidemics, and these and other diseases caused by bacteria, parasites, and protozoans are a dominant concern for farmers. Although biosecurity characteristics and practices are considered likely to be highly variable among production systems and individual farms, it is clear that pathogens are commonly discharged from farms in wastewater, sediment, and sludge, and enter neighboring farms in influent waters. The development of specific pathogen-free (SPF) breeding lines and postlarvae has been important in mitigating some of the pathogens of highest concern, but shrimp continue to be vulnerable to infection during grow-out in all but the most contained and biosecure facilities. Intensive production systems with high stocking densities are typically considered more vulnerable to disease outbreaks (supported by reports of higher antimicrobial use in these systems), but with more common use of water treatment and recirculation, they have the potential for greater biosecurity compared to the low stocking densities but simpler practices of extensive and shrimp-mangrove systems in the thousands of small family farms in Vietnam. Although there are regulations relating to fish and shrimp health and biosecurity in aquaculture in Vietnam, academic studies indicate that there are limited resources for enforcement and that farmers may still choose to dump infected water or not report disease outbreaks to neighboring farms or the authorities. Despite clear evidence of the discharge of pathogens from farms and the presence of many of the same pathogens in the environment and in wild shrimp (e.g., in wild broodstock), it remains challenging to determine what impacts, if any, these pathogens have on wild shrimp. Without clear data or evidence with which to understand the impacts of farm pathogens on wild shrimp, the risk-based assessment has been used. Although all systems are considered at least partly open to the introduction and discharge of pathogens, the greater risk of disease in intensive systems results in a final numerical score for Criterion 7—Disease of 4 out of 10 for intensive systems. With lower density and less likelihood of pathogen amplification, the score for extensive, shrimp-rice, and shrimp-mangrove systems is 6 out of 10. Without clearly different risk characteristics between the two species of farmed shrimp, the score applies to both *L. vannamei* and *P. monodon*.

Criterion 8X: Source of Stock—Independence from Wild Fish Stocks

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—*L. vannamei*—all production systems

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

Criterion 8X Summary—*P. monodon*—all production systems

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0–10)	–6	
Critical?	NO	YELLOW

Brief Summary

Farm production of *L. vannamei* in Vietnam relies entirely on farm-raised broodstock, so this criterion is not applicable to this species (i.e., the final score for Criterion 8X—Source of Stock is a deduction of 0 out of –10 for *L. vannamei*).

For *P. monodon*, although production of domesticated broodstock is increasing, the shrimp farming industry is still largely dependent on wild-caught broodstock from a fishery located approximately 30 miles south of Vietnam. With an estimated annual capture of 197,100 *P. monodon* broodstock and an estimated 60,000 farm-raised broodstock, the *P. monodon* shrimp farming industry is approximately 69.6% reliant on wild-caught sources. Although overseen by the national fisheries regulations, there are no specific regulations regarding the broodstock fishery, and without formal assessments, the sustainability of the fishery is currently considered to be unknown. The final score for Criterion 8X—Source of Stock for *P.* monodon is a deduction of –6 out of –10. Although it is possible that the use of wild-caught versus farm-raised broodstock varies by production system, there are insufficient data with which to separate them, and the scores are applied to all production systems for each species.

Justification of Rating

This criterion assesses the use of wild juveniles (postlarvae, or PL, in the case of shrimp farming) or wild broodstock. Although shrimp-mangrove production systems still obtain small amounts of wild PL by passive influx when ponds are filled (of *P. monodon* and other local species), hatchery supply of PL is now dominant for both species of shrimp assessed here (Anh et al., 2020)(Merican, 2021b).

Vietnam now has an established network of hundreds of hatcheries supplying billions of PL per year (Merican, 2021b). The key shrimp seed production area is in South Central Vietnam, including Ninh Thuận and Bình Thuận Provinces, which produce 56% of the total each year (Le, 2021). The bulk of the remainder is produced in the Mekong Delta Provinces such as Bạc Liêu and Cà Mau, with some production in the northern Provinces of Nghệ An, Hà Tĩnh, and Quảng Ninh. Ninh Thuận Province has nearly 500 facilities producing 45 billion postlarvae, which supplies 35% of Vietnam's total demand (VietFish, 2021).

Because the supply of PLs comes almost entirely from hatcheries as opposed to wild capture, this criterion assesses the source of broodstock from which hatchery PLs are produced. To avoid confusion with hatchery-raised PLs, broodstock are referred to here as either wild-caught (from capture fisheries) or domesticated (raised on farms or specialist broodstock units, as opposed to wild-caught[102]).

<u>*L. vannamei* broodstock</u>
L. vannamei is a nonnative species in Vietnam, and aquaculture production relies entirely on domesticated breeding programs for broodstock. According to Van Der Pijl (2022), Vietnam imports approximately 205,000 *L. vannamei* broodstock, and produces approximately 20,000 in-country. The Directorate of Fisheries reported that the number imported in 2021 was 240,300.[103] With no use of wild caught broodstock (or PL), the final score for Criterion 8X—Source of Stock for *L. vannamei* is a deduction of 0 out of –10.

<u>*P. monodon* broodstock</u>
Hai et al. (2015), and more recently Rosmiati et al. (2022) and Van der Pijl (2022), consider that PL production of *P. monodon* still relies largely on the capture of mature wild broodstock from a broodstock fishery located approximately 30 miles south of Vietnam in the outer gulf of Thailand. According to the Asian Shrimp Improvement Collaborative (ASIC),[104] most of the fishing takes place around the island group of Hon Khoai. Official records on the numbers of broodstock landed are limited by a requirement[105] to only report the numbers of animals that are quarantined and subsequently moved out of the landing province (primarily Cà Mau and

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[102] Note these broodstock may not truly be "domesticated" in terms of lengthy selective breeding for specific traits, but the term is still useful to distinguish from wild-caught sources.

[103] General Department of Fisheries > News > News (tongcucthuysan.gov.vn)

[104] Southeast Asian Black Tiger Broodstock Fisheries Improvement Summary - http://www.asicollaborative.org/newsandresources (accessed 12/4/2022)

[105] According to regulation No: 26/2016/TT-BNNPTNT

Bạc Liêu Provinces) (pers. comm., Vo Nam Son, 2022). The official average landings from 2015 to 2021 from the Department of Fisheries and the Department of Animal Health and Husbandry (provided by pers. comm., Vo Nam Son [2022]) are 145,897 per year, but given the reporting requirements, the actual number landed is considered to be higher. According to unpublished data (pers. comm., Vo Nam Son, 2022), the estimated total number of wild-caught *P. monodon* broodstock landed per year is 197,100.

Regarding farm-raised domesticated broodstock, McIntosh and Jeerajit (2021) reviewed domestication efforts (in Thailand) beginning in 2003, with successful reproduction eventually allowing selective breeding by 2014. There are currently three global suppliers of farm-raised *P. monodon* broodstock: Charoen Pokphand Foods (CP) in Thailand; Moana Technologies in Hawaii, United States; and Unima in Madagascar (Merican, 2021b). Moana Marine Biotech[106] in Vietnam (supplied with PL from Moana Technologies in Hawaii) has the only broodstock production center in the country (in Ninh Thuận Province), currently producing 20,000 broodstock per year with a capacity for 60,000 (pers. comm., Lan Tran, 2022). In addition, Van der Pilj (2022) notes imports of approximately 5,000 *P. monodon* broodstock each year, although the Directorate of Fisheries reported that this number was only 532 in 2021.[107] It is considered likely that there are other sources of pond-raised *P. monodon* broodstock in Vietnam (and likely some exports), and although there do not appear to be any readily available official data, Vo Nam Son (pers. comm., 2022) estimated a total use of domesticated *P. monodon* broodstock in Vietnam (i.e., including Moana Marine Biotech and imported sources) of 60,000 per year, and this figure is used here.

Overall, it can be seen that PL production of *P. monodon* is dominated by wild-caught broodstock sources. Using the estimate of 197,100 total landings and the 60,000 from domesticated sources, it can be calculated that approximately 69.6% of PL production of *P. monodon* comes from wild-caught broodstock.

Fishery sustainability for wild-caught *P. monodon* in Vietnam

The lack of FAO fishery landing data from Vietnam immediately highlights the challenge of assessing the sustainability of the *P. monodon* fishery in Vietnam. The fishery is regulated according to the national laws (e.g., the 2017 Law on Fisheries—18/2017/QH14 and more recent implementation rules—26/2019/ND-CP) but there are no specific requirements relating to the broodstock fishery other than those on quality, quarantine, and reporting (26/2016/TT-BNNPTNT). Seafood Watch does not currently have a published assessment of the fishery, and FishSource[108] states that the stock structure of Penaeid shrimp species distributed along the Indo-West Pacific region is not known, and FishSource also has not assessed this fishery. It does not appear to be certified to any sustainability standard. Thus, the sustainability of the fishery is currently considered unknown.

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[106] http://www.moananinhthuan.com/en/

[107] General Department of Fisheries > News > News (tongcucthuysan.gov.vn)

[108] www.fishsource.org

Conclusions and Final Score

Farm production of *L. vannamei* in Vietnam relies entirely on farm-raised broodstock, so this criterion is not applicable to this species (i.e., the final score for Criterion 8X—Source of Stock is a deduction of 0 out of –10 for *L. vannamei*).

For *P. monodon*, although production of domesticated broodstock is increasing, the shrimp farming industry is still largely dependent on wild-caught broodstock from a fishery located approximately 30 miles south of Vietnam. With an estimated annual capture of 197,100 *P. monodon* broodstock and an estimated 60,000 farm-raised broodstock, the *P. monodon* shrimp farming industry is approximately 69.6% reliant on wild-caught sources. Although overseen by the national fisheries regulations, there are no specific regulations regarding the broodstock fishery, and without formal assessments, the sustainability of the fishery is currently considered to be unknown. The final score for Criterion 8X—Source of Stock for *P.* monodon is a deduction of –6 out of –10. Although it is possible that the use of wild-caught versus farm-raised broodstock varies by production system, there are insufficient data with which to separate them, and the scores are applied to all production systems for each species.

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.

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

Criterion 9X Summary—all species and production systems

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0–10)	**–5**	
Critical?	NO	YELLOW

Brief Summary

Overall, there is no specific evidence of wildlife mortality concerns on Vietnamese shrimp farms, but the available evidence indicates that nonlethal exclusion and deterrents are commonly used, so a potential for the use of lethal control remains, and mortality numbers are unknown. According to the International Union for the Conservation of Nature (IUCN), there are 57 "Red-Listed" animals in Vietnam, and the IUCN lists "small holder farming," "shifting agriculture," and "agro-industry farming" as the top three threats; however, little appears to be known about their specific interaction with shrimp farms. Some regulations are in place (and others may be present), but enforcement measures are uncertain. The types and abundance of species interacting with different types of farms in former agricultural areas or mangrove areas may vary considerably (in addition to the responses of the farmers in each case), but there is insufficient evidence with which to distinguish specific concerns between the different production systems (or species) assessed here. Because of the lack of data, the risk assessment must be used (i.e., the data score for Wildlife Mortalities is 2.5 out of 10 in Criterion 1—Data), and the final score for Criterion 9X—Wildlife Mortalities is –5 out of –10.

Justification of Rating

Shrimp farms potentially affect a variety of species during their initial construction (for which broader habitat impacts from land use changes are assessed in Criterion 3—Habitat) and during routine operations. Regarding the latter, 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) or the introduction of diseases

(Nguyen et al., 2021). In general, predators on shrimp farms that can feed directly on shrimp can include amphibians, birds, crustaceans, finfish, mammals, and snakes (FAO, 1986).

Vietnam is considered highly diverse in terms of species of fauna, flora, and microorganisms, with a variety of terrestrial, freshwater, and marine ecosystems.[109] According to the IUCN, Vietnam hosts 59 Red-Listed species, of which 57 are animals (Figure 33; noting that one-third are considered data deficient), occurring in a variety of terrestrial and aquatic environments. The only species listed under the threat of "marine and freshwater aquaculture" is the Yangtze giant softshell turtle, but it is unclear (from the IUCN data) where the distribution of concern for this species is regarding aquaculture in Vietnam.

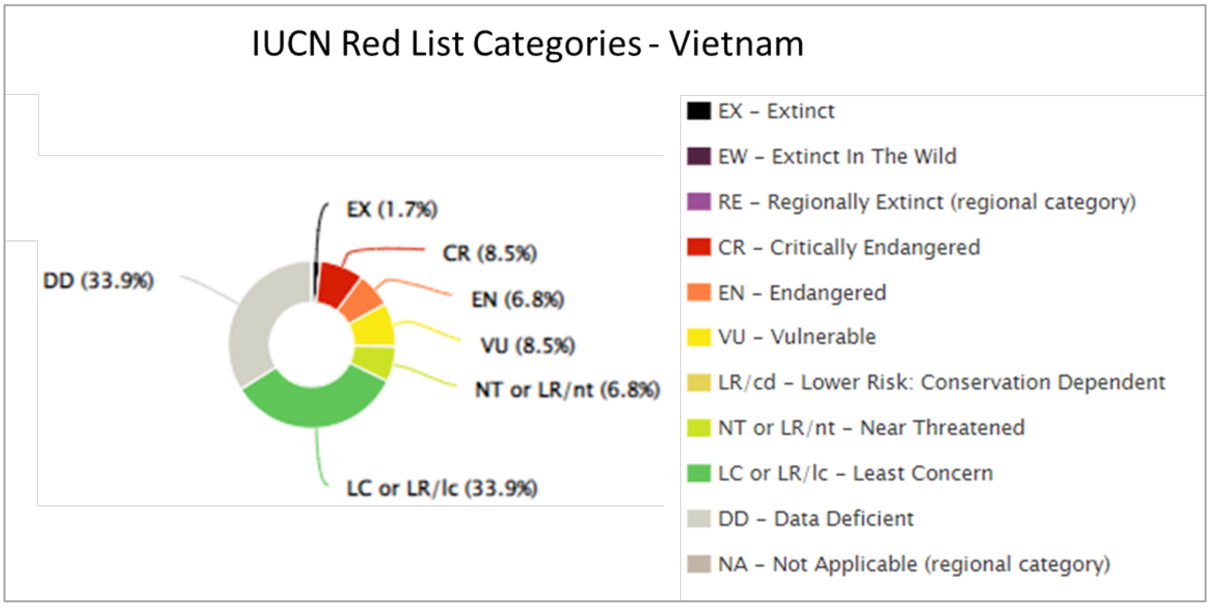

Figure 33: IUCN Red-Listed species categories in Vietnam. Graph reproduced from IUCN.

Vietnam has its own Red Book of endangered species,[110] and regulations on the management of such species, particularly in relation to their trade (e.g., Decree No. 06/2019/ND-CP On Management of Endangered, Precious and Rare Species of Forest Fauna and Flora and Observation of Convention on International Trade in Endangered Species of Wild Fauna and Flora—CITES).

Although the IUCN lists "small holder farming," "shifting agriculture," and "agro-industry farming" as the top three threats, little appears to be known about their specific interaction with shrimp farms (e.g., direct control versus broader habitat impacts). According to some now-dated references, most shrimp farms generally apply nonlethal, exclusionary techniques, such as fireworks or dogs, to scare birds away from the pond during the production cycle (Gunalan, 2015)(Balakrishnan, 2011), but there do not appear to be any recent publicly available data on

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[109] Convention on Biological Diversity, draft biodiversity profile. https://www.cbd.int/countries/profile/?country=vn

[110] https://vi.wikipedia.org/wiki/S%C3%A1ch_%C4%91%E1%BB%8F_Vi%E1%BB%87t_Nam

wildlife mortalities or control methods in Vietnam. As noted in Criterion 4—Chemical Use, it is considered common practice to control predatory fish in influent waters with the lethal use of chemicals such as saponin, but this is considered unlikely to have any substantial impact on the populations of affected species. The scale of use of deterrents versus lethal control for any other type of predator or other wildlife is uncertain. Audit reports and Biodiversity-inclusive Environmental Impact Assessments (B-EIA) from certification schemes such as the Aquaculture Stewardship Council[111] indicate that deterrents are used (such as netting or screens over and around ponds and water inlets), and these standards prohibit lethal control, but these practices cannot be assumed to be representative of all shrimp farms in Vietnam.

Conclusions and Final Score

Overall, there is no specific evidence of wildlife mortality concerns on Vietnamese shrimp farms, but the available evidence indicates that nonlethal exclusion and deterrents are commonly used, so a potential for the use of lethal control remains, and mortality numbers are unknown. According to the International Union for the Conservation of Nature (IUCN) there are 57 “Red-Listed” animals in Vietnam, and the IUCN lists “small holder farming,” “shifting agriculture,” and “agro-industry farming” as the top three threats; however, little appears to be known about their specific interaction with shrimp farms. Some regulations are in place (and others may be present), but enforcement measures are uncertain. The types and abundance of species interacting with different types of farms in former agricultural areas or mangrove areas may vary considerably (in addition to the responses of the farmers in each case), but there is insufficient evidence with which to distinguish specific concerns between the different production systems (or species) assessed here. Because of the lack of data, the risk assessment must be used (i.e., the data score for wildlife mortalities is 2.5 out of 10 in Criterion 1—Data), and the final score for Criterion 9X—Wildlife Mortalities is –5 out of –10.

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[111] www.asc-aqua.org

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.

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

Criterion 10X Summary—*L. vannamei*—all production systems

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	>90.0	0
Biosecurity score of the source of animal movements (0–10)		8
Biosecurity score of the farm destination of animal movements (0–10)		2
Species-specific score 10X Score		–2.0
C10X Introduction of Secondary Species Final Score		**–2.0**
Critical?	No	Green

Criterion 10X Summary—*P. monodon*—all production systems

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	2.0	9
Biosecurity score of the source of animal movements (0–10)		2
Biosecurity score of the farm destination of animal movements (0–10)		2
Species-specific score 10X Score		–0.8
C10X Introduction of Secondary Species Final Score		**–0.8**
Critical?	No	Green

Brief Summary

The global shrimp farming industry has been severely affected by a variety of pathogens that have been moved from one country to another as unintentional "hitchhiker" species during live animal shipments. The industry for *L. vannamei* in Vietnam is largely dependent on movements of broodstock and PLs from international breeding centers to broodstock facilities and hatcheries in Vietnam. The score for Factor 10Xa for *L. vannamei* is 0 out of 10 (indicating >90% reliance on international or trans-waterbody movements). Because the large majority of *P. monodon* broodstock comes from domestic wild capture (from a fishery located approximately 30 miles south of Cà Mau) and there are more hatcheries closer to the main grow-out regions, there is less international or trans-waterbody movement of this species. The score for Factor

10Xa is 9 out of 10 for *P. monodon*, based on the 2% dependence on international movements of farm-raised domesticated broodstock or PLs.

The international sources of *L. vannamei* typically have high biosecurity and testing for specific pathogen-free (SPF) certification, so the score for Factor 10Xb is 8 out of 10 (indicating a low risk of unintentionally introducing a secondary species during shipments). For *P. monodon*, the fishery landings must be quarantined and screened for pathogens, which indicates that at least some biosecurity measures are in place for the otherwise nonbiosecure capture fishery. The score for Factor 10Xb for *P. monodon* is 2 out of 10 (indicating a higher risk of unintentionally transporting a secondary species from the coastal fishery). The scores for Factors 10Xa and 10Xb combine to give final score for Criterion 10X—Introduction of Secondary Species of –2 out of –10 for *L. vannamei* and –0.8 out of –10 for *P. monodon*, indicating an overall low risk for both species.

Justification of Rating

The concern regarding the introduction of secondary species during live animal movements is perhaps exemplified by the rapid international spread of various shrimp pathogens, and Arulmoorthy et al. (2020) consider that the shipment of broodstock and postlarvae from one geographical region to another has often resulted in the spread of diseases. For example, according to Lee et al. (2022), the first reports of white spot syndrome virus (WSSV) in Penaeid shrimp occurred in China and Taiwan in 1992, and then spread to Korea (1993), Japan (1993), Vietnam and Thailand (1994), and Malaysia and Indonesia (1995). WSSV also occurred in America (Latin America, such as Ecuador, Mexico, and Brazil in 1999, and North America in 1995), the Middle East in 2001, Africa (such as Mozambique and Madagascar in 2011), and most recently at an Australian shrimp farm in 2016. Lee et al. (2022) also considered that the ongoing translocation of broodstock that are unscreened or inadequately tested for WSSV has led to the spread of WSSV back to Asia from the Americas.

Because of the differing characteristics of the two species assessed here, they are discussed and scored separately below.

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

- *L. vannamei*

  Vietnam is heavily dependent on imported broodstock and postlarvae (Tan, 2021)(Van der Pijl, 2022) and this is particularly the case for *L. vannamei.* As discussed in Criterion 8X—Source of Stock, according to Van Der Pilj (2022), Vietnam imports approximately 90% of its *L. vannamei* broodstock (205,000 imports as opposed to approximately 20,000 produced in-country). According to the Directorate of Fisheries, the number imported in 2021 was 240,300, which would be equivalent to 91.7%. Occasional snapshots of import information are available—for example, a 2022 list of Vietnamese companies importing broodstock from Shrimp Improvement Systems[112] [113]—but a centralized source of data is not readily available. Vietnam has a large number of facilities supplying broodstock, larvae, and PL to the industry that are spread throughout the country, but some areas (with particularly suitable production characteristics such as temperature and water quality) are becoming focused on hatchery production, such as South-Central Vietnam, including Ninh Thuận and Bình Thuận Provinces. These two provinces produce 56% of the total PL each year (Le, 2021) and transport them to other provinces. For example, Joffre et al. (2018) reported that 1.8 billion PL are transported by truck into Sóc Trăng Province each year.

With the dependence of production on imported broodstock, in addition to widespread movements of PL that are likely to include some that would be considered trans-waterbody movements (i.e., defined as the source waterbody being ecologically distinct from the destination), production of *L. vannamei* in Vietnam is considered to be >90% reliant on trans-waterbody movements of shrimp, so the score for Factor 10Xa is 0 out of 10.

- *P. monodon*

As noted in Criterion 8X—Source of Stock, farming of *P. monodon* in Vietnam is largely dependent on wild-caught broodstock from a fishery to the south of Vietnam in the outer Gulf of Thailand (Hai et al., 2015)(Rosmiati et al., 2022)(Van der Pijl 2022). In addition, there are small amounts of in-country production of domesticated broodstocks (approximately 21% of production) and a small number of imports (approximately 2% of production). As noted above for *L. vannamei*, occasional snapshots of import information are available—for example, a partial 2018 list of Vietnamese companies importing *P. monodon* broodstock from Moana Marine Biotech[114] [115]—but a centralized source of data is not readily available. It appears that the focus of *P. monodon* hatcheries in South-Central Vietnam provinces is less intense than for *L. vannamei*; for example, of the approximately 500 hatcheries in Ninh Thuận Province, there are only 3 production facilities for *P. monodon* PL (including the Moana broodstock center) (VietFish, 2021). Joffre et al. (2018) noted that, of Vietnam's total 1,750 shrimp hatcheries, 870 were small-scale facilities in Cà Mau Province in the Mekong Delta. Though these numbers may have changed since then (for example Le [2021] considered that there were 2,224 hatcheries in 2020), it seems likely that substantial numbers of *P. monodon* hatcheries are located closer to the farming centers of this species in the Mekong Delta. This also likely reflects the location of the broodstock fishery to the south of Vietnam (i.e., approximately 30 miles south of Cà Mau; see Criterion 8X—Source of Stock). Given this proximity to the source, there are not considered to be trans-waterbody movements of wild-caught monodon broodstock or their PLs. Therefore, the focus here is on the international movement of *P. monodon*, which was estimated to supply approximately 2% of production, and without further data, this value is used for the reliance on transwaterbody movements. The score for Factor 10Xa for *P. monodon* is 9 out of 10.

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[112] http://nguoinuoitom.vn/danh-sach-cac-cong-ty-nhap-tom-bo-me-sis-tai-viet-nam-trong-thang-6-2022/
[113] http://www.shrimpimprovement.com/
[114] https://thuysanvietnam.com.vn/danh-sach-trai-giong-nhap-tom-bo-me-moana/
[115] http://www.moananinhthuan.com/en/mona-technologies-hawaii/

Factor 10Xb—Biosecurity of source/destination

- Source of movements

Two sources of movements are considered here: the international facilities supplying broodstock and postlarvae of both *L. vannamei* and *P. monodon*, and the facilities within Vietnam that produce and distribute PL from those broodstock (or the PL derived from the broodstock that were grown from imported PL). The development of specific pathogen-free (SPF) breeding lines in biosecure locations has been the driver of the international trade in live shrimp in the form of broodstock and postlarvae.[116] Although never entirely biosecure, these tank-based recirculation facilities test their stocks extensively during production and before shipment, and are considered to have a low risk of introducing secondary species at the source of movements (i.e., before entering Vietnam).

Regarding wild-caught *P. monodon* only, the readily available evidence indicates that they are appropriately screened and quarantined before distribution to hatcheries (according to law 26/2016/TT-BNNPTNT). Regarding the Vietnamese sources of domestic shrimp movements for both species, Anh et al. (2020) considered that hatcheries have been set up to supply high-quality seeds, and Joffre et al. (2018) considered that the regulatory framework for the control of PL quality and the operation of hatcheries is well designed, with standard procedures, control stations at the provincial and district levels, and a dedicated department within provincial DARDs to implement control. But, Joffre et al. (2018) identified a gap between the rules and their enforcement, with a limited ability to control the large number of hatcheries in addition to the movements of PL and larvae between provinces. Further, Le (2021), quoting the Deputy Minister of Agriculture and Rural Development, noted that the quality management, production, and transportation of shrimp seed still have some limitations; for example, during the peak season of stocking in the key provinces for commercial shrimp farming, there are still a large number of PL transported from the South-Central coast provinces without origin certification and not under quarantine. In addition, many establishments have not been inspected to issue production certificates according to the provisions of the Fisheries Law, yet they are still granted quarantine certificates. Thus, there are many facilities that do not guarantee the conditions required to provide PL to the market (Le, 2021), and Joffre et al. (2018) noted that some farmers do not trust the health certification of disease-free PLs, which is supposed to guarantee the quality of the product for buyers. This implies a lower level of biosecurity for these sources of domestic shrimp movements. Nevertheless, it is unclear what proportion of these domestic movements would be considered trans-waterbody and that would therefore represent a risk of unintentionally introducing a novel species (particularly given the likely widespread nature of shrimp pathogens in Vietnam). Therefore, the focus here

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[116] The PL shipped from these international locations into Vietnam are typically used to grow broodstock within Vietnam, which are subsequently provided to hatcheries that spawn them and produce large numbers of PL for on-growing in farms.

is on the large number of imported shrimp from international sources for *L. vannamei* and the large number of wild caught *P. monodon.*

- Destination of movements

Although many international shipments of shrimp are destined for breeding centers and hatcheries with broadly similar biosecurity to the shipment sources, the final destination of the majority of shrimp movements (for PLs) is considered to be grow-out ponds. As discussed in Criterion 2—Effluent and Criterion 7—Disease, because of the more open nature of these production systems (for example, the exchange of water with the external environment with uncertainties regarding the use and effectiveness of water treatment and/or disinfection), the biosecurity of these locations on average[117] is considered to be lower than at the source hatcheries.

Overall, the score for Factor 10Xb for *L. vannamei* is based on the higher biosecurity of the international sources of live shrimp imports into Vietnam. These tank-based recirculation systems, in addition to comprehensive pathogen testing and certification, are considered to have high biosecurity, and the score for Factor 10Xb is 8 out of 10. For *P. monodon*, the source (i.e., the coastal fishery) and the destination (farm ponds) are considered to have low biosecurity, but with biosecurity management measures in place in the form of quarantine and testing after capture, the score for Factor 10Xb is based on the origin of live *P. monodon* movements, so the score for Factor 10Xb is 2 out of 10.

Conclusions and Final Score

The global shrimp farming industry has been severely affected by a variety of pathogens that have been moved from one country to another as unintentional “hitchhiker” species during live animal shipments. The industry for *L. vannamei* in Vietnam is largely dependent on movements of broodstock and PLs from international breeding centers to broodstock facilities and hatcheries in Vietnam. The score for Factor 10Xa for *L. vannamei* is 0 out of 10 (indicating >90% reliance on international or trans-waterbody movements). Because the large majority of *P. monodon* broodstock comes from domestic wild capture (from a fishery located approximately 30 miles south of Cà Mau), and there are more hatcheries closer to the main grow-out regions, there is less international or trans-waterbody movement of this species. The score for Factor 10Xa is 9 out of 10 for *P. monodon*, based on the 2% dependence on international movements of farm-raised domesticated broodstock or PLs.

The international sources of *L. vannamei* typically have high biosecurity and testing for specific pathogen-free (SPF) certification, so the score for Factor 10Xb is 8 out of 10 (indicating a low risk of unintentionally introducing a secondary species during shipments). For *P. monodon*, the fishery landings must be quarantined and screened for pathogens, which indicates that at least some biosecurity measures are in place for the otherwise nonbiosecure capture fishery. The

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[117] It is recognized here that some high-intensity farms have high biosecurity, but these are considered to be a minority across the range of farms in Vietnam.

score for Factor 10Xb for *P. monodon* is 2 out of 10 (indicating a higher risk of unintentionally transporting a secondary species from the coastal fishery). The scores for Factors 10Xa and 10Xb combine to give a final score for Criterion 10X—Introduction of Secondary Species of –2 out of –10 for *L. vannamei* and –0.8 out of –10 for *P. monodon*, indicating an overall low risk for both species.

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

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Appendix 1: Key Policies on Mangrove Protection and Development in Vietnam

Reproduced from Pham et al. (2022)

Decision No. 1719/QD-TTg of the Prime Minister dated 4 October 2011, approving criteria for assessment of projects under the Supporting Program on Responding to Climate Change (SP-RCC). This provides priorities for 12 sectors and inter-sectors and 7 eco-regions. Of those sectors, reforestation and afforestation of mangrove forests, as well as integrated coastal management, are high priorities for project investment.

Decision No. 1206/QD-BNN-TCLN dated 8 April 2016, announcing economic and technical cost-norms for seedling production, and the planting, maintenance and protection of mangrove forests.

Decision No. 38/2016/QD-TTg dated 14 September 2016, providing regulations and government support, particularly financial, for forest protection, the planting of forests (special use and protection forests) and forest certification, as well as support for infrastructure development in forested areas.

Intended Nationally Determined Contribution (INDC) of Vietnam affirms the significance of mangroves in addressing climate change. The INDC, for example, proposes the restoration and development of mangroves as both a mitigation and adaptation strategy (MONRE 2016a). It also reports that the forestry sector contributes considerably to emission reduction by reducing deforestation and forest degradation, and by enhancing removal through forest restoration and development. The total GHG mitigation potential generated by the forestry sector for 2021–2030 ranges from 82.2 to 156.3 million tons CO_2, of which GHG mitigation potential from mangroves is estimated at 4.4 million tons CO_2 (Phuong et al., 2018). The INDC is being updated, as the NDC and National Development Strategy (NDS) include seven mitigation options in land use, land-use change and forestry (LULUCF). Mitigation options focus on conservation of forest areas (including mangroves), forest restoration and the enhancement of degraded natural forests and mangroves, improvements in the productivity of plantations for saw log supply, the scaling up or replication of successful agro-forestry models, and sustainable forest management. Annual GHG mitigation from these options is estimated at 7.6 million tons CO_2 for 2021–2030, with national budget support alone. This could reach 13.9 million tons of CO_2 if Vietnam were to receive external support for mitigation. The GHG mitigation potential of LULUCF accounts for 21% of GHGs in the Business as Usual scenario (Phuong et al., 2018).

Decree No. 119/2016/ND-CP dated 23 August 2016, focusing on management, protection and development of mangrove forests in response to climate change. This policy regulates the management of mangrove forests, including investment, protection, allocation, benefits, and the responsibilities of government and other organizations. It affirms a government commitment to invest its own resources in the conservation and restoration of mangroves, especially the incentive payment for forest protection and promoting allocation of mangroves to local communities for protection and management.

Decree No 99/2010/ND-CP (now is regulated in Decree No. 156/2018/ND-CP), stimulating payments between service providers and users. Service user groups are required to deliver payment for the following services:

i) soil protection, reduction of erosion, and sedimentation of reservoirs, rivers and streams; ii) regulation and maintenance of water sources for production and domestic uses; iii) forest carbon sequestration and retention, reduction of GHG emissions through prevention of forest degradation and loss of forest area, and through sustainable forest development; iv) protection of the natural landscape and conservation of forest ecosystem biodiversity for tourism services; and v) provision of spawning grounds, feeding sources and natural seeds, and use of water from forests for aquaculture. Since this policy was put into practice, it has generated about USD 70 million annually to pay forest owners through contracts for protection. This policy has not been applied to mangrove forests as there is no regulation at the present. However, it is being piloted in a mangrove area of Dat Mui national park in Cà Mau province.

National REDD+ Action Program. This program replaced the national REDD+ action plan issued by Decision No. 799/QD-TTg in 2012. Objectives include increasing forest cover to 42% by 2020 and to 45% by 2030, and contributing to emission reduction targets set in the INDC. These emission reduction targets aim at 8% with Vietnam's own resources compared to BAU, and up to 25% with external support. This program also provides details of policies and measures for REDD+ implementation until 2030. It focuses on the drivers of deforestation and forest degradation, including loss of mangroves.

Revised Forestry Law 2017, passed by the National Assembly on 15 November 2017, addressed the following areas: i) strict management of conversion of natural forests; ii) allow permit-only logging in natural forests that fall under certified sustainable forest management (SFM); iii) focus on forestry as environmental services and limit logging from natural forests; iv) promotion of forestry business; v) improve forest tenure to clearly identify forest owners/users; vi) national forestry planning; and vii) control of forest products through Voluntary Partnership Agreements (VPAs)/Forest Law Enforcement, Governance and Trade (FLEGT), and multisector engagement. This law provides strengthened forest governance and clearer laws on how to solve deforestation, with more emphasis on involving local communities in protection.

Decision No. 120/QD-TTg of the Prime Minister dated 22 January 2015, approving projects for the protection and development of coastal protection forests to respond to climate change. This aims to protect coastal forest area of 310,695 ha (forests in sandy areas and mangrove forests), restore 9,602 ha of degraded forest, and reforest 46,058 ha (of which 29,500 ha is mangrove forest). This project covers 28 coastal provinces and the total budget is VND 5,415 billion for 2014–2020 (70% from state budget). As of 2017, 42 sub-projects were approved for implementation from 2015 onward, across the country. About 89,000 ha of mangrove forests was restored.

Decision No. 886/QD-TTg of the Prime Minister dated 16 June 2017, approving the national program for sustainable forestry development over 2016–2020. This program aims at improving and finalizing policies and capacity, as well as ensuring infrastructure and applying science to achieve sustainable management of the forestry sector. The budget for implementation is VND 59,000 billion, including about VND 14,000 billion from the national budget. This program will support forest protection, forest regeneration and enrichment, local communities in the buffer zone of special use forest areas, forest certification and capacity building. Financial support will follow guidance in Decision No. 38/2016/QD-TTg.

Appendix 2: Data Points and all Scoring Calculations

Criterion 1: Data—All Production Systems	
Data Category	**Data Quality**
Production	7.5
Management	5.0
Effluent	5.0
Habitat	7.5
Chemical Use	5.0
Feed	5.0
Escapes	5.0
Disease	5.0
Source of stock	5.0
Wildlife mortalities	2.5
Escape of secondary species	5.0
C1 Data Final Score (0–10)	**5.227**
	Yellow

Criterion 2: Effluent—Shrimp-Mangrove—*P. monodon*	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0–10)	**10**
Critical?	NO

Criterion 2—Effluent–Intensive Systems—*L. vannamei* Risk-based assessment	
2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	38.300
eFCR	1.190
Fertilizer N input (kg N/ton fish)	7.700
Protein content of harvested fish (%)	17.800
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	80.623
N output in each ton of fish harvested (kg)	28.480
Waste N produced per ton of fish (kg)	52.143

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

Adjustment 1 (if applicable)	–0.170
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)	0.340
Waste discharged per ton of production (kg N ton^{-1})	17.729
Waste discharge score (0–10)	8.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1
2.2 Effluent management effectiveness	0.800
C2 Effluent Final Score (0–10)	**5**
Critical?	No

Criterion 2—Effluent—Rice-shrimp—*L. vannamei*

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	n/a
eFCR	0.0
Fertilizer N input (kg N/ton fish)	27.500
Protein content of harvested fish (%)	17.800
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	27.500
N output in each ton of fish harvested (kg)	28.480
Waste N produced per ton of fish (kg)	0.000

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.510
Adjustment 1 (if applicable)	0.000
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)	0.510
Waste discharged per ton of production (kg N ton^{-1})	0.000
Waste discharge score (0–10)	10.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1

2.2 Effluent management effectiveness	0.800
C2 Effluent Final Score (0–10)	**10**
Critical?	No

Criterion 2: Effluent—Intensive Systems—*P. monodon*

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	40.900
eFCR	1.540
Fertilizer N input (kg N/ton fish)	16.800
Protein content of harvested fish (%)	18.900
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	117.578
N output in each ton of fish harvested (kg)	30.240
Waste N produced per ton of fish (kg)	87.338

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.510
Adjustment 1 (if applicable)	-0.170
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)	0.340
Waste discharged per ton of production (kg N ton^{-1})	29.695
Waste discharge score (0–10)	7.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1
2.2 Effluent management effectiveness	0.800
C2 Effluent Final Score (0–10)	**4**
Critical?	No

Criterion 2: Effluent—Improved Extensive Systems—*P. monodon*

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	40.900
eFCR	0.000
Fertilizer N input (kg N/ton fish)	42.700

Protein content of harvested fish (%)	18.900
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	42.700
N output in each ton of fish harvested (kg)	30.240
Waste N produced per ton of fish (kg)	12.460

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})	3.364
Waste discharge score (0–10)	9.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1
2.2 Effluent management effectiveness	0.800
C2 Effluent Final Score (0–10)	**6**
Critical?	No

Criterion 2: Effluent—Shrimp-Rice—*P. monodon*

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	40.900
eFCR	0.000
Fertilizer N input (kg N/ton fish)	27.500
Protein content of harvested fish (%)	18.900
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	27.500
N output in each ton of fish harvested (kg)	30.240
Waste N produced per ton of fish (kg)	0.000

2.1b Production System discharge	**Data and Scores**
Basic production system score	0.510
Adjustment 1 (if applicable)	0.000
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)	0.510
Waste discharged per ton of production (kg N ton^{-1})	0.000
Waste discharge score (0–10)	10.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	1
2.2 Effluent management effectiveness	0.800
C2 Effluent Final Score (0–10)	**10**
Critical?	No

Criterion 3: Habitat
Intensive systems—*P. monodon, L. vannamei*
Extensive systems—*P. monodon*
Shrimp-mangrove—*P. monodon*

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	2
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	2.400
C3 Habitat Final Score (0–10)	**1.467**
Critical?	No

Criterion 3: Habitat
Rice-shrimp—*P. monodon, L. vannamei*

F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	7
F3.2 Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	2
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	2.400
C3 Habitat Final Score (0–10)	**5.467**
Critical?	No

Criterion 4: Chemical Use
Intensive systems—*P. monodon, L. vannamei*

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?	Yes

Criterion 4: Chemical Use
Extensive systems—*P. monodon*
Rice-shrimp—*P. monodon*, *L. vannamei*

Single species assessment	Data and Scores
Chemical use initial score (0–10)	6.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0–10)	**6.0**
Critical?	No

Criterion 4: Chemical Use
Shrimp-mangrove—*P. monodon*

Single species assessment	Data and Scores
Chemical use initial score (0–10)	8.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0–10)	**8.0**
Critical?	No

Criterion 5: Feed
Intensive systems—*P. monodon*

5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	7.500
Fishmeal from by-products, weighted inclusion %	26.200
By-product fishmeal inclusion (@ 5%)	1.310
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.800
Fish oil from by-products, weighted inclusion %	2.200
By-product fish oil inclusion (@ 5%)	0.110
Fish oil yield value, weighted %	5.000
eFCR	1.540
FFER Fishmeal value	**0.603**
FFER Fish oil value	**0.280**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	1.204

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	**1.600**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	40.900
Protein INPUT kg/100k g harvest	62.986
Whole body harvested fish protein content	18.900
Net protein gain or loss	–69.993
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 CO_2-eq kg^{-1} farmed seafood protein)	**15.070**
Contribution (%) from fishmeal from whole fish	5.329
Contribution (%) from fish oil from whole fish	0.389
Contribution (%) from fishmeal from by-products	18.616
Contribution (%) from fish oil from by-products	1.069
Contribution (%) from crop ingredients	65.691
Contribution (%) from land animal ingredients	5.535
Contribution (%) from other ingredients	3.371
Factor 5.3 score	**6**
C5 Final Feed Criterion Score	**3.1**
Critical?	**No**

Criterion 5: Feed **Intensive systems—*L. vannamei***	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	5.600
Fishmeal from by-products, weighted inclusion %	20.800
By-product fishmeal inclusion (@ 5%)	1.040
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.800
Fish oil from by-products, weighted inclusion %	1.500
By-product fish oil inclusion (@ 5%)	0.075
Fish oil yield value, weighted %	5.000

eFCR	1.190
FFER Fishmeal value	**0.351**
FFER Fish oil value	**0.208**
Critical (FFER > 4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	1.224
Critical Source fisheries?	No
SFW “Red” Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER ≥ 1)?	No
Final Factor 5.1 Score	**2.350**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	38.300
Protein INPUT kg/100 kg harvest	45.577
Whole body harvested fish protein content	17.800
Net protein gain or loss	–60.945
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 CO_2-eq kg^{-1} farmed seafood protein)	**12.697**
Contribution (%) from fishmeal from whole fish	4.212
Contribution (%) from fish oil from whole fish	0.411
Contribution (%) from fishmeal from by-products	15.644
Contribution (%) from fish oil from by-products	0.772
Contribution (%) from crop ingredients	69.534
Contribution (%) from land animal ingredients	5.859
Contribution (%) from other ingredients	3.568
Factor 5.3 score	**7**
C5 Final Feed Criterion Score	**3.7**
Critical?	**No**

Criterion 5: Feed **Extensive systems—*P. monodon*** **Rice-shrimp—*P. monodon, L. vannamei*** **Shrimp-mangrove—*P. monodon***	

5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	0.0
Fishmeal from by-products, weighted inclusion %	0.0
By-product fishmeal inclusion (@ 5%)	0.0
Fishmeal yield value, weighted %	0.0
Fish oil from whole fish, weighted inclusion level %	0.0
Fish oil from by-products, weighted inclusion %	0.0
By-product fish oil inclusion (@ 5%)	0.0
Fish oil yield value, weighted %	0.0
eFCR	0.0
FFER Fishmeal value	**0.0**
FFER Fish oil value	**0.0**
Critical (FFER > 4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	n/a
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER $\geq$ 1)?	No
Final Factor 5.1 Score	**10**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	0.0
Protein INPUT kg/100 kg harvest	0.0
Whole body harvested fish protein content	17.800
Net protein gain or loss	Gain
Species-specific Factor 5.2 score	**10**
Critical (Score = 0)?	No
Critical (FFER > 3 and 5.2 score < 2)?	No

5.3 Feed Footprint	**Data and Scores**
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	0.0
Contribution (%) from fishmeal from whole fish	n/a
Contribution (%) from fish oil from whole fish	n/a
Contribution (%) from fishmeal from by-products	n/a
Contribution (%) from fish oil from by-products	n/a
Contribution (%) from crop ingredients	n/a
Contribution (%) from land animal ingredients	n/a
Contribution (%) from other ingredients	n/a

Factor 5.3 score	**10**
C5 Final Feed Criterion Score	**10.0**
Critical?	**No**

Criterion 6: Escapes—*L. vannamei*	**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

Criterion 6: Escapes—*P. monodon*	**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	7
C6 Escape Final Score (0–10)	**4.0**
Critical?	No

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

Criterion 7: Disease— **Improved extensive systems** **Rice-shrimp systems** **Shrimp-mangrove systems**	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0–10)	**6**
Critical?	No

Criterion 8X Source of Stock—*L. vannamei*	**Data and Scores**
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0–10)	10.0

Use of ETP or SFW “Red” fishery sources	No
Lowest score if multiple species farmed (0–10)	n/a
C8X Source of stock Final Score (0–10)	**-0**
Critical?	No

Criterion 8X Source of Stock—*P. monodon*	**Data and Scores**
Percent of production dependent on wild sources (%)	69.6
Initial Source of Stock score (0–10)	–6.0
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)	**–6**
Critical?	No

Criterion 9X Wildlife Mortality parameters All systems and species	**Data and Scores**
Single species wildlife mortality score	–4
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**–5**
Critical?	No

Criterion 10X: Introduction of Secondary Species *L. vannamei*	**Data and Scores**
Production reliant on trans-waterbody movements (%)	>90
Factor 10Xa score	0
Biosecurity of the source of movements (0–10)	8
Biosecurity of the farm destination of movements (0–10)	2
Species-specific score 10X score	–2.000
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–2.000**
Critical?	n/a

Criterion 10X: Introduction of Secondary Species *P. monodon*	**Data and Scores**
Production reliant on trans-waterbody movements (%)	2
Factor 10Xa score	9

Biosecurity of the source of movements (0–10)	2
Biosecurity of the farm destination of movements (0–10)	2
Species-specific score 10X score	–0.800
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–0.800**
Critical?	n/a