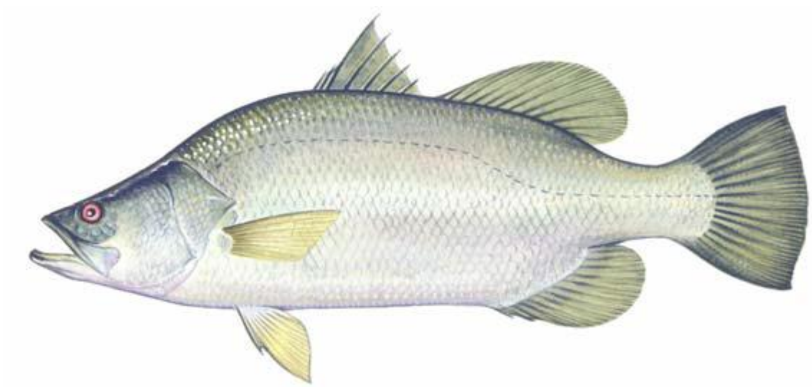
Barramundi

*Lates calcarifer*



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Vietnam

Net Pens

*March 1, 2021*

*Seafood Watch Staff*

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## Table of Contents

# 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.

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

| Criterion | Score | Rank | Critical? |
|---|---|---|---|
| C1 Data | 7.50 | Green | |
| C2 Effluent | 6.00 | Yellow | NO |
| C3 Habitat | 6.80 | Green | NO |
| C4 Chemicals | 8.00 | Green | NO |
| C5 Feed | 4.75 | Yellow | NO |
| C6 Escapes | 4.00 | Yellow | NO |
| C7 Disease | 6.00 | Yellow | NO |
| | | | |
| C8X Source | 0.00 | Green | NO |
| C9X Wildlife mortalities | 0.00 | Green | NO |
| C10X Introduced species escape | 0.00 | Green | |
| **Total** | **43.05** | | |
| **Final score (0-10)** | **6.151** | | |

OVERALL RANKING

| | |
|---|---|
| Final Score | 6.151 |
| Initial rank | Yellow |
| Red criteria | 0 |
| Interim rank | Yellow |
| Critical Criteria? | NO |

| FINAL RANK |
|---|
| **Yellow** |

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

**Summary**

The final numerical score for barramundi *(Lates calcarifer)* produced in net pen production system in Van Phong Bay, Vietnam is 6.151 out of 10 which is in the Yellow range. The final recommendation is a Yellow "Good Alternative".

# Executive Summary

The scope of this assessment includes all barramundi (*Lates calcarifer*) grown in Norwegian style net pen production systems in Vietnam. Although barramundi are also produced in both ponds and small-scale marine cages, the scope of this assessment is limited to those produced in large Norwegian style marine net pens.

The amount of barramundi produced each year from Norwegian style net pens is about 5,000 mt $yr^{-1}$. Well over the majority, roughly 70%, of this production is exported to the United States of America.

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

Data on Vietnam barramundi production in Van Phong Bay were generally made available through personal communication with farmers. Given the relatively small industry barramundi represents within the aquaculture and fisheries industry in Vietnam, insight from academic research in the region and industry organizations or associations was limited. The average of all the sub-criterion was calculated to determine an overall final score for Criterion 1 – Data of 7.50 out of 10.

Overall, the concern for effluent is low-moderate. The effluent data quality and availability is good for barramundi farmed in Vietnam, so the Evidence-Based Assessment was used. The farm features a series of Norwegian style net pens and is located roughly 8 miles offshore from mainland Vietnam (but 800 to 2,000 meters from Hon Lon islands) and all effluent resulting from the production system enters the surrounding environment without treatment. To minimize the potential impacts of effluent to the surrounding ocean environment, the legally required EIA highlights mitigation techniques adopted by the farming operation such as utilizing pelleted feed, maintaining adequate fish stocking density, selecting a site with beneficial oceanographic characteristics, and fallowing of sites between cycles. Results from water quality samples taken from the water column and sediment at farm and control site locations from 2010-2019 demonstrate that effluents occasionally cause impacts in the surrounding water body, likely temporarily, and may be contributing to cumulative level impacts. Primarily, the results demonstrate that there is a measurable nutrient effect occurring at the farm sites, as net pens are unable to treat or contain effluent discharge. The range of measurements indicates that the impact is temporary and oscillates through time, but due to inconsistent sampling methodology in time, place, parameters measured, and low sample size, it is challenging to determine the frequency of impact occurrences. It is important to note that measurements have never exceeded regulatory thresholds. Control site samples had a large range, and/or a median that is greater than farm measurement medians (excluding DO) adding to the difficulty in determining whether or not farms are contributing to cumulative impacts at the waterbody or regional scale. Sediment monitoring data within the allowable zone of effect (AZE) demonstrates that effluent impacts are likely temporary, as fallowing results in improvements in redox potential measurements. Long term monitoring of biodiversity of the benthic community found there is no significant difference between the edge of the allowable zone of effect (AZE) (edge of the AZE is 50 meters from the cage site) and control sites (*p*-value $<0.05$) indicating that benthic impacts are likely temporary outside of the AZE as well. Therefore, the data show that effluent discharge results in occasional yet temporary impacts within the immediate vicinity of the farm, and there is potential for cumulative impacts at the waterbody scale. As a result, the final score for Criterion 2- Effluent is low-moderate and scores a 6 out of 10.

Given the scale of the industry and avoidance of sensitive marine habitat during farm siting, barramundi net pen operations have a minimal impact to marine ecosystems and the score for Factor 3.1 Habitat conversion and function is scored 9 out of 10. The content of habitat management measures is moderate. The management system is based on ecological principles, but the EIAs assessed do not fully align with the requirements of the Fishery Law of 2017 and do not account for habitat connectivity which creates the potential for cumulative impacts on ecosystem services. As a result, the score for Factor 3.2a is 3 out of 5. Enforcement of habitat management measures is also limited. Enforcement organizations are identifiable but there are limitations in available resources and in technical guidance to fully implement marine habitat protections required by law. Specifically, the important ecological principles outlined in the Fishery Law of 2017 are not applied to the EIAs assessed for barramundi marine net pen production and the enforcement is thus absent. As a result, cumulative impacts of farming operations may occur, and enforcement is scored a 2 out of 5. Therefore, Factor 3.1, Factor 3.2a, and Factor 3.2b combine in a final score of 6.8 out of 10 for Criterion 3 - Habitat.

Given the small size of the marine net pen barramundi industry in Vietnam, there is not a great deal of information available concerning the sector's chemical usage beyond direct communication with the operating company. Laws regulate which chemicals can be used, who may supply them for aquaculture purposes, and the enforcement bodies are identifiable. Open production systems, such as the net pens employed by the operating company, are open exchange with the surrounding water body enabling the risk of chemical treatments impacting the surrounding waterbody. There are 16 reported chemicals used during barramundi farming, though the two that represent potential ecological risks are formalin (as an antiparasitic) and the antibiotic oxytetracycline. Formalin is used to treat ectoparasites on juvenile fish and is used infrequently (on average, 1 out of every 4 batches are treated); the risk of formalin impacting the surrounding environment is very low. Oxytetracycline (OTC) is a highly important antimicrobial according to the World Health Organization and most of the application of OTC in net pens occurs immediately following the transfer of barramundi from the hatchery. The frequency of application is low and is calculated to be roughly 0.62 treatments for a typical production cycle and is consistent with the requirements of the ASC certification held by the farm. As data show that chemical treatments are applied, on average, less than once per production cycle, this results in a low concern for antimicrobial or antibiotic use and a score of 8 out of 10. Benthic biodiversity monitoring data collected by the production operation suggests that there is no impact of chemical use on non-target organisms outside the AZE, and sediment monitoring data suggests that there is no impact within the AZE, further justifying low concern (a score of 8 out of 10). As a result, the score for Criterion 4: Chemical Use is an 8 out of 10.

Barramundi production in Van Phong Bay net pens use feeds that contain fishmeal and fish oil sourced from both whole wild fish and from by-product raw material. The fishmeal inclusion level is 30% and the fish oil inclusion is 6%, with 100% of fishmeal and 50% of fish oil sourced from by-products from tuna fisheries, and the remaining 50% of fish oil originates from sardine and anchovy fisheries. The Feed Fish Efficiency Ratio (FFER) is moderate (1.014), meaning that 1.014 mt of wild fish are needed to produce the fish oil required to produce one mt of farmed barramundi. The sustainability of the source fisheries is also moderate and scores a 4.14 out of 10. Combined with the FFER, the Factor 5.1 – Wild fish use score is 5.01 out of 10. The net protein loss of -75.16% is high and results in a score of 2 out of 10 for Factor 5.2 – Net protein gain or loss. The feed footprint is low with approximately 12.99 kg of $CO_2$-eq per kg of harvested protein, resulting in a score of 7 out of 10 for Factor 5.3 – Feed footprint. Altogether, the three factors combine to give a final score of 4.75 out of 10 for Criterion 5-Feed.

Marine net pen production systems are open and vulnerable to escapes, but multiple escape prevention methods are employed including strategic farm siting, size grading with appropriate mesh size, and a detailed Escape Management Protocol system that emphasizes training, decision models, and action items. While a single large escape (>5% of the holding unit) has occurred in the last ten years, it was due to a stochastic event (Typhoon Damray) which prompted the operating company to adapt the construction and design of the net pens to prevent future occurrences. It was reported that nearly all escapees were recaptured by local fisherman, though this could not be confirmed. No such escapes have occurred in the five years since and as such, the adaptations made justify a lower level of concern for open systems with effective best management practices for design, construction, and management of escape prevention. Besides this event, escape events appear minimal from 2010-2018. The accounting of barramundi at stocking and harvest is within the error/variability of the accounting machine and model for all years except 2016, confirmed by third-party certification audits. If it is assumed that the reason for the difference between stocking and harvest of barramundi is due to trickle losses and not statistical error, then the total number of barramundi that may have escaped over these years could be up to 10,524, a number considered unlikely to cause population level impacts to wild species. Overall, the escape risk concern is moderate and the score for Factor 6.1 Escape Risk is 4 out of 10. Should barramundi escape from net pens, they may cause competitive and/or genetic impacts to wild species. There is limited data or literature readily available that evaluate or document the genetic risk or lack thereof between native, wild barramundi and farmed stock in Vietnam, though it is apparent that farm stock are multiple generations removed from the wild and have been selected for favorable traits. Despite this, the farm is located at least 800 km from suitable spawning grounds and there is no evidence that escapees have successfully spawned with wild barramundi. Documentation of other marine organisms such as fish, coral, crustaceans, invertebrates etc. inhabiting Van Phong Bay were unavailable in the Environmental Impact Assessment (2012) beyond noting the location of coral reefs proximal to the current operation, some of which appear to be <1 km from production areas (see Figure 10 in Factor 3.1). No information is available regarding the health of these reefs, though it is assumed that these areas host numerous species of fauna. Given the carnivorous nature of barramundi, it is considered possible that escapees may predate upon and/or compete for resources with fish, crustaceans, and other organisms that they interact with. However, given the limited number of escaped fish over the entire lifetime of the farm, any competitive, predatory, and/or genetic impacts that may occur from escapees are unlikely to affect the population status of wild species. As a result, the concern for 6.2 Competitive and genetic interactions is moderate and scores a 4 out of 10. Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6 – Escapes.

Overall, the open nature of net pen barramundi farms means that fish are readily exposed to pathogens and parasites occurring in the waterbody, on wild fish, or on other natural hosts. There is some documentation of clinical disease on the farm, but through effective biosecurity management and vaccination, clinical disease frequency and severity as well as resulting mortality all appear very low. There is no documentation of transmission of diseases from farmed barramundi to the surrounding marine ecosystem. Therefore, the concern for Disease Risk is Low-moderate and scores a 6 out of 10.

The barramundi marine net pen farming industry in Vietnam is entirely reliant on domesticated, hatchery-raised broodstock, eggs, and juveniles. The final score for Criterion 8x – Source of Stock is 0 out of -10.

Overall, deliberate lethal wildlife control is not used on the farm and there has been no death or injury to predators or wildlife since the start of operation about 10 years ago. The operating company employs high quality nets with proprietary tensioning and small mesh to limit the ability of predators to grip, enter, and or become entangled with the net pens. Interactions with birds are not uncommon, but predation is rare and interventions have not been required. The final numerical score for Criterion 9X – Wildlife Mortalities is 0 out of -10.

Barramundi are native to Vietnam and Van Phong Bay. Broodstock are maintained in local hatcheries in the bay; thus, there is no risk of exotic pathogens being introduced by barramundi and all transfers of fish occur within the bay.  The final score for Criterion 10X – Escape of secondary species is 0 out of -10.

Overall, the final numerical score Norwegian style net pen farmed barramundi *(Lates calcarifer)* in Vietnam is 6.151 out of 10, which is in the Yellow range. With zero Red criteria, the final rank is Yellow and a “Good Alternative” recommendation.

# Introduction

## Scope of the analysis and ensuing recommendation

**Species**

- Barramundi (*Lates calcarifer*)

**Geographic Coverage**

- Vietnam

**Production Method(s)**

- Norwegian style net pens

## Species Overview

**Brief overview of the species**

Barramundi or Asian sea bass (*Lates calcarifer*) is an estuarine species of the family Centropomidae (Lates: perches). Barramundi are native to the Indo-Pacific and its range extends as far north as Taiwan, south to the eastern Australian coast, east to Papua New Guinea, and as far west as the Persian Gulf (Greenwood 1976; Tucker et al. 2002). They are caught commercially and produced by aquaculture farmers. It is a prized sport fish capable of reaching up to six and a half feet in length, can live for twenty years, and weigh in excess of 50 kilograms (kg) (Shaklee et al. 1993). Barramundi are catadromous (fish that migrate from fresh water to salt water to spawn or reproduce) and move between fresh and saltwater during various stages of their life cycle.

Mature barramundi commonly live in estuaries and associated coastal waters or in the lower reaches of rivers. Preference is for slow-moving water in rivers, creeks, swamps, and estuaries, but may also be found around near-shore islands and reefs. They can tolerate a wide range of environmental conditions as well as high population densities. Farm raised barramundi can reach 500 grams(g) within 12 months, but some studies have suggested that 800 g may be possible within the same time frame at higher temperatures. Large barramundi (2-3 kg) can be grown within 18-24 months (Tucker et al. 2002; Barlow 1997).

Barramundi are protandrous hermaphrodites (i.e., juveniles develop into males first and then into females). Most start life as males and undergo sexual inversion to become functional females at five to seven years of age. Barramundi are highly fecund; a single female may produce 30–40 million eggs per spawning event (Moore 1982). Consequently, only relatively small numbers of broodstock are necessary to provide adequate numbers of larvae for hatchery production. They are well suited for aquaculture as they are hardy, fast-growing (Boonyaratpalin 1991), and universally regarded as a fine table fish. Additionally, barramundi have the ability to synthesize long chain omega-3 fatty acids (Tu et al. 2012) whose contribution to human health has been found to be important.

**Production system**

In Vietnam, there are two types of production methods farming barramundi: ponds and net pens. Pond production methods are characterized by the farming intensity, and the inclusion of polyculture. Net pen production methods are categorized depending on the size and location of the net pens.

*Net Pen farming in Vietnam - sea based family sized net pens*

Most family run cages are situated in sheltered sites close to fishing villages to ensure a good supply of trash fish as this is 95% of the diet (Kongkeo et al., 2010). These are mostly wooden or bamboo framed cages, supported with plastic or expanded polystyrene and anchored at each corner (Van Dung et al., 2016).

**Figure 1** Small sized cages in Central Vietnam (Kongkeo et al., 2010)

**Figure 2** Medium scale cages in central Vietnam (Kongkeo et al., 2010)

*Net Pen farming in Vietnam - large Norwegian style (polar-circle type) floating cages*

Large circular plastic framed cages with hanging nets are used in more exposed sites. These cages were imported at first but in 2003 a local company started manufacturing them. Cages are stocked with fingerlings from land based nurseries, and feed is entirely pelleted diet (Peet, 2014). The cages can produce 80-100 MT per batch (De Silva and Phillips, 2007).

**Figure 3** Norwegian style (polar-circle type) cage in southern Vietnam (Viet, 2018)

Although barramundi are also produced in both ponds and small-scale marine cages, the scope of this assessment is limited to those produced in large Norwegian style marine net pens.

**Production Statistics**

Vietnam does not report barramundi production, specifically, to the FAO, nor does the General Statistics Office of Vietnam release aquaculture data separated by species. Therefore, insight into the total production at the country level for barramundi production is limited to literature. Of the literature reviewed, estimates of production from 2010 to 2017 are illustrated in Figure 4, while 2018 and 2019 statistics are projected. At the time of writing this report, country-wide production volumes of barramundi in 2018 and 2019 were unavailable. Production totals for 2017 is estimated to be 15,226 mt $yr^{-1}$ (Seaman 2018). However, this estimate may be overly optimistic, as other expert estimates have suggested that annual production is around 8,450-8,950 mt (Goldman pers. com. 2018). For this assessment, the 8,450-8,950 mt production estimate for barramundi for 2018 is used.

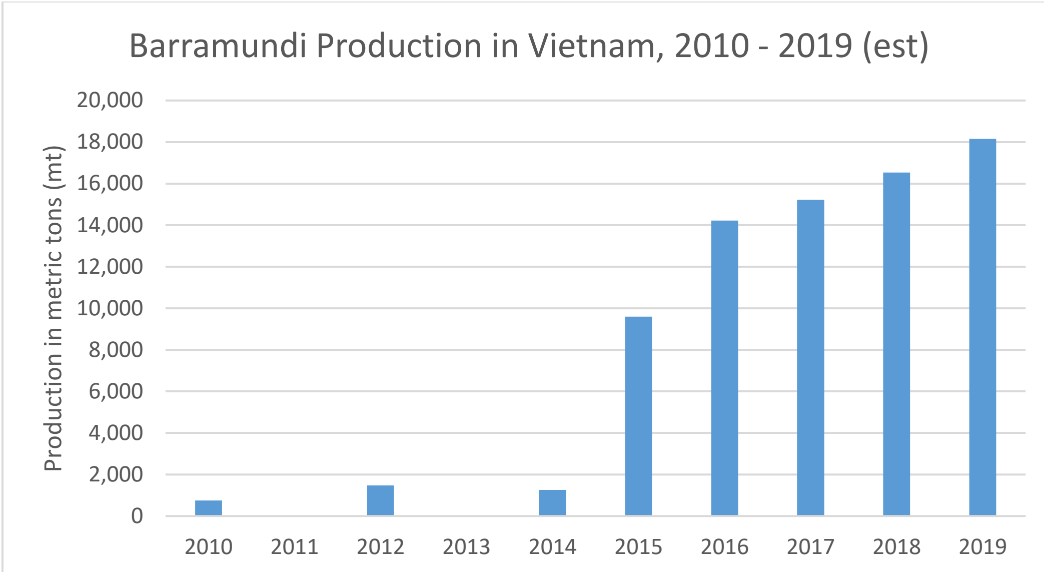


**Figure 4** Aquaculture production of barramundi in Vietnam in metric tonnes. 2010 data from Kongkeo et al. (2010), 2012 data from Petersen et al. (2015), 2015 -2017 data and 2018-2019 forecast extracted from Seaman (2018)

Given the aggregated nature of the available production volume statistics, limited information could be obtained regarding the volumes produced by each production system (ponds, small marine cages, and Norwegian style net pens).

Goldman (2018) estimates that roughly 3,200 – 3,700 mt $yr^{-1}$ of Barramundi are produced in ponds from Northern and Southern Vietnam. Northern Vietnam accounts for about 1,200 mt $yr^{-1}$ of barramundi production. These small-holder farms are organized into several cooperatives and grow barramundi in brackish and freshwater ponds. Southern Vietnam farmers are mostly located in the Soc Trang and Ben Tre provinces where there are several farms operating and producing about 2,000-2,500 mt $yr^{-1}$ of barramundi. Other Mekong Delta provinces that produce pond cultured barramundi are Tien Giang, Soc Trang, Bac Lieu, Camau and Kien Giang.

As for net pen production, Goldman (2018) estimates that net pen production accounts for roughly 5,250 mt $yr^{-1}$ with about 5,000 mt $yr^{-1}$ from Norwegian style net pens and 250 mt $yr^{-1}$ from small-scale marine cages.

**Import and Export Sources and Statistics**

There are no available official barramundi export statistics from Vietnam, but the vast majority of barramundi production is thought to be consumed within the country; however, the export fraction is growing with increasing awareness amongst western consumers (SFW, 2014).

According to Goldman (2018), about 60% of the 1,200 mt $yr^{-1}$ of pond production from Northern Vietnam is destined for China, while the remaining 40% heads to the domestic markets. In Southern Vietnam 2,000 to 2,500 mt per year of barramundi are destined for markets in the USA, EU, Asia and domestically. Finally, 70% of the roughly 5,000 mt $yr^{-1}$ of barramundi produced from large Norwegian style net pens is destined for the United States of America, while 20% is destined for Australia and the remaining 10% is for other markets.

Since estimates indicate that net pens account for 56-59% of total Vietnam barramundi production, of which 70% is exported to the United States of America with limited information regarding the export of barramundi produced in ponds and small marine cages, this assessment is limited in scope to Norwegian style marine net pen production from Vietnam.

**Common and Market Names**

| | |
|---|---|
| Scientific Name | *Lates calcarifer* |
| Common Name | Asian Sea bass, sea perch, giant sea perch, two fin seabass, blind seabass, giant palmer, narifish, kokopputih, bektiapahap, palakapong, nokogirihata |
| United States | Barramundi |
| Spanish | Barramundi |
| French | Barramundi |
| Japanese | バラマンディ |

**Product forms**
In the United States Barramundi is most frequently sold either as plate-sized fish (1-2lbs) or fillet-sized fish (2 to 6lbs) (SFW, 2014).

# Criterion 1: Data quality and availability

**Impact, unit of sustainability and principle**

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

**Criterion 1 Summary**

| Data Category | Data Quality | Score (0-10) |
|---|---|---|
| Industry or production statistics | 7.5 | 7.5 |
| Management | 7.5 | 7.5 |
| Effluent | 7.5 | 7.5 |
| Habitat | 7.5 | 7.5 |
| Chemical use | 7.5 | 7.5 |
| Feed | 7.5 | 7.5 |
| Escapes | 5 | 5 |
| Disease | 5 | 5 |
| Source of stock | 10 | 10 |
| Wildlife mortalities | 7.5 | 7.5 |
| Escape of secondary species | 10 | 10 |
| **Total** | | **82.5** |

| | | |
|---|---|---|
| **C1 Data Final Score (0-10)** | **7.50** | **GREEN** |

**Brief Summary**

Data on Vietnam barramundi production in Van Phong Bay were generally made available through personal communication with farmers. Given the relatively small industry barramundi represents within the aquaculture and fisheries industry in Vietnam, insight from academic research in the region and industry organizations or associations was limited. The average of all the sub-criterion was calculated to determine an overall final score for Criterion 1 – Data of 7.50 out of 10.

**Justification of Rating**

**Industry and Production Statistics**

Total annual statistics for Vietnam barramundi production were not well detailed, Vietnam does not report barramundi production, specifically, to the FAO, nor does the General Statistics Office of Vietnam release aquaculture data separated by species. Production from Norwegian style net pens, the scope of this assessment, were available, however. Insight into farm size, production system description, production volume, industry organization infrastructure, and export data were all gathered from literature, and personal communication. As a result, the industry and production statistics is moderate and scores a 7.5 out of 10.

**Management and Regulations**

Information regarding regulation, management, and enforcement of barramundi net pen production in Vietnam was obtained from literature, personal communication, and the FAO. Legislation was found and additional literature was available to help provide context to the laws and environmental protections framework. Insight into how enforcement and regulation is applied at the local level was somewhat limited, but some details could be found by evaluating the Environmental Impact Assessments, which were made available. As a result, data quality regarding management and regulation is moderate and receives a score of 7.5 out of 10.

**Effluent and Habitat**

Farm effluent standards and the farm siting process are well detailed and was obtained through personal communication and through government websites. Farm location, habitat type, history of conversion, and habitat impacts were all found from the Environmental Impact Assessment of barramundi operations in Van Phong Bay, Vietnam. Regulatory content was found through government websites and literature, but evidence of enforcement was more limited. Monitoring of effluent was made available by the barramundi operation in Van Phong Bay, which included water quality and nutrient enrichment measurements from the water column and sediment, as well as some benthic biodiversity monitoring data. The data provided for both habitat and effluent are considered to give a reliable representation of the operations impacts although there is some uncertainty as to whether the effluent data is fully representative. As a result, the data quality is moderate-high and scores a 7.5 out of 10.

### Chemical Use

The type of chemicals used for barramundi production is known and was provided through personal communication. Regulations related to chemical usage were detailed in government documents. Frequency of chemical use was provided by the operating company, though there was no literature citing the impacts, or lack thereof, of chemical treatments on farms to the surrounding ecosystems. Enforcement is apparent with harvest residue testing, onsite inspections, and certification audits. Therefore, the data quality and confidence regarding the use and impacts of chemicals is moderate-high and scores a 7.5 out of 10.

### Feed

Data for feed use efficiency and feed composition were gathered through personal communication and is considered fully representative of the diet for grow out production under the scope of this assessment. Detailed information such as the ingredient composition, source fishery, and inclusion levels were all provided, though some uncertainty remains in the source fisheries supplying wild fish ingredients. Therefore, the data quality confidence level is moderate-high and the score is 7.5 out of 10.

**Escapes**

Data were made available for barramundi escapes in Van Phong Bay from net pens through personal communication and include the results of a BAP audit and company accounting data that represents 9 years of projected and actual harvested barramundi. The potential competitive and genetic impacts of escapees to wild populations are not well detailed in the literature, however. As a result, the data quality is considered moderate for escapes and is scored 5 out of 10.

**Disease**

Information regarding disease affecting barramundi production in Van Phong Bay was obtained through personal communication. Biosecurity protocols, regulations, and mitigation strategies were well documented and provided through personal communication, alongside mortality ranges for specific pathogens. Literature about the impacts of these diseases on farmed barramundi was well documented, though the impacts (or lack thereof) of on-farm disease from Van Phong Bay net pen production to wild stocks were not well detailed. As a result, the quality of data is moderate, and scores a 5 out of 10.

**Source of Stock**

Information about the source of farm stocks and potential usage of wild fisheries was documented and made available through personal communication. The information is considered a reliable representation of the operation and its impacts and scores. As a result, the data quality is considered high and scores a 10 out of 10.

**Wildlife and Predator Mortalities**

Information about the predator and wildlife interactions and their management at farms was made available through personal communication. While confidence is limited in non-verifiable company provided statements, third-party certification audits confirm the accounting of species interactions and occurrences. Therefore, the data provided is useful, and certification audits help to strengthen confidence in the data. As a result, the data quality is considered moderate-high, and scores a 7.5 out of 10.

**Escape of Secondary Species**

Information about the location of hatchery operations, proximity to the net pen production in Van Phong Bay, and how barramundi are transported, were made available through personal communication. The data quality is considered high and scores a 10 out of 10.

**Conclusions and Final Score**

Data on Vietnam barramundi production in Van Phong Bay were generally made available through personal communication with farmers. Given the relatively small industry barramundi represents to the aquaculture and fisheries industry in Vietnam, insight from academic research in the region and industry organizations or associations was limited. The average of all the sub-criterion was calculated to determine an overall final score for Criterion 1 – Data of 7.50 out of 10.

# Criterion 2: Effluent

**Impact, unit of sustainability and principle**

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

**Criterion 2 Summary**

Effluent Evidence-Based Assessment

| | | |
|---|---|---|
| **C2 Effluent Final Score (0-10)** | **6** | **YELLOW** |

**Brief Summary**

Overall, the concern for effluent is low-moderate. The effluent data quality and availability is good for barramundi farmed in Vietnam, so the Evidence-Based Assessment was used. The farm features a series of Norwegian style net pens and is located roughly 8 miles offshore from mainland Vietnam (but 800 to 2,000 meters from Hon Lon islands) and all effluent resulting from the production system enters the surrounding environment without treatment.

To minimize the potential impacts of effluent to the surrounding ocean environment, the legally required EIA highlights mitigation techniques adopted by the farming operation such as utilizing pelleted feed, maintaining adequate fish stocking density, selecting a site with beneficial oceanographic characteristics, and fallowing of sites between cycles. Results from water quality samples taken from the water column and sediment at farm and control site locations from 2010-2019 demonstrate that effluents occasionally cause impacts in the surrounding water body, likely temporarily, and may be contributing to cumulative level impacts. Primarily, the results demonstrate that there is a measurable nutrient effect occurring at the farm sites, as net pens are unable to treat or contain effluent discharge. The range of measurements indicates that the impact is temporary and oscillates through time, but due to inconsistent sampling methodology in time, place, parameters measured, and low sample size, it is challenging to determine the frequency of impact occurrences. It is important to note that measurements have never exceeded regulatory thresholds. Control site samples had a large range, and/or a median that is greater than farm measurement medians (excluding DO) adding to the difficulty in determining whether or not farms are contributing to cumulative impacts at the waterbody or regional scale. Sediment monitoring data within the allowable zone of effect (AZE) demonstrates that effluent impacts are likely temporary, as fallowing results in improvements in redox potential measurements. Long term monitoring of biodiversity of the benthic community found there is no significant difference between the edge of the allowable zone of effect (AZE) (edge of the AZE is 50 meters from the cage site) and control sites (*p*-value <0.05) indicating that benthic impacts are likely temporary outside of the AZE as well.

Therefore, the data show that effluent discharge results in occasional yet temporary impacts within the immediate vicinity of the farm, and there is potential for cumulative impacts at the waterbody scale. As a result, the final score for Criterion 2- Effluent is low-moderate and scores a 6 out of 10.

**Justification of Rating**

**Evidence-Based Assessment:**
As effluent data quality and availability is high (Criterion 1 score of 7.5 out of 10), the Seafood Watch Evidence-Based Assessment was utilized.

The organic wastes which are generated as a by-product of farming fish in open net pens inevitably flow unimpeded from the culture zone into the surrounding environment. These wastes primarily include fish feces and uneaten food, which are dispersed as solid particles, alongside dissolved nutrients (primarily nitrogen and phosphorus), which are released from the gills and also from the urine of fish.

There is a substantial body of literature on the fate and impact of nutrient wastes from net pen fish farms, and key recent reviews such as Price et al. (2015) provide a useful summary. Price et al. (2015) conclude modern operating conditions have minimized impacts of individual fish farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment of the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). However, when sited nearshore, extra caution should be taken to manage farm location, size, biomass, feeding protocols, orientation with respect to prevailing currents, and water depth to minimize near- and far-field impacts, and Price et al. caution that regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the additive (i.e. cumulative) impacts of discharge from multiple, proximal farms, potentially leading to increased primary production and eutrophication.

Also, intensive fish farming activities may generate a localized gradient of organic enrichment in the underlying and adjacent sediments as a result of uneaten food and feces and can strongly influence the abundance and diversity of infaunal communities. In the area under the net pens or within the regulatory allowable zone of enforcement (AZE), the impacts may be profound and are now relatively well understood (see Black et al. 2008 for a review of these impacts). Primarily, changes can be anticipated in total volatile solids, redox potential, and sulfur chemistry in the sediments in the immediate vicinity of operational net pens, along with changes to the species composition, total taxa, abundance, and total biomass (Keeley et al. 2013). Significant decreases in both the abundance and diversity of macrofauna are sometimes seen under farms located in depositional areas, characterized by slow currents and fine-grained sediments, while net pens located in erosional environments with fast currents and sediments dominated by rock, cobble, gravel, and shell hash can dramatically increase macrobenthic production (Keeley et al. 2013). Furthermore, nutrient loading can reduce benthic biodiversity and in tropical oligotrophic areas benthic environments such as coralline algae and seagrass are especially sensitive to sedimentation (Olsen et al. 2008). To avoid benthic impacts, farms sited in areas with favorable oceanographic characteristics can help flush and disperse particulate matter (Olsen et al. 2008).

The currently operating barramundi net pen facility is located in Van Phong Bay, which has approximately 100,000 hectares of surface area with a depth between 20-30 meters. Throughout the Bay, there is a mixture of benthic habitat that includes coral species, seaweed, and substrate classified as "fine sand with grey or ash grey color" (EIA, 2012). The Bay opens to the South and into the South China Sea where water exchanges are driven by tides and surface wind. The waters are considered oligotrophic (personal communication Goldman, 2019).

There are roughly 10 sites that are permitted to grow barramundi in net pens around Hon Lon Island in 3 growing areas: Hon Den, Hon Me, and the Channel area. During operation, typically 4 farms are in use at any one time (see Figure 7) between the 10 sites/3 growing areas (personal communication Goldman, 2020). Each farm consists of 14 net pens (2 column x 7 row array), and each net pen is spaced 80 meters from one another and approximately 10-20 meters from the benthic zone (see Figure 5 and Figure 6) (personal communication Goldman, 2020). This allows for adequate flow around cages and flushing of bottom benthic area. The water flow at 10 meters depth was between 4-56 cm/s, while at 30 meters depth the water flow was between 2-45 cm/s, and was deemed suitable for aquaculture production (EIA, 2012). Each growing area is managed to maintain equal biomass between the growing areas, while also managing for fallowing, and seasonality (see Figure 5). Sites are fallowed between production cycles for at least one year (personal communication Goldman, 2020). Additional management strategies are implemented to minimize benthic impacts like alternating net pen stocking (see Figure 5), ensuring low stocking density of 10-20 fish/$m^3$, pet net pen, using pelleted feed (as opposed to whole fish), and cleaning all net pens before stocking and after harvest (personal communication Goldman, 2020; EIA, 2012). Combined, all practices and farm siting considerations discussed align with the mitigation and effluent related considerations described by Price et al. 2015 as "modern aquaculture practices".

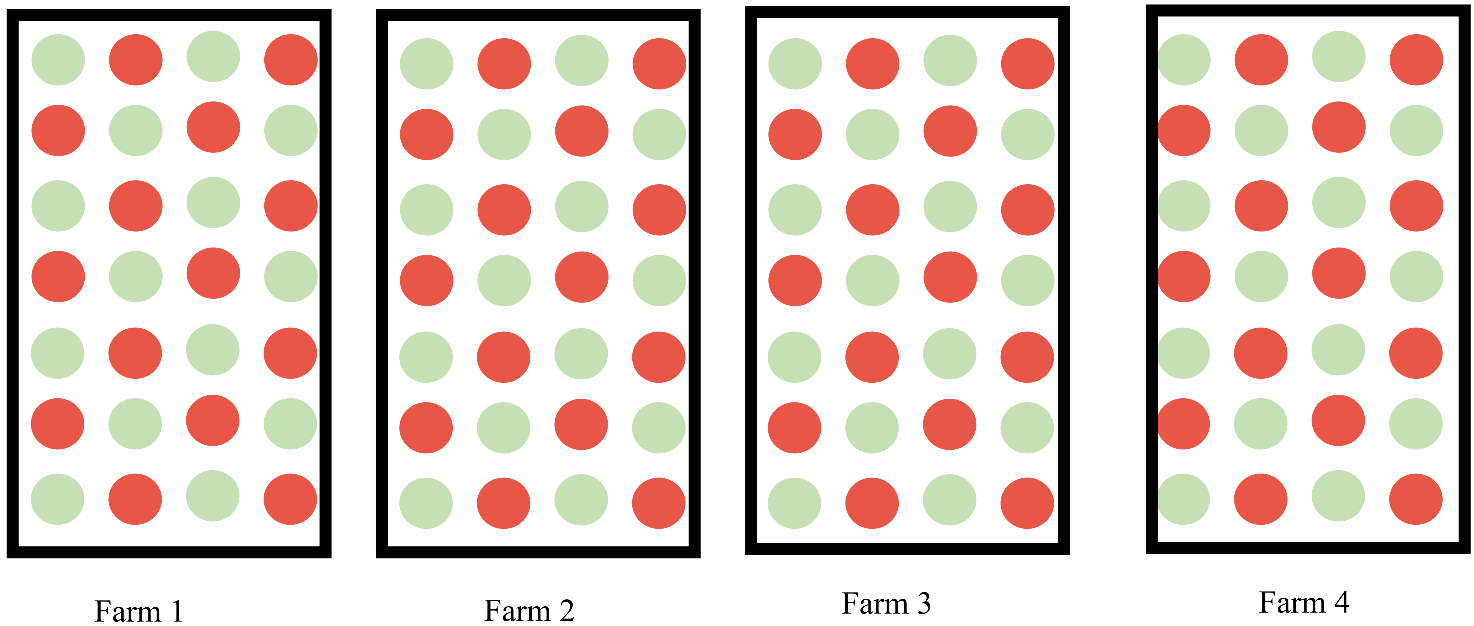


**Figure 5:** Net pens are configured into 4 modules each consisting of 28 net pens spaced into 4 columns and 7 rows that are spaced about 7-10 meters apart. The fallowing methodology consists of alternate use of cages to minimize benthic impacts. To capture the described fallowing methodology, a color scheme of green and red was used to illustrate net pens in use (green), net pens not in use (red). Source: Environmental Impact Assessment, 2012.

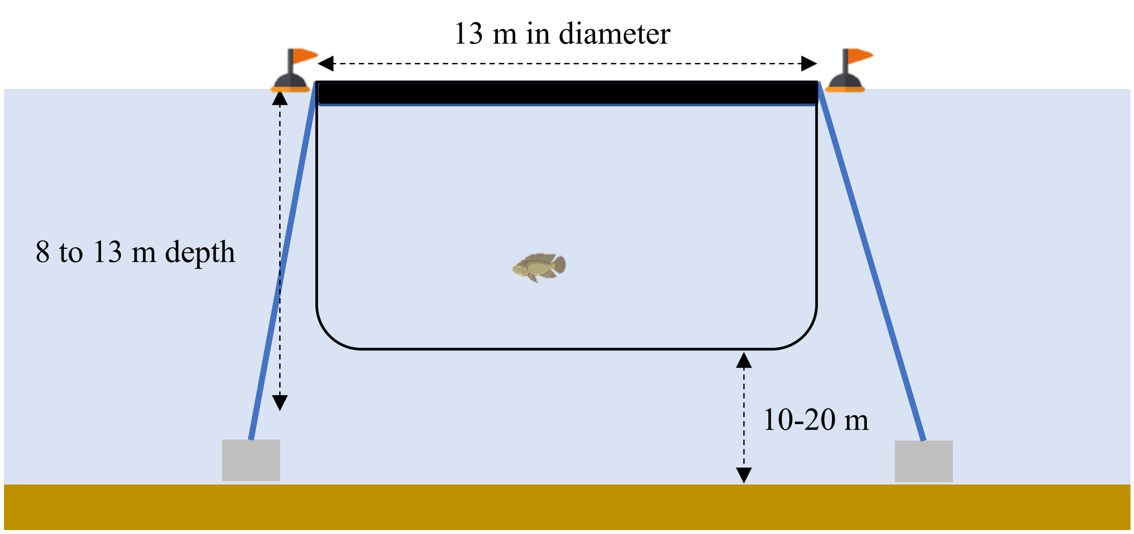


**Figure 6:** Net pen dimensions and configuration. Pens are 13 meters in diameter, are 12 to 13 meters in depth, and are positioned between 5-7 meters from the benthic zone. Each cage is anchored to concrete blocks. Source: Environmental Impact Assessment, 2012.


**Figure 7** Each module is situated around the Hon Lon Island. The image shows how farms are rotated between the three sites (Hon Den, Hon Me, and Channel area) to help manage production and effluent related impacts.

With respect to regulation, aquaculture management in Vietnam is structured through the Master Plan of Vietnam Fisheries and Aquaculture Development through 2020 and Vision to 2030. This vision sets the overarching goals for aquaculture production, while also protecting the environment. The environmental legislative tools that seek to achieve these goals include the Fisheries Law of 2017, the Law on Environmental Protection, which provides the legality for Environmental Impact Assessments, and "secondary legislation, mainly decrees, adopted on the basis of these laws." (Murekezi, 2014).

Effluent regulations are determined by relevant government agencies, and standards after an aquaculture leasing and approval process is completed. Several governmental groups are involved in the authorization process for an aquaculture lease, including local government "People's Committees," regional offices of the Natural Resources and Environment Sections, the state-level Ministry of Natural Resources and Environment (MONRE), and the Ministry of Agriculture and Rural Development (MARD) (Murekezi, 2014). In order to obtain a lease, a feasibility study, justification of technical capacity and an environmental impact assessment (EIA) must be completed by the environmental management agency (Murekezi, 2014). The environmental impact assessment must include the following (Murekezi 2014):

1. "the location of the execution of the project;
2. the type and scale of production, business or service, and materials and fuel used;
3. the kind of wastes generated; and
4. the commitment to apply measures to minimize and treat wastes and to strictly comply with the provisions of the Law on Environmental Protection."

For the currently operating barramundi operation, the environmental impact assessment (2012) concludes that ambient pre-farming water quality parameters that consume or produce oxygen (primary productivity, biological oxygen demand, primary productivity in sediment) are all low, which suggests that the waterbody and ecosystem is oligotrophic. Other water quality parameters such as dissolved oxygen concentrations, pH, salinity, nitrogen, phosphorous, silica, and heavy metals were all measured to be within ranges that are suitable for marine aquaculture as determined by Vietnam's National Technical Standards on coastal water quality (QCVN 43: 2012/BTNMT). Phosphate levels were elevated at times in one of the operating areas, known as Hon Me, so management plans were deemed necessary to minimize phosphorous input. The sediment bottom is characterized as a heterotrophic environment with low primary productivity and higher respiration that can result in anaerobic conditions. The sediment samples also indicated high levels of petroleum hydrocarbons that the report attributes to the heavy marine traffic in the area. Water sample results of coliform bacteria and *E. coli* levels were considered low.

To comply to the findings of the EIA, the implementation of mitigation measures was deemed necessary to limit effluent related impacts. Strategies implemented include site fallowing, feed management, and biomass/stocking density management. Also, net pens are strategically spaced 80 meters from one another to allow for water flow under and around net pens, and each farm location was partially selected for adequate water flow rates (EIA, 2012).

Water quality monitoring data were made available by the Van Phong Bay barramundi operation. The operation provided water quality measurements for 18 parameters taken from the water column and sediment twice a year (October and April) from 2010-2013 at the Hon Me, Hon Den, and Control locations. During this time, Hon Me was operating as a nursery site, Hon Den was a grow out location, and the control site was approximately 5 km south of the Hon Me and Hon Den area. Water quality sample measurements were taken directly below production cage position at Hon Me site A, Hon Den site A, but Hon Me site B and Hon Den site B samples were taken 500 m south of the Hon Me site A production pen. From 2014-2019, water quality measurements for sediment and water column were measured at three production sites Hon Me, Hon Den and the Channel (see Figure 7 where each production site is shown, but not all individual farm locations). Hon Me has four farm locations documented as: HM, A, B, and D. Hon Den has 5 documented farm locations: A, B, 2, 3, and B3. The Channel has three documented production sites: C1, C3 and Channel. All measurements were taken directly below the production net pens. There are two control sites: C, which is located 5 km south of Hon Me and Hon Den production sites, and D, which is located 2 km south of Channel 3 farm. Samples were measured in March/April and October/November from 2014-2019. Roughly 42 water quality parameters were measured for each sample with parameters ranging from nutrients, heavy metals, pesticides, and bacteria.

These datasets were combined to create a continuous record of sediment and water column samples from 2010 to 2019. Not all farm sites and/or parameters were consistently measured in the fall and spring of each year, so there are some gaps in the data. Also, there is a low sample size for some parameters. The dataset is summarized in Appendix 2: Summary of water column and sediment measurements.

This dataset was then used to evaluate the scale of ecological impact, and frequency of impact occurrences from barramundi net pen effluent in Van Phong Bay. Data was grouped by the farm site for all years, and box and whisker plots were used to visualize and analyze the parameters (see Appendix 2: Summary of water column and sediment measurements).

Results show that barramundi effluent has a measurable effect on the surrounding water body, likely temporarily, and may be contributing to cumulative level impacts (See Appendix 2: Summary of water column and sediment measurements). There are a wide range of measurements for both water column and sediment samples from parameters such as dissolved oxygen, ammonium, phosphate, sulfate, total organic nitrogen, total organic phosphorous, nitrate, biological oxygen demand, and redox. Two water quality parameters – ammonium and phosphate – are shown in Figure 8 and 9 and are highlighted here as they demonstrate the patterns seen with other parameters. Primarily, the measurements demonstrate that there is a measurable effect occurring at the farm sites, as net pens are unable to treat or contain effluent discharge. The range of measurements indicates that the impact is temporary and oscillates through time, but due to inconsistent sampling methodology in time, place, parameters measured, and low sample size, it is challenging to determine the frequency of impact occurrences. Control site samples had a large range, and/or a median that is greater than farm measurement medians (excluding DO), which may indicate that barramundi farm effluent is contributing to cumulative level impacts.

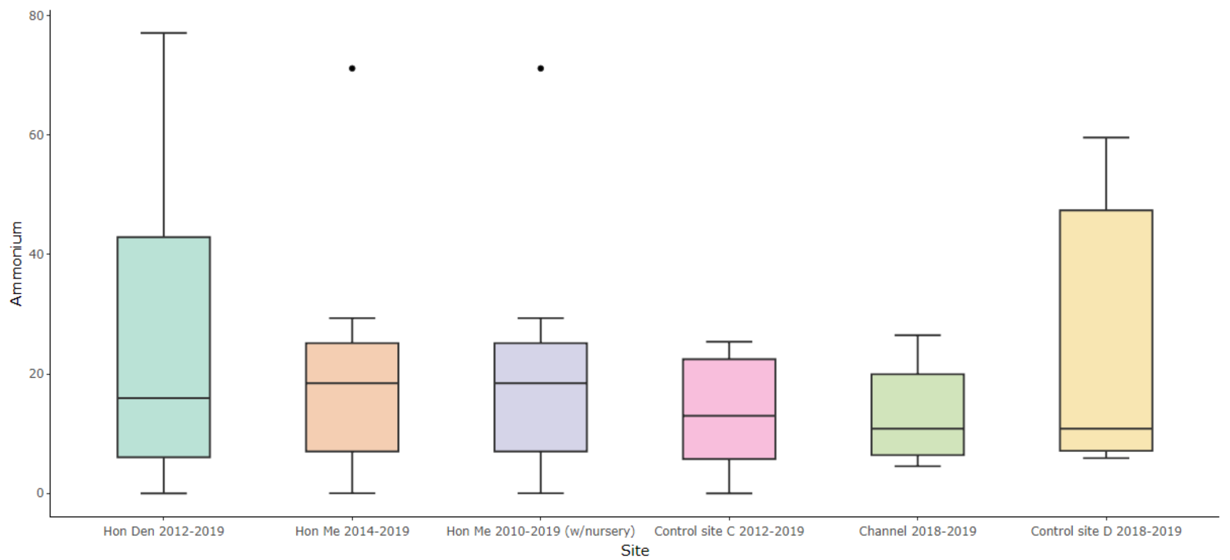


**Figure 8** Box plot of ammonium measurements taken from the water column and grouped by the farm site with measurement years noted. Farm sites are Hon Den, Hon Me as a grow out farm and Hon Me as a nursery. Control sites are Control site C, Channel, and Control site D. The box plots show the 25th and 75th percentiles, the horizontal line indicates the median. The dots represent outliers.

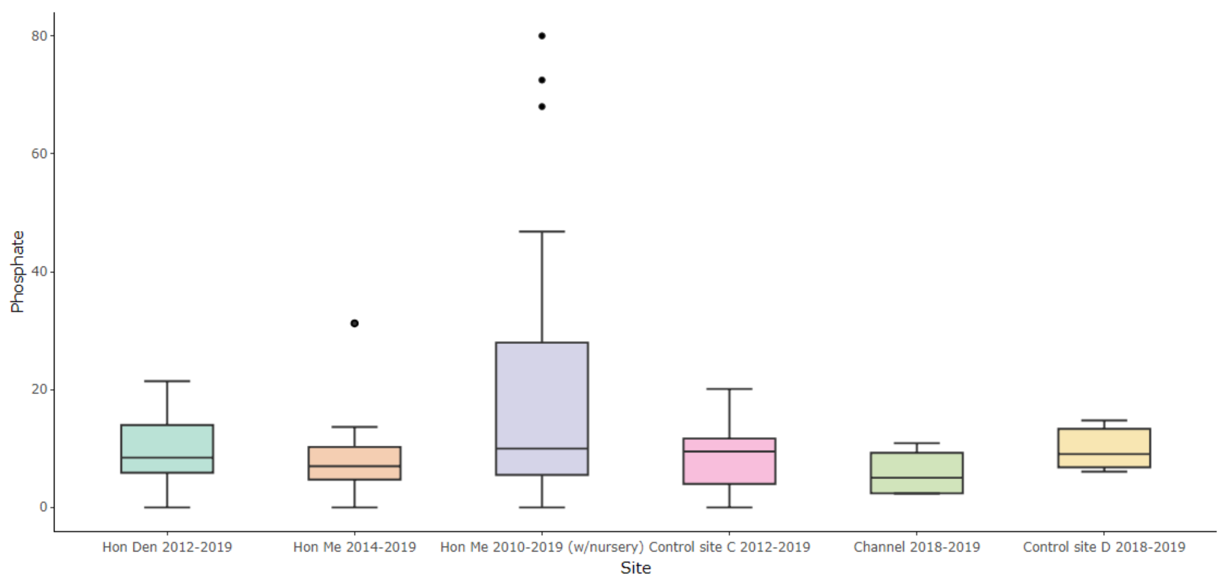


**Figure 9** Box plot of phosphate measurements taken from the water column and grouped by the farm site with measurement years noted. Farm sites are Hon Den, Hon Me as a grow out farm and Hon Me as a nursery. Control sites are Control site C, Channel, and Control site D. The box plots show the 25th and 75th percentiles, the horizontal line indicates the median. The dots represent outliers.

For all the parameters measured, there have been zero instances where effluent exceeded the National Technical Regulations on Coastal Water Quality limits. The effluent standards (n=24 parameters) are applicable for all aquaculture operations within 3 miles from the coast and is managed by the Ministry of Natural Resources and Environment (see an abbreviated list is shown in Table 1). The degree to which these standards consider ecological impacts from multiple farms at a cumulative level is not known, and documentation on how these prescriptive limits were generated is unknown.

**Table 1:** Water column effluent limits for aquaculture operations operating within 3 miles from the coast. There are 24 parameters total, but is abbreviated here.

| Parameter | Limit |
|---|---|
| **pH** | 6.5-8.5 |
| **Total Suspended Solids (mg/l)** | 50 |
| **Dissolved Oxygen (mg/l)** | ≥5 |
| **Ammonium (µ/l)** | 100 |
| **Phosphorous (µg/l)** | 200 |
| **Chlorophyll a (µg/l)** | 100 |
| **Coliform (MNP/100 ml)** | 1000 |

**Table 2** Sediment monitoring data by site within the AZE before, during and after a period of fallowing.

| | Pre farming (on farm) | Control Site | Last sample before fallowing (on farm) | Months Fallow | After Fallowing Period |
|---|---|---|---|---|---|
| **Channel 3** | *Nov-18* | *Nov-18* | *May-19* | *Sep-19* | *Jun-20* |
| pH | 7.54 | 7.49 | 7.31 | | 7.31 |
| Redox | -60.4 | -73.1 | -60 | 9 | -28.2 |
| Free sulfide | 51.9 | 36.8 | 4.6 | | 157.7 |
| **Channel 4** | *Dec-19* | *Dec-19* | *Jun-20* | *Jun-20* | *Dec-20* |
| pH | NA | NA | 7.29 | | 7.48 |
| Redox | -60.97 | -61.63 | -26.5 | 6 | -29.3 |
| Free sulfide | 614.4 | 15.0 | 125.9 | | 197.16 |
| **Channel 2** | | | *Apr-18* | *Oct-18* | *Dec-20* |
| pH | NA | NA | 7.45 | | 7.54 |
| Redox | -60.97 | -61.63 | -48.4 | 26 | -31.0 |
| Free sulfide | 614.4 | 15.0 | 5.19 | | 4.98 |
| **HonMe D** | *Nov-18* | *Nov-18* | *Jun-20* | *May-20* | *Dec-20* |
| pH | 7.41 | 7.43 | 7.29 | | 7.42 |
| Redox | -63.20 | -55.4 | -26.8 | 7 | -23.6 |
| Free sulfide | 75.8 | 27.5 | 234.4 | | 5.53 |
| **HonDen 2** | | *Apr-15* | *Apr-17* | *Sep-18* | *Jun-20* |
| pH | NA | 7.32 | 7.21 | | 7.31 |
| Redox | NA | -93 | -75 | 21 | -27.6 |
| Free sulfide | NA | 129.0 | 1.5 | | 16.2 |

To help mitigate potential benthic issues, fallowing is implemented at each farming site with a fallowing period of about one year between production cycles (personal communication Goldman, 2020). To help determine the effectiveness of fallowing, a separate dataset was provided of monitoring data within the AZE, which allowed for an evaluation of the farming operations impact (or lack there of) on sediment bottom before, during and after a period of fallowing (see Table 2). Sediment water quality measurements such as pH, Redox, and free sulfide were sampled at 5 sites (e.g. Channel 3, Channel 4, Channel 2, Hon Me D, and Hon Den 2) along with a control site for each location. Measurements were taken directly beneath the farms (except for the control site). Sample dates varied based on the site, but generally were taken before farming began at the farming site and control site, just before fallowing began, and lastly, a sample was measured some time (6-26 months) after fallowing started. Each value reported is representative of a single measurement, except for some of the measurements taken during the fallowing period (e.g. Channel 4, Channel 2, and Hon Me D). These values are reporting the mean of 3 samples, presumably all taken around the same time. In general, there is an upward trend in water quality measurements sampled from farming operations to the fallowing period (e.g., pH and Redox). The redox potential measurements increase suggesting that the sediment area more aerobic due to a change in microbial activity from the lack of effluent. But it is challenging to contextualize how effective fallowing is since the fallowing measurements for Redox are greater than baseline or reference values (e.g. the control sites, and pre farming measurements) and free sulfide measurements are inconsistent. This may be due to sampling methodology (e.g., low sample size, manual sampling inconsistencies) and/or other activities in Van Phong Bay altering the free sulfide and redox measurements. This pattern is consistent with the water column and other sediment samples and, thus, may signal that farming activities are potentially contributing to cumulative impacts at the waterbody scale. Regardless, fallowing does result in a small increase in pH and a trend of redox samples becoming moderately more aerobic (although all readings are still negative) effectively demonstrating that effluent impacts within the AZE are likely temporary.

Besides water quality parameter measurements, impacts of net pen finfish production can be assessed by evaluating the biodiversity of the benthic community. The net pens in Van Phong Bay are located above benthic sediment characterized as “fine sand with grey or ash grey color” and at 30 meters in depth the water flow was between 2-45 cm/s (EIA, 2012), which can be characterized as a slow current. Given these characteristics, significant decreases in both the abundance and diversity of macrofauna are sometimes seen under farms located in depositional areas (Keeley et al. 2013). Long-term monitoring of biodiversity of the benthic community collected and analyzed by the barramundi operation found that there is no significant difference between the edge of the allowable zone of effect (AZE) (edge of the AZE is 25 meters from the cage site) and control sites ($p$-value <0.05) (Summary of Benthic Biodiversity Results, 2019). Insight and data for biodiversity impacts within the allowable zone of effect were not found.

**Conclusions and Final Score**

Overall, the concern for effluent is low-moderate. The effluent data quality and availability is good for barramundi farmed in Vietnam, so the Evidence-Based Assessment was used. The farm features a series of Norwegian style net pens and is located roughly 8 miles offshore from mainland Vietnam (but 800 to 2,000 meters from Hon Lon islands) and all effluent resulting from the production system enters the surrounding environment without treatment.

To minimize the potential impacts of effluent to the surrounding ocean environment, the legally required EIA highlights mitigation techniques adopted by the farming operation such as utilizing pelleted feed, maintaining adequate fish stocking density, selecting a site with beneficial oceanographic characteristics, and fallowing of sites between cycles. Results from water quality samples taken from the water column and sediment at farm and control site locations from 2010-2019 demonstrate that effluents occasionally cause impacts in the surrounding water body, likely temporarily, and may be contributing to cumulative level impacts. Primarily, the results demonstrate that there is a measurable nutrient effect occurring at the farm sites, as net pens are unable to treat or contain effluent discharge. The range of measurements indicates that the impact is temporary and oscillates through time, but due to inconsistent sampling methodology in time, place, parameters measured, and low sample size, it is challenging to determine the frequency of impact occurrences. It is important to note that measurements have never exceeded regulatory thresholds. Control site samples had a large range, and/or a median that is greater than farm measurement medians (excluding DO) adding to the difficulty in determining whether or not farms are contributing to cumulative impacts at the waterbody or regional scale. Sediment monitoring data within the allowable zone of effect (AZE) demonstrates that effluent impacts are likely temporary, as fallowing results in improvements in redox potential measurements. Long term monitoring of biodiversity of the benthic community found there is no significant difference between the edge of the allowable zone of effect (AZE) (edge of the AZE is 50 meters from the cage site) and control sites ($p$-value $<0.05$) indicating that benthic impacts are likely temporary outside of the AZE as well.

Therefore, the data show that effluent discharge results in occasional yet temporary impacts within the immediate vicinity of the farm, and there is potential for cumulative impacts at the waterbody scale. As a result, the final score for Criterion 2- Effluent is low-moderate and scores a 6 out of 10.

## Criterion 3: Habitat

**Impact, unit of sustainability and principle**

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

**Criterion 3 Summary**

| Habitat parameters | Value | Score |
|---|---|---|
| F3.1 Habitat conversion and function | | 9 |
| F3.2a Content of habitat regulations | 3 | |
| F3.2b Enforcement of habitat regulations | 2 | |
| F3.2 Regulatory or management effectiveness score | | 2.4 |
| **C3 Habitat Final Score (0-10)** | | **6.8** |
| Critical? | No | **Green** |

**Brief Summary**

Given the scale of the industry and avoidance of sensitive marine habitat during farm siting, barramundi net pen operations have a minimal impact to marine ecosystems and the score for Factor 3.1 Habitat conversion and function is scored 9 out of 10. The content of habitat management measures is moderate. The management system is based on ecological principles, but the EIAs assessed do not fully align with the requirements of the Fishery Law of 2017 and do not account for habitat connectivity which creates the potential for cumulative impacts on ecosystem services. As a result, the score for Factor 3.2a is 3 out of 5. Enforcement of habitat management measures is also limited. Enforcement organizations are identifiable but there are limitations in available resources and in technical guidance to fully implement marine habitat protections required by law. Specifically, the important ecological principles outlined in the Fishery Law of 2017 are not applied to the EIAs assessed for barramundi marine net pen production and the enforcement is thus absent. As a result, cumulative impacts of farming operations may occur, and enforcement is scored a 2 out of 5. Therefore, Factor 3.1, Factor 3.2a, and Factor 3.2b combine in a final score of 6.8 out of 10 for Criterion 3 - Habitat.

**Justification of Rating**

The habitat criterion assesses the impacts of farm construction and operation/presence on the coastal ocean environment where the barramundi farm is located in Van Phong Bay Vietnam.

**Factor 3.1. Habitat conversion and function**

Van Phong Bay is located in central Vietnam and has approximately 100,000 hectares of sea surface area. Barramundi net pen production is located greater than 8 km offshore from mainland Vietnam in Van Phong Bay but is concentrated around Hon Lon island (see Figure 11). Production began in 2008 and has expanded as recently as of 2018. The recent expansion includes the addition of net pens and associated structures covering 100 ha of sea surface area and is located next to the Hon Me location. Currently, there are 4 farms operating totaling 100 ha (roughly 0.1% of Van Phong Bay's surface area) spread around Hon Lon island about 800-2,000 m from shore. Each module consists up to 14 net pens (2 column x 7 row array), and each net pen is spaced 80 meters from one another and approximately 10-20 meters from the benthic zone, as measured from the bottom of each pen. Each cage is anchored to a steel anchors positioned on the benthic zone (personal communication, 2020). The benthic habitat where farm production is located consists of "fine sand with grey or ash grey color" and "clay mud" (EIA, 2012). Marine seaweed and roughly 200 species of coral are found in Van Phong Bay but are not found under the farm production locations (EIA, 2012). The distance between farm location and coral habitat is unclear, and the spatial distribution of coral reefs are illustrated in Figure 10. The distance between the marine net pens and seaweed appears significant. According to Vo et al. (2020), seagrass meadows in Van Phong Bay are located near My Giang, Tuan Le, and Xuan Tu, all locations are greater than 5km from any production site.

Considering the location of the farm (800 to 2000 m from Hon Lon Island), the depth of the marine environment (~20 m), and the benthic substrate (sand/clay), the marine habitat type that best describes the area barramundi marine net pens occupy is nearshore and coastal. It is unknown if the three-dimensional area that this farm occupies has any impact to marine organisms that may value the sandy bottom habitat or if this area is an important migratory corridor for marine species.

Overall, the scale of barramundi net pen farming in Van Phong Bay is small but expanding. Including the recent expansion, the operation occupies roughly <1% of the entire bays surface area. Given the proximity of barramundi operations to Hon Lon Island (800 to 2000m) and the depth of net pen operations (<20 m) the habitat type is considered nearshore and coastal. There is no documentation that suggests the operation has impacted sensitive marine habitat species such as coral or seaweed, and analysis indicates that the risk of impact is very low given the distance between them and the farm sites. The ecosystem services that the sandy benthic coastal habitat provides for Van Phong Bay is not documented but given the relatively small footprint of the operation, the overall habitat impact is likely minimal. Therefore, the score for Factor 3.1 is 9 out of 10.

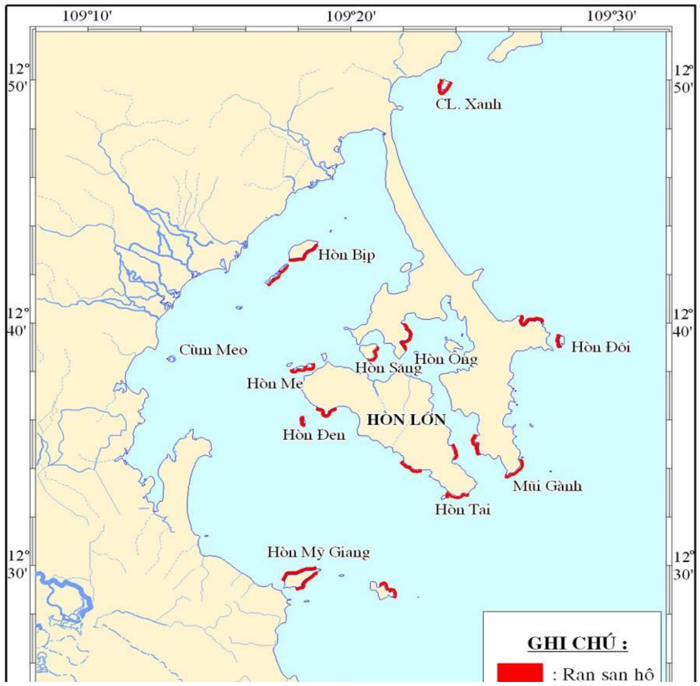


**Figure 10:** Van Phong Bay with coral reef locations marked in red. Source: EIA, 2012

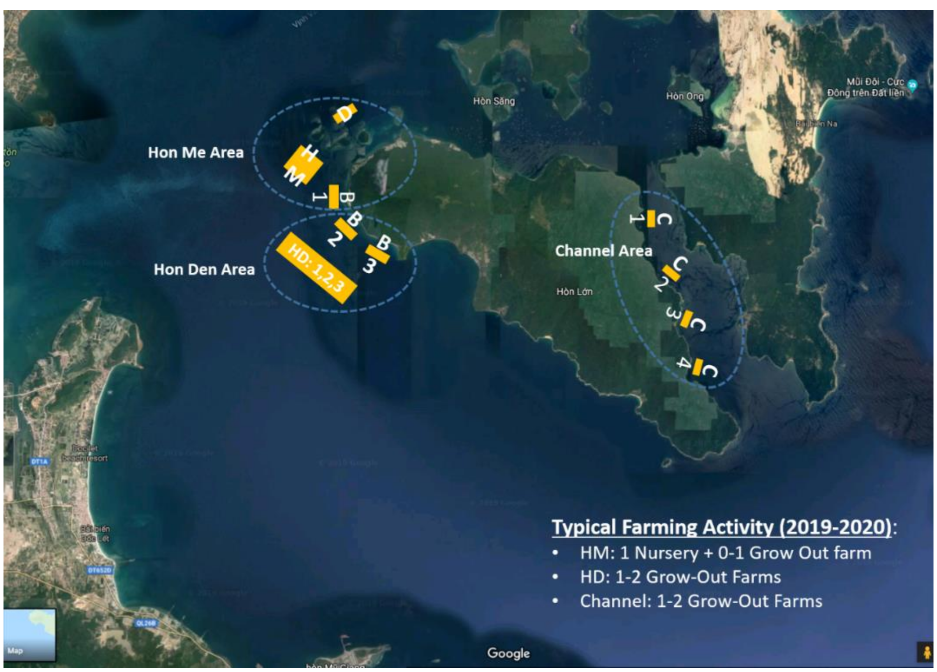


**Figure 11** Van Phong Bay and net pen aquaculture farming sites. Source: EIA, 2012

**Factor 3.2 Farm siting regulation and management**

Factor 3.2 assesses the effectiveness of the regulatory and farm management practices in addressing the potential cumulative impacts from multiple farming sites.

Factor 3.2a: Content of habitat management measures

The Master Plan of Vietnam Fisheries and Aquaculture Development through 2020 and Vision to 2030 sets three main targets for Vietnam aquaculture industry (Hong et al. 2017):

1. "To increase international competitiveness and high productivity in the context of globalization and regional integration.
2. To foster modernization and industrialization of Vietnam's fisheries and aquaculture while protecting environment and marine ecosystem in the coastal areas.
3. To reinforce sustainability of Vietnam's fisheries and aquaculture which successfully composes three pillars of environment, economics and society objectives"

The main legislative tools that are in place that seek to meet the goals of the Master Plan by developing sustainable aquaculture and protecting habitats include the Fisheries Law of 2017, the Law on Environmental Protection which provides the legality for Environmental Impact Assessments, and "secondary legislation, mainly decrees, adopted on the basis of these laws." (Murekezi, 2014).

All net pen barramundi aquaculture operations must first go through a formal permitting process, which is articulated in the Fisheries Law of 2017 and determines the necessary steps for access, lease, and obligations of marine areas for aquaculture purposes.

The governing body that may grant access for marine net pen farming depends on the distance from shore. Farms less than 6 nautical miles from shore must obtain permission for aquaculture development from the local People's Committee, and farms greater than 6 nautical miles from shore must obtain access from the Ministry of Agriculture and Rural Development's Department of Aquaculture (Fisheries Law Article 39, 2017). However, any access must be in accordance with the Master Plan of Vietnam Fisheries and Aquaculture Development through 2020 and Vision to 2030 (Murekezi, 2014; Fisheries Law of 2017, Article 44; Hong et al., 2017).

Farms cannot be built in estuaries or destroy mangrove forests, and must avoid Marine Protected Areas, and "encroachment or damage to protected zones" (Fisheries Law of 2017 Article 7). Protected zones are defined as:

> "An aquatic resource protected area is a habitat, reproductive area or a place where offspring live regularly or seasonally of at least one aquatic species included in the list of endangered, precious and rare aquatic species, native aquatic species or transboundary aquatic species." (Fisheries Law of 2017, Article 17).

Protected areas are determined by the Ministry of Agriculture and Rural Development (MARD), and the People's Committee of each province with guidelines for managing protected areas determined by MARD (Fishery Law of 2017).

If access is granted (alongside compliance with the provisions above), an environmental impact assessment must be conducted and upon approval, a lease is developed (Murekezi, 2014). Leases must be less than 20 years and may be renewed. However, leases may be revoked if (Murekezi, 2014):

- "the marine area is misused;
- the marine area has not been used continuously for 24 months except for proper reasons accepted by competent State agencies;
- the users of marine areas `for aquaculture do not fully comply with the obligations established in the Aquaculture Chapter of Viet Nam's Fisheries Law;
- the users of marine areas for aquaculture voluntarily return the allocated or leased areas; or
- the State needs to revoke for public security and national defense purposes."

There are three phases to the environmental impact assessment: "strategic environmental assessment, environmental impact assessment reports, and environmental protection commitments." (Murekezi, 2014).

The initial procedure is the strategic environmental assessment. "The strategic environmental assessment is an analysis and forecast of the environmental impacts of a project, undertaken in order to draft development strategies, planning and plans to strive for sustainable development prior to the project approval." (Murekezi , 2014).

Then an Environmental Impact Assessment Report is conducted. An environmental impact assessment report evaluates impacts to the environment that may occur during a projects implementation and operation, and must be conducted by an appraisal council or third party consultant (Murekezi , 2014). According to the Fisheries Law of 2017 (Article 7), aquaculture operations cannot destroy:

- "aquatic resources,
- aquatic ecosystems,
- reproductive areas,
- areas where offspring live and the residence of aquatic species"

Furthermore, the Fisheries Law of 2017 (Article 7) states that aquaculture operations cannot obstruct the "natural migration patterns of aquatic species."

For net pen barramundi, specific categories/subjects evaluated in the environmental impact report that must and/or should be controlled and/or minimized during construction and operations include (EIA, 2012): ground leveling , dust from transportation, storage and maintenance of materials, construction of infrastructure, activities of construction workers, solid waste pollution, waste from construction material, pollution from toxic waste, noise and vibration, air pollution, odor, fish meal dust from processing, exhaust gas from transportation, water pollution, liquid waste, and farming activities (cleaning of cages, fallowing, feeding tactics, cage spacing, control of drug use and density).

Combined, these provisions create a management system that requires farms to be sited according to ecological principles and environmental considerations. For example, the farm siting process is subjected to the guidance determined by the Fishery Law of 2017, the Law of Environmental Protections, EIA, and the siting approval determined by the relevant authorities (district, provincial, and national).

However, secondary legislation and/or decrees that provide clarity and the technical guidance to meet these key habitat protections is lacking (Hong et al. 2017). Missing from the EIA (2012) report is the assessment of whether barramundi net pen farming impacts or destroys “aquatic resources, aquatic ecosystems, reproductive areas, or areas where offspring live and the residence of aquatic species,” and whether the operation obstructs the “natural migration patterns of aquatic species.”, which is required under the Fisheries Law of 2017. There has been no update to the EIA in 2012 to document compliance of this original site to the Fishery Law of 2017. But in 2018, an updated EIA was conducted to include the expansion of barramundi production and it concludes that there is no sea grass or coral underneath the production area, but there is no “detailed research and survey documents on biological resources in the project area so it is not possible to accurately assess the fisheries resources in the project area.” (EIA, 2019). Consistent with this finding is the lack of comprehensive marine spatial planning to help guide offshore or nearshore aquaculture siting (Santos et al. 2019) and there is no definition of offshore aquaculture in any laws or decrees in Vietnam.

Overall, the content of habitat management measures is moderate. The management system is based on ecological principles as demonstrated with the Master Plan of Vietnam Fisheries and Aquaculture Development through 2020 and Vision to 2030, the Fishery Law of 2017, farm siting process and EIA components. But the EIAs assessed do not fully align with the requirements of the Fishery Law of 2017 and do not account for habitat connectivity which creates the potential for cumulative impacts to ecosystem services. For example, the Fishery Law of 2017 requires all EIAs to assess what the impact of aquaculture production may have on marine ecosystems including: “aquatic resources, aquatic ecosystems, reproductive areas, or areas where offspring live and the residence of aquatic species,” and whether the operation obstructs the “natural migration patterns of aquatic species.” But all of these components are missing from the EIAs provided for this assessment. This is likely due to a lack of technical data on this subject and guidance for marine spatial planning. As a result, the score for Factor 3.2a is 3 out of 5.

Factor 3.2b – Enforcement of habitat management measures

The habitat protection measures described in section 3.2a are enforced by a combination of local, provincial, and national agencies and committees whose jurisdiction varies by the operational phase of the farm (pre-operational and operational).

Before farms can operate, they must apply and be approved to construct farm infrastructure. For net pen barramundi production, distance from shore is a key measure for determining which agency or committee has the initial approval for interested farmers. If the proposed farm is less than 6 nautical miles from shore, permission to operate is determined by the local People's Committee, but if the farm is greater than 6 nautical miles from shore, permission to operate is determined by the Ministry of Agriculture and Rural Development (MARD) (Fisheries Law, 2017). It is up to the initial application agency (MARD or the local People's Committee) to enforce the farm siting habitat protections described in Factor 3.2a.

If the project is allowed to move forward at a particular location, an environmental impact assessment is developed. The Ministry of Natural Resources and Environment provides the guidance and enforcement for implementing EIAs and EIA assessments for projects (Decree Prescribing environmental protection master plan, strategic environmental assessment, environmental impact assessment and environmental protection plan, 2015. Article 24). EIAs are conducted by approved organizations who are trained and certified by MNRE (Decree Prescribing environmental protection master plan, strategic environmental assessment, environmental impact assessment and environmental protection plan, 2015. Article 13). All EIA reports must be approved by MNRE, and if within 6 miles from shore, must also be approved by the local Economic Zone Authority and the locale People's Committee (Circular On strategic environmental assessment, environmental impact assessment, and environmental protection plans. 2015. Article 9, EIA, 2012).

Once operational, management measures to protect habitat impacts must be monitored and enforced by the entities assigned during the EIA process. For net pen barramundi production, monitoring requirements for potential habitat impacts are enforced by the MARD, local People's Committee, and the district Police (Fisheries Law, 2017; EIA, 2012). Inspections are made at least once per year by local and provincial government officials from environmental and aquaculture departments to check for compliance, and ensure permits are up to date (personal communication Goldman, 2020). Failure to meet the obligations and terms of the EIA may result in the revocation of a farming lease (Murekezi, 2014). While terms for lease revocation are known, the process of revoking a lease is unclear, and there is no evidence that the current barramundi net pen farming operations in Van Phong Bay has had any issues with abiding by the conditions of their lease.

The effectiveness of this pre and during operation vetting process in protecting marine habitats is unclear. Approval for barramundi net pet production occurred in 2012, and the EIA made no evaluation or consideration of habitat protections now deemed necessary for all EIAs since the passing of the Fisheries Law in 2017. There is no documentation to indicate that an update has been made. After expansion of barramundi marine net pen operations in Van Phong Bay in 2018, the EIA of 2019 does not address some key habitat protections that are outlined in the Fishery Law of 2017. For example: there is no "detailed research and survey documents on biological resources in the project area so it is not possible to accurately assess the fisheries resources in the project area." (EIA, 2019). Therefore, the ability of the institutions to enforce its laws, and regulations aimed at protecting the marine environment and habitat appears limited.

The World Governance Indicators (WGI) can be used as an additional source of information to determine a countries ability to support, manage, and enforce sustainable aquaculture (Davies et al. 2019). As a nation, Vietnam scores poorly in key components of the WGI that address governing and enforcement: The Rule of Law receives a score of 0, Government Effectiveness receives a scores of -0.4, and Control of Corruption receives a score of -0.58 – all are scored on a scale of -2.5 to 2.5. The sampling, and scoring methodology is documented by Kaufmann et al. (2010). These scores signal that Vietnam may not be able to develop and implement sustainable aquaculture governance effectively. However, the Ocean Health Index evaluated the marine biodiversity (on a scale of 0 to 100) of Vietnam as an 84 for species health, and 91 for marine habitat health. At a macro level, it appears that Vietnam may not have strong institutions for effective sustainable aquaculture governance, but that has not necessarily come at the expense of marine biodiversity and marine habitats.

In the past, the ability of identified enforcement organizations in Vietnam to uphold protection measures has been critiqued. According to Nair (2015), the Vietnamese government does not yet have the capacity for punitive enforcement of mandatory standards and has to rely on encouraged self-regulation. Philips et al. (2009) found that provincial environmental authorities lacked sufficient facilities, laboratories, and suitable staff to effectively monitor aquaculture, and with no additional information indicating a reform of provincial environmental authorities or increased capacity, this suggests that current systems may still not be appropriate to the scale of the industry. There is a lack of marine spatial planning resources for offshore or nearshore aquaculture siting in Vietnam, but it is currently being developed (Santos et al. 2019). At the time of writing this assessment, there is no definition of offshore aquaculture in any laws or decrees in Vietnam. As a result, the gap between legislation and technical guidance and resources for marine spatial planning and environmental protection enforcement appear to be a key barrier for Vietnam.

Overall, enforcement of habitat management measures appears limited. Enforcement organizations are identifiable as documented in the laws, secondary legislation and appointed responsible enforcement entities described in the EIAs. However, literature points out that there are limitations in resources, and in technical guidance that negate marine habitat protections. Specifically, the important ecological principles outlined in the Fishery Law of 2017 are not applied to the EIAs assessed for barramundi marine net pen production and therefore enforcement of these ecological principles is absent. As a result, cumulative impacts of farming operations may occur, and enforcement is scored a 2 out of 5.

**Conclusions and Final Score**

Given the scale of the industry and avoidance of sensitive marine habitat during farm siting, barramundi net pen operations have a minimal impact to marine ecosystems and the score for Factor 3.1 Habitat conversion and function is scored 9 out of 10. The content of habitat management measures is moderate. The management system is based on ecological principles, but the EIAs assessed do not fully align with the requirements of the Fishery Law of 2017 and do not account for habitat connectivity which creates the potential for cumulative impacts on ecosystem services. As a result, the score for Factor 3.2a is 3 out of 5. Enforcement of habitat management measures is also limited. Enforcement organizations are identifiable but there are limitations in available resources and in technical guidance to fully implement marine habitat protections required by law. Specifically, the important ecological principles outlined in the Fishery Law of 2017 are not applied to the EIAs assessed for barramundi marine net pen production and the enforcement is thus absent. As a result, cumulative impacts of farming operations may occur, and enforcement is scored a 2 out of 5. Therefore, Factor 3.1, Factor 3.2a, and Factor 3.2b combine in a final score of 6.8 out of 10 for Criterion 3 - Habitat.

# Criterion 4: Evidence or Risk of Chemical Use

**Impact, unit of sustainability and principle**

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

**Criterion 4 Summary**

| Chemical Use parameters | Score | |
|---|---|---|
| C4 Chemical Use Score (0-10) | **8** | |
| Critical? | NO | **Green** |

**Brief Summary**

Given the small size of the marine net pen barramundi industry in Vietnam, there is not a great deal of information available concerning the sector's chemical usage beyond direct communication with the operating company. Laws regulate which chemicals can be used, who may supply them for aquaculture purposes, and the enforcement bodies are identifiable. Open production systems, such as the net pens employed by the operating company, are open exchange with the surrounding water body enabling the risk of chemical treatments impacting the surrounding waterbody. There are 16 reported chemicals used during barramundi farming, though the two that represent potential ecological risks are formalin (as an antiparasitic) and the antibiotic oxytetracycline. Formalin is used to treat ectoparasites on juvenile fish and is used infrequently (on average, 1 out of every 4 batches are treated); the risk of formalin impacting the surrounding environment is very low. Oxytetracycline (OTC) is a highly important antimicrobial according to the World Health Organization and most of the application of OTC in net pens occurs immediately following the transfer of barramundi from the hatchery. The frequency of application is low and is calculated to be roughly 0.62 treatments for a typical production cycle and is consistent with the requirements of the ASC certification held by the farm. As data show that chemical treatments are applied, on average, less than once per production cycle, this results in a low concern for antimicrobial or antibiotic use and a score of 8 out of 10. Benthic biodiversity monitoring data collected by the production operation suggests that there is no impact of chemical use on non-target organisms outside the AZE, and sediment monitoring data suggests that there is no impact within the AZE, further justifying low concern (a score of 8 out of 10). As a result, the score for Criterion 4: Chemical Use is an 8 out of 10.

**Justification of Rating**
The expansion of commercial aquaculture has necessitated the routine use of veterinary medicines to prevent and treat disease outbreaks, assure healthy stocks, and maximize production (FAO, 2012); however, the characteristics of chemical use are highly variable according to the species produced and the management characteristics. This Seafood Watch assessment focuses on antibiotics and pesticides as the dominant veterinary chemicals applied to net pen barramundi farming. Although other types of chemicals may be used (e.g., antifoulants, anesthetics), the risk of impact to the surrounding ecosystem is widely acknowledged to be less than that for antibiotics and pesticides. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

To help control chemical treatment in the aquaculture industry, Vietnam has created a legislative framework to regulate its use. The general legislative framework includes the Fisheries Law of 2017, the Ordinance on Food Hygiene and Safety, the decision of "Promulgating the Regulation on Control of Residues of Toxic and Hazardous Substances in Reared Aquatic Animals and Products Thereof", and the Ordinance on Veterinary Medicine.

Any chemical treatment that is applied for the purposes of adjusting the aquaculture environment must be approved for use. The Fisheries Law of 2017 defines what "adjusting aquaculture environment" as: "a product used for adjusting physical, chemical and biological properties of the environment in favor of aquaculture." (Fisheries Law, 2017). All chemicals used to adjust aquaculture environment must be approved for use by the Minister of Agriculture and Rural Development (Murkezi, 2014).

The decision of "Promulgating the Regulation on Control of Residues of Toxic and Hazardous Substances in Reared Aquatic Animals and Products Thereof" describes the "responsibilities and powers of the various involved bodies, including state departments, testing labs, rearing establishments, and processing facilities in controlling residues in reared aquatic animals." (Murekezi, 2014).

The use, production, and trade of chemicals for aquaculture is regulated by the Ordinance on Veterinary Medicine. This legislation mandates that all participants of the chemical supply chain (producers, processers, and/or sellers) are registered and certified to do so (Murekezi, 2014).

To comply with these legislative components controlling chemical use in the aquaculture industry, all farms must:

1. Not use any banned chemicals, veterinary drugs, or growth stimulants (Murekezi, 2014)
2. Document any veterinary medicines use and any use of chemicals for adjusting aquaculture environment (Fisheries Law, 2017, Article 42)

3. “Document and “notify the supervising bodies of the species being reared, rearing forms and acreage, harvesting time, drugs being used, and other information relevant to the control of residues” (Murekezi, 2014)
4. “fully and accurately fill in reared aquatic animal origin declaration forms and hand them to the processing enterprises and collecting-purchasing establishments upon sale and delivery” (Murekezi, 2014)
5. “make written records on aquatic raw materials lots when detecting samples with residues in excess of the permitted level or on the list of banned substances” (Murekezi, 2014)

Chemicals and antibiotics that are banned and not allowed to be sold or used in Vietnamese aquaculture industry are described in the Promulgating the Lists of Chemicals and Antibiotics (see Table 3 and the Ministry of Agriculture and Rural Development (MARD, 2014). In total, there are 17 types of chemicals and antibiotics banned for use. There are 26 antimicrobials that are restricted but allowed for use in Vietnamese aquaculture industry. Table 4 summarizes the type of antimicrobial allowed but restricted, maximum residue level (ppb), and the WHO classification of the antimicrobial type. According to the World Health Organization (WHO) (2018), there are 14 antimicrobials allowed for use that are considered Critically Important Antimicrobials, 11 antimicrobials considered Highly Important Antimicrobials, and 1 antimicrobial considered an Important Antimicrobial.

**Table 3:** List of Banned Chemicals and Antibiotics. Source: Promulgating the Lists of Chemicals and Antibiotics, which are Banned or Restricted from Use in Fisheries Production and Business, 2005, and MARD, 2014.

| Name | Classification |
|---|---|
| Arstolochia spp and preparations thereof | Banned |
| Chloramphenicol | Banned |
| Chloroform | Banned |
| Chlorpromzaine | Banned |
| Colchicine | Banned |
| Dapsone | Banned |
| Dimetridazole | Banned |
| Enrofloxacin | Banned |
| Fluoroquinolones | Banned |
| Florfenicol | Banned |
| Glycopeptides | Banned |
| Metronidazole | Banned |
| Nitrofuran (including Furazolidone) | Banned |
| Ronidazole | Banned |
| Green Malachite | Banned |
| Ipronidazole | Banned |
| Other Nitroimaidzaoles | Banned |
| Clenbuterol | Banned |

| | |
|---|---|
| Diethylstilbestrol (DES) | Banned |
| Glycopeptides | Banned |
| Trichlorfon (Dipterex) | Banned |

**Table 4:** List of Restricted Chemicals and Antibiotics. Source: Promulgating the Lists of Chemicals and Antibiotics, which are Banned or Restricted from Use in Fisheries Production and Business, 2005, MARD, 2014 and WHO, 2018

| Name | Maximum Residue Level (ppb) | WHO Classification |
|---|---|---|
| Amoxicillin | 50 | Critically Important Antimicrobial |
| Ampicillin | 50 | Critically Important Antimicrobial |
| Benzylpenicillin | 50 | Highly Important Antimicrobial |
| Cloxacillin | 300 | Highly Important Antimicrobial |
| Dicloxacillin | 300 | Highly Important Antimicrobial |
| Oxacillin | 300 | Highly Important Antimicrobial |
| Danofloxacin | 100 | Critically Important Antimicrobial |
| Difloxacin | 300 | Critically Important Antimicrobial |
| Ciprofloxacin | 100 | Critically Important Antimicrobial |
| Oxolinic acid | 100 | Critically Important Antimicrobial |
| Flumequine | 600 | Critically Important Antimicrobial |
| Colistin | 150 | Critically Important Antimicrobial |
| Erythromycine | 200 | Critically Important Antimicrobial |
| Tilmicosin | 50 | Critically Important Antimicrobial |
| Tylosin | 100 | Critically Important Antimicrobial |
| Lincomycine | 100 | Highly Important Antimicrobial |
| Neomycin | 500 | Critically Important Antimicrobial |
| Paromomycin | 500 | Critically Important Antimicrobial |

| | | |
|---|---|---|
| Spectinomycin | 300 | Important Antimicrobial |
| Chlortetracycline | 100 | Highly Important Antimicrobial |
| Oxytetracycline | 100 | Highly Important Antimicrobial[2] |
| Tetracycline | 100 | Highly Important Antimicrobial[3] |
| Sulfonamide (all types) | 100 | Highly Important Antimicrobial |
| Trimethoprim | 50 | Highly Important Antimicrobial |
| Tricaine methanesulfonate | 15-330 | *NA* |
| Cypermethrim | 50 | *NA* |
| Deltamethrin | 10 | *NA* |
| Diflubenzuron | 1,000 | *NA* |
| Teflubenzuron | 500 | *NA* |
| Amamectin | 100 | *NA* |
| Sarafloxacin | 30 | *NA* |

The regulatory authorities that oversee chemical use in the aquaculture industry is outlined in the Ordinance on Food Hygiene and Safety and include:

1. the Ministry of Agriculture and Rural Development (MARD) is responsible for regulating what chemicals (including biological preparations and microorganisms) are allowed to be used and what chemicals are banned from aquaculture use (Murekezi, 2014; Article 31, Fisheries Law, 2017).
2. Department of Animal Health regulates chemical use and veterinary drug use in aquaculture (ASEAN, 2013)
3. State and Provincial level structures in charge of animal health (Murkeezi, 2014)
4. the People's Committees, state and Provincial level structures are in charge of "controlling the hygiene and safety of foodstuffs in their respective localities." As well as animal health through veterinary networks. (Murkeezi, 2014)

For barramundi, the net pen production system utilized has no filtration of water entering and or exiting the pens and has constant exchange with the ocean environment, and as such, there is risk for chemical applications to impact the surrounding ocean environment. A variety of chemicals are used during the hatchery, nursery and grow-out rearing phases (personal

[2] Countries where transmission of brucellosis from non-human sources to humans is common should consider making tetracycline a critical antibiotic, as there is considerable concern regarding the availability of effective products where Brucella spp. are endemic.
[3] Countries where transmission of brucellosis from non-human sources to humans is common should consider making tetracycline a critical antibiotic, as there is considerable concern regarding the availability of effective products where Brucella spp. are endemic.

communication Goldman, 2019) but is compliant to the legislation described above. The type of chemical, application method, dose, and frequency of application is summarized in Table 5. Of the 16 reported chemicals used during barramundi farming, 12 are considered nutritional supplements that encourages healthy physiology and are administered prophylactically by mixing with fish feed. The anesthetic is used to help reduce fish stress during handling periods and contains eugenol, which is extracted from clove oil (Aqui-S, 2020). None of these are considered to present an ecological risk.

Formalin is applied to juvenile fish that weigh less than 200 g to treat ectoparasites growing on the exterior of the fish (personal communication Goldman, 2020). It is applied at the hatchery RAS facility, but also in net pens (personal communication Goldman, 2019) where nylon tarps are used to minimize the volume required (Seafood Watch, 2014). The farm's application of formalin is not likely to harm non-target organisms or the environment as it is rapidly diluted and effectively biodegrades in the marine environment in a day or two, depending on the characteristics of the sea water like temperature, oxygen, and presence of degrading microbes (Leal et al., 2016). Additionally, the average frequency of use is low with roughly 1 out of 4 batches treated, likely only once per production cycle (personal communication Goldman, 2020).

The antibiotic oxytetracycline (OTC) is used by the farm (personal communication Goldman, 2019) and is classified as a highly important antimicrobial by the World Health Organization. Before oxytetracycline is used, a diagnosis of bacterial disease must be confirmed, typically through observation of clinical symptoms and may include the use of polymerase chain reaction (PCR) testing by a 3rd party. Although a veterinary prescription is not needed, a team of 6 on-site fish health specialists conduct fish health monitoring and approval of all applied therapeutants, including oxytetracycline. Most of the application of OTC at net pens occurs immediately following the transfer of barramundi from the hatchery (personal communication Goldman, 2020) From 2017 to 2020 there were a total of 84 batches of barramundi, 46 of the batches (55%) did not receive any oxytetracycline treatments, 24 batches (29%) received one treatment and 14 batches (17%) received two treatments. To determine the average number of treatments for a typical production cycle, the weighted average was calculated by multiplying the number of treatments (0, 1 or 2) by the percentage of barramundi batches that were treated by the representative treatment batch. The resulting weighted average calculation is 0.62 and is the average number of treatments of OTC per cycle of barramundi production. This is consistent with the requirements of the Aquaculture Stewardship Certification for Tropical Marine Finfish (frequency of antibiotic treatments must be $\leq 3$ per production cycle), which the sole current operation under the scope of this assessment is certified to. Altogether, the frequency of oxytetracycline application is low and is considered to be, on average, <1 treatment per production cycle.

**Table 5:** Chemical use by the type, how its applied, dose, and frequency. Source: Personal Communication Goldman, 2019.

| Type of chemical | Name | Administration route | Dose | Frequency |
|---|---|---|---|---|
| Vitamin | Aqua C Fish | Mixing with feed | 3gr/kg feed | Every day for Nursery stage |
| Multi Vitamin | Pfi-lyte | Mixing with feed | 2gr/kg feed | Everyday for fish below 50gr |
| Probiotic | Aquastar – Growout | Mixing with feed | 5gr/kg feed | Every day for fish below 50gr |
| Multi Vitamin | Avit | Mixing with feed | 10-15mL/kg feed | Everyday for fish below 50gr |
| Probiotic | Bactocell | Mixing with feed | 3-5g/kg feed | Everyday for fish below 10gr |
| Probiotic | Marine LABs | Mixing with feed | 1gr/kg feed | Everyday for fish below 3gr |
| Acid amin and Vitamin | Bio Squid – Liver oil | Mixing with feed | 10-15mL/kg feed | When feed need coating |
| Acid amin | Doxalase | Mixing with feed | 30gr/kg feed | 7 days per month |
| Yeast Extract | DV Aqua | Mixing with feed | 2g/kg feed | Everyday for fish below 50gr |
| Garlic Extract and Vitamin | Agarlic | Mixing with feed | 10-15mL/kg feed | Before grading, vaccination and transfer |
| Multi Acid | Silohealth | Mixing with feed | 10-15mL/kg feed | Everyday for fish below 100g |
| Supplement | Beta Glucan | Mixing with feed | 4g/kg feed | Before grading, vaccination and transfer |
| Anesthetic | Aqui-S | Water | 5-30ppm | Every grading, vaccination and transfer |
| Antibiotic | Oxytetracycline | Mixing with feed | 100ppm | 7 days per treatment for Nursery stage Used on growout stages as well |
| Chemical | Formalin | Water treatment | | 1 out of 4 batches |
| Chemical | XC90 | Chlorine/Disinfectant | | |

The impact of these chemical treatments to the surrounding waterbody in Van Phong Bay has not been documented in primary literature. Oxytetracycline (OTC) is known to sorb to dissolved organic matter and biosolids, such as suspended aquaculture solids (i.e., uneaten fish feed and excrement), and become largely biologically unavailable (Schmidt et al. 2007). As mentioned previously, once formalin is released into the ocean environments, it degrades in sea water in a day or two depending on the characteristics of the sea water like temperature, oxygen, and presence of degrading microbes (Leal et al., 2016). Information and data on the concentration of formalin discharge into the environment, examination of oxytetracycline in sediments, or analysis of antibiotic resistance is not available. However, long-term monitoring of biodiversity of the benthic community collected and analyzed by the barramundi operation demonstrates that there is no significant difference between the edge of the allowable zone of effect (AZE) (edge of the AZE is 25 meters from the cage site) and control sites ($p$-value <.05) (Summary of Benthic Biodiversity Results, 2019). This suggests that any chemical treatments applied are not negatively impacting the benthic community or having a measurable affect outside the AZE. Monitoring data within the AZE – as discussed in Criterion 2 Effluent – did not indicate any impact that is directly or indirectly related to chemical treatments.

**Conclusions and Final Score**

Given the small size of the marine net pen barramundi industry in Vietnam, there is not a great deal of information available concerning the sector's chemical usage beyond direct communication with the operating company. Laws regulate which chemicals can be used, who may supply them for aquaculture purposes, and the enforcement bodies are identifiable. Open production systems, such as the net pens employed by the operating company, are open exchange with the surrounding water body enabling the risk of chemical treatments impacting the surrounding waterbody. There are 16 reported chemicals used during barramundi farming, though the two that represent potential ecological risks are formalin (as an antiparasitic) and the antibiotic oxytetracycline. Formalin is used to treat ectoparasites on juvenile fish and is used infrequently (on average, 1 out of every 4 batches are treated); the risk of formalin impacting the surrounding environment is very low. Oxytetracycline (OTC) is a highly important antimicrobial according to the World Health Organization and most of the application of OTC in net pens occurs immediately following the transfer of barramundi from the hatchery. The frequency of application is low and is calculated to be roughly 0.62 treatments for a typical production cycle and is consistent with the requirements of the ASC certification held by the farm. As data show that chemical treatments are applied, on average, less than once per production cycle, this results in a low concern for antimicrobial or antibiotic use and a score of 8 out of 10. Benthic biodiversity monitoring data collected by the production operation suggests that there is no impact of chemical use on non-target organisms outside the AZE, and sediment monitoring data suggests that there is no impact within the AZE, further justifying low concern (a score of 8 out of 10). As a result, the score for Criterion 4: Chemical Use is an 8 out of 10.

## Criterion 5: Feed

### Impact, unit of sustainability and principle

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

### Criterion 5 Summary

| Feed parameters | Value | Score |
|---|---|---|
| F5.1a Feed Fish Efficiency Ratio (FFER) | 1.014 | |
| F5.1b Source fishery sustainability score | | 4.14 |
| F5.1: Wild fish use score | | 5.01 |
| F5.2a Protein INPUT (kg/100kg fish harvested) | 72.45 | |
| F5.2b Protein OUT (kg/100kg fish harvested) | 18.00 | |
| F5.2: Net Protein Gain or Loss (%) | -75.155 | 2.00 |
| F5.3: Species-specific kg CO2-eq $kg^{-1}$ farmed seafood protein | 12.99 | 7.0 |
| **C5 Feed Final Score (0-10)** | | **4.75** |
| Critical? | NO | **YELLOW** |

### Brief Summary

Barramundi production in Van Phong Bay net pens use feeds that contain fishmeal and fish oil sourced from both whole wild fish and from by-product raw material. The fishmeal inclusion level is 30% and the fish oil inclusion is 6%, with 100% of fishmeal and 50% of fish oil sourced from by-products from tuna fisheries, and the remaining 50% of fish oil originates from sardine and anchovy fisheries. The Feed Fish Efficiency Ratio (FFER) is moderate (1.014), meaning that 1.014 mt of wild fish are needed to produce the fish oil required to produce one mt of farmed barramundi. The sustainability of the source fisheries is also moderate and scores a 4.14 out of 10. Combined with the FFER, the Factor 5.1 – Wild fish use score is 5.01 out of 10. The net protein loss of -75.16% is high and results in a score of 2 out of 10 for Factor 5.2 – Net protein gain or loss. The feed footprint is low with approximately 12.99 kg of $CO_2$-eq per kg of harvested protein, resulting in a score of 7 out of 10 for Factor 5.3 – Feed footprint. Altogether, the three factors combine to give a final score of 4.75 out of 10 for Criterion 5-Feed.

## Justification of Rating

### Factor 5.1. Wild Fish Use

Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed barramundi with a measure of the sustainability of the source fisheries. Table 6 shows the data used and the calculated Feed Fish Efficiency Ratio (FFER) for fishmeal and fish oil.

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

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

Data used for ingredient composition and other metrics for this criterion were gathered from the sole operating barramundi operation in Van Phong Bay, and it represents 100% of the feed used for barramundi grow out in this assessment. Given the proprietary nature of feed formulation and ingredient composition, the data provided is aggregated and evaluated to determine a representative feed ingredient composition. The data provided gave a range for many ingredient inclusion levels as well as lifetime average values for some ingredients; overall, the lifetime averages were utilized where provided, and averages for the other ingredient ranges were utilized to reach a total ingredient inclusion level for all ingredients equaling 100%. Total fishmeal (FM) inclusion is 30%,and 100% is sourced from by-products – trimmings from IFFO/MarinTrust certified tuna processing plants/fisheries, detailed further in Factor 5.1b. Total fish oil inclusion level is 6% with 50% obtained from whole fish and 50% sourced from by-products – again, trimmings from IFFO/MarinTrust certified tuna processing plants/fisheries. The company-reported eFCR is 1.61. It is difficult to rely on a single eFCR value as it changes due to many variables over time, but an eFCR of 1.61 is considered accurate for the industry this assessment represents. An eFCR of 1.61 is also in the range of the reported eFCR from the Best Aquaculture Practices certification audit, Aquaculture Stewardship certification audit, and industry figures from barramundi production in Australia (Booth, 2015).

The Feed Criterion considers the FFER from both fishmeal and fish oil and uses the higher of the two to determine the score. Fish meal and oil sourced from by-products are partially included in the FFER calculation at a rate of 5% of the inclusion level(s), in order to recognize the ecological cost of their production; please see the Seafood Watch Aquaculture Standard for additional details. As seen in Table 6, the fish oil inclusion level drives the FFER for Vietnam farmed barramundi, and and 1.014 tons of wild fish are required to provide sufficient fish oil to produce one ton of farmed barramundi.

**Table 6.** Parameters used and their calculated values to determine the use of wild fish in feeding farmed barramundi.

| Parameter | Data |
|---|---|
| **Fishmeal inclusion level (total)** | **30%** |
| Fishmeal inclusion level (whole fish) | 0% |
| Fishmeal inclusion level (by-product) | 30% |
| Fishmeal yield | 22.5% |
| **Fish oil inclusion level (total)** | **6%** |
| Fish oil inclusion level (whole fish) | 3% |
| Fish oil inclusion level (by-product) | 3% |
| Fish oil yield | 5.00% |
| Economic Feed Conversion Ratio (eFCR) | 1.61 |
| **Calculated values** | |
| Fish meal feed fish efficiency ratio (FFERfm) | 0.107 |
| Fish oil feed fish efficiency ratio (FFERfo) | 1.014 |
| **Assessed FFER** | **1.014** |

Factor 5.1b – Sustainability of the Source of Wild Fish

The basic wild fish use score (Factor 5.1a) is adjusted based on the sustainability of the source fisheries of fishmeal and fish oil. Data regarding source fisheries were provided by a barramundi operation in Van Phong Bay, which provided species, gear type, FAO fishing region, and IFFO/MarinTrust certification status. These data are considered representative of the industry for this assessment. Fish oil originating from whole fish raw material was sourced from sardines (*Sardinella spp. and/or Stragomera bentincky*) and anchovies (*Engraulis ringens*). Fishmeal and fish oil from by-product raw material were sourced from farmed pangasius, and tuna species such as skipjack, albacore, yellowfin, and bigeye (*Katsuwonus pelamis, Thunnus alalonga, Thunnus albacares,* and *Thunnus obesus*, respectively). The data provided and the resulting source fishery sustainability score for each species is described (see Table 7 for a summary of scores).

**Skipjack**

There are several fishing regions where skipjack are sourced from – Western Indian Ocean, Western Central Pacific, and the Eastern Central Pacific region. The IFFO/MarinTrust by-product certification applies to fish processed in Vietnam from the following fishing methods and regions: purse seines, gillnet, and pole and line in the Western Indian Ocean; longline, purse seine, and pole and line in the Western Central Pacific Ocean and purse seine, pole and line, and long line in the Eastern Central Pacific Ocean. FishSource Scores exist for all of these regions and methods, but Seafood Watch ratings are only available for the Western/Central purse seines with and without fish aggregating devices (FADs). Since the source fishery sustainability score is different for each of these scenarios the average score is calculated. The resulting source fishery sustainability score for skipjack is 6 out of 10.

**Albacore**

Albacore are sourced from the Western Central Pacific and the Eastern Central Pacific FAO fishing regions. The by-products from Western Central Pacific and the Eastern Central Pacific are IFFO/MarinTrust certified in Vietnam for fishing methods such as set-net, gill-net, longline, pole-and-line, troll, and purse seine fisheries. Since the region and fishing methods are known, additional source fishery sustainability information can be evaluated such as Seafood Watch ratings and FishSource scores. Seafood Watch ratings exist for albacore caught in the North and South Pacific for the following methods: longline, pole and line, and trolling and are summarized in Table 7. FishSource scores for albacore do not exist for Eastern/Western Central Pacific regions, but do exist for North and South Pacific and were used to aide this assessment. Since more granular fishing origin detail such as regional or flagship country data was unavailable the aggregate score for North or South Pacific FishSource score was used. If given a range for a metric (e.g. management strategy, managers compliance, fishers compliance, current health and/or future health) a precautionary approach was utilized and the lowest value was taken.

Since all of these source fisheries are possible for albacore, the average was calculated and results in a source fishery sustainability score for albacore of 5.

**Yellowfin**

Yellowfin are sourced from FAO fishing regions of the Western Central Pacific and the Eastern Central Pacific. They are IFFO/MarinTrust certified by-products processed in Vietnam from the following fishing methods and regions: purse seine, longline, and pole and line from Western Central Pacific, and purse seines, purse seines with floating objects and longlines from the Eastern Central Pacific. Seafood Watch ratings exist only for Western Central Pacific purse seines with FADs and without FADs. FishSource scores were available for the FAO fishing regions. All scenarios are considered, and the average is taken and results in a source fishery sustainability score for yellowfin of 5.2 and is rounded to 5.

**Bigeye**

Bigeye tuna are sourced from the Western Indian Ocean FAO fishing regions. Although IFFO/MarinTrust certification is documented for this source fishery, it is unclear for which country of origin it recognizes. Therefore, only the FishSource score for the Western Indian Ocean and the IFFO/MarinTrust certification are considered and the average is calculated resulting in a source fishery sustainability score for bigeye of 5.

**Pangasius**

Farmed pangasius by-products are used as a source for fishmeal and fish oil for barramundi feed. Since this is a farmed product it is not included in this calculation assessing the sustainability of wild fish sources.

**Sardines and Anchovies**

Sardines and anchovies are sourced from the FAO fishing areas of the Eastern Central Atlantic, Atlantic South East, Western Indian Ocean and the South East Pacific. Multiple sardine species are given (*Strongomera bentincky* and *Sardinella spp.*), while only one anchovy species ( *Engraulis ringens)* was listed. These fisheries are IFFO/MarinTrust certified (personal communication Goldman, 2020), and the chain of custody documentation ensures that these source fisheries are used at the Vietnam processing center (Marin Trust, 2017). This documentation is valid until January 2021. Without further details like the species, gear type, and country of origin, neither a FishSource score or a Seafood Watch rating can be determined. As a result, the source fishery sustainability results in a score of a 4 for both sardine and anchovies.

Considering the sustainability of both whole fish and by-product ingredients together (e.g., sardines, anchovies, and tuna species), the final score for Factor 5.1b – Source fishery sustainability is 4.14 out of 10.

When this score is combined with an FFER of 1.014 (Factor 5.1a), the final score for Factor 5.1 – Wild Fish Use is 5.01 out of 10.

**Table 7** Source fishery sustainability for tuna species. sardine species, and anchovies.

| Species | Region/Method[a] | Management Strategy | Managers Compliance | Fishers Compliance | Current Stock Health | Future Stock Health | SFW Fishery Report | SFW Score |
|---|---|---|---|---|---|---|---|---|
| Skipjack (*Katsuwonus pelamis)* | IFFO Certified | | | | | | | 4 |
| | WIO | ≥6 | ≥6 | ≥6 | 8.8 | 9.6 | | 8 |
| | WCP | ≥6 | ≥6 | ≥6 | 10 | 10 | | 8 |
| | WCP purse seine (FAD) | | | | | | 6 | 6 |
| | WCP purse seine (non-FAD) | | | | | | 2 | 2 |
| | ECP | ≥6 | ≥6 | ≥6 | ≥8 | ≥8 | | 8 |
| Albacore (Thunnus alalonga) | IFFO Certified | | | | | | | 4 |
| | WCP* | ≥6 | ≥6 | <6 | ≥8 | 10 | | 4 |
| | S. Pacific longline | | | | | | 2 | 2 |
| | S. Pacific pole and line | | | | | | 6 | 6 |
| | S. Pacific troll | | | | | | 6 | 6 |
| | ECP* | ≥6 | ≥8 | ≥6 | ≥8 | 8.8 | | 8 |
| | N. Pacific longline | | | | | | 2 | 2 |
| | N. Pacific pole and line | | | | | | 6 | 6 |
| | N. Pacific troll | | | | | | 6 | 6 |
| Yellowfin (Thunnus albacares) | IFFO Certified | | | | | | | 4 |
| | WCP | ≥6 | ≥6 | ≥6 | 9.5 | 8.8 | | 8 |
| | WCP purse seine (non - FAD) | | | | | | 6 | 6 |
| | WCP purse seine (FAD) | | | | | | 2 | 2 |
| | ECP | ≥6 | ≥6 | ≥6 | 7 | 7.5 | | 6 |
| Bigeye (Thunnus obesus) | IFFO Certified | | | | | | | 4 |
| | WIO | ≥6 | ≥6 | ≥6 | 8.9 | 7.2 | | 6 |
| Sardine (Sardinella spp, Stragomera bentincky) | IFFO Certified | | | | | | | 4 |
| Anchovy (Engraulis ringens) | IFFO Certified | | | | | | | 4 |

[a]Region/Method entries includes the FAO fishing region and the fishing method when available, or the IFFO certification. FAO fishing regions are abbreviated as West Central Pacific (WCP), East Central Pacific (ECP), and Western Indian Ocean (WIO).
[*]Albacore FAO fishing regions were provided as East and West, and do not align with the FishSource scores that assess the fishery as North and South Pacific regions. For this analysis, an assumption was made to align the FAO Fishing Regions and FishSource Scores: WCP = South Pacific, and the ECP = North Pacific.

**Factor 5.2. Net Protein Gain or Loss**

The crude protein content of the feed is 45% which is the calculated average for the data provided. A value for the protein content of whole harvested barramundi was unable to be found in the primary literature, so an approximate value of 18% was used (see Appendix 3 of the Seafood Watch Standard for Aquaculture). With an eFCR of 1.61, alongside a whole-barramundi protein content of 18%, the net protein loss is -75.15%. This results in a score of 2 out of 10 for Factor 5.2 – Net protein gain or loss.

| Parameter | Data |
|---|---|
| Protein content of feed | 45% |
| Economic Feed Conversion Ratio | 1.61 |
| Total protein INPUT per ton of farmed fish | 724.50 kg |
| Protein content of whole harvested fish | 18% |
| Total protein OUTPUT per ton of farmed fish | 180.0 kg |
| **Net protein loss** | -75.15% |
| **Seafood Watch Score (0-10)** | **2** |

**Factor 5.3. Feed Footprint**

Factor 5.3 – Feed Footprint is an approximation of the embedded global warming potential (kg $CO_2$-eq including land-use change (LUC)) of the feed ingredients required to grow one kilogram of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database[4] to estimate the GWP of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

As noted previously, feed ingredient composition was gathered from a farm operator in Van Phong Bay, Vietnam and the reported data are considered representative of Vietnamese net pen barramundi industry.

Typical ingredients for Vietnam barramundi feed include fishmeal and fish oil (as explained in Factor 5.1), and terrestrial crop ingredients (e.g., vegetable oil, wheat flour, corn meal (maize), and soybean meal), land animal ingredients (e.g., poultry) and other ingredients such as minerals and vitamins. The degree to which inclusions of these ingredients vary depends on a number of different factors such as the manufacturing company, diet type, price of ingredient, and/or availability of the ingredient. Many of these ingredients are imported and while the origin of some ingredients are known (e.g., poultry, wheat flour, maize, fish meal and fish oil) it was not possible to make an approximation of origin for each ingredient, nor map each ingredient directly to the GFLI database, given the available data.

Fishmeal and fish oil ingredients (both whole fish and by-products) are sourced from a variety of sources and origins. Fish oil originating from whole fish raw material is sourced from sardines

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

(*Sardinella spp.* and/or *Stragomera bentincky*) and anchovies (*Engraulis ringens*) originating from multiple fishing regions, and as such the origin of these ingredients is considered unknown; therefore , the GWP value used is an average value between the listed global (GLO) non-species-specific fish oil value and worst non-species-specific fish oil value. Fish oil originating from by-products is sourced from tuna species such as skipjack, albacore, yellowfin, and bigeye (*Katsuwonus pelamis, Thunnus alalonga, Thunnus albacares,* and *Thunnus obesus*, respectively), from multiple fishing regions, and as such the origin of these ingredients is considered unknown; therefore, the GWP value used is an average value between the listed global (GLO) non-species-specific fish oil value and worst non-species-specific fish oil value. Fishmeal all originates from by-products sourced from farmed pangasius, and tuna species such as skipjack, albacore, yellowfin, and bigeye (*Katsuwonus pelamis, Thunnus alalonga, Thunnus albacares,* and *Thunnus obesus*, respectively); while the pangasius originates in Vietnam, the tuna fisheries are in multiple fishing regions and again, the origin of these ingredients is considered unknown. Thus, , the GWP value used is an average value between the listed global (GLO) non-species-specific fishmeal value and worst non-species-specific fishmeal value.

The terrestrial crop ingredients are vegetable oil, wheat flour, maize, and soybean. Vegetable oil is sourced from various countries of origin, though the type of vegetable oil is not specified and the GFLI database only has one listing for aggregated vegetable oil – "total vegetable oils" from Europe – and this value was used. Wheat flour origin comes from the United States, but the GFLI database had no listing for the US, so the average between the global (GLO) value and the worst listed value for wheat flour was applied following the methodology outlined in the Seafood Watch Aquaculture Standard. Maize is sourced from the United States, but the specific U.S. state is unknown so the average for the U.S. was selected. The soybean meal country source is unknown, so the average between the global (GLO) value and the worst listed value for soybean meal was applied following the methodology outlined in the Seafood Watch Aquaculture Standard.

The land animal ingredients used is poultry meal from Germany. The GFLI database did not have data available from Germany for poultry meal, so the European average was selected.

Lastly, vitamins, and minerals are also included in barramundi diets. The country source is unknown, and the GFLI database has one entry, so the European average was selected.

**Table 8** Estimated embedded global warming potential of one mt of a typical barramundi feed.

| Feed ingredients (≥2% inclusion) | GWP (incl. LUC) Value | Ingredient inclusion% | kg CO2 eq / mt feed |
|---|---|---|---|
| Fishmeal from by-products | Fish meal, from fish meal and oil production, at plant/GLO Economic S | 30% | 279.46 |
| Fish oil from wholefish | Fish oil, from fish meal and oil production, at plant/GLO Economic S | 3% | 19.56 |
| Fish oil from by-products | Fish oil, from fish meal and oil production, at plant/GLO Economic S | 3% | 19.56 |
| Terrestrial Crop Ingredients | Total vegetable oils, at plant/RER Economic S | 38% | 839.34 |
| | Wheat flour, from dry milling, at plant/GLO Economic S<br>Wheat flour, from dry milling, at plant/ ES Economic S | | |
| | Maize, at farm/US Economic S | | |
| | Soybean meal, from crushing (solvent), at plant/GLO Economic S<br>Soybean meal, from crushing (solvent), at plant/AR Economic S | | |
| Land animal ingredients | Animal meal, poultry, from dry rendering, at plant/RER Economic S | 18% | 221.4 |
| Other ingredients | Total minerals, additives, vitamins, at plant/RER Economic S | 5% | 58.8 |
| | **Sum of total** | 98% | **1,438.78** |

As can be seen in Table 8, the estimated embedded GWP of one mt of a typical Vietnam barramundi feed is 1,438.78 kg $CO_2$-eq. Considering a whole harvest barramundi protein content of 18% and an eFCR of 1.61, it is estimated that the feed-related GWP of one kg farmed barramundi protein is 12.99 kg $CO_2$-eq. This results in a score of 7 out of 10 for Factor 5.3 – Feed Footprint.

## Conclusions and Final Score

Barramundi production in Van Phong Bay net pens use feeds that contain fishmeal and fish oil sourced from both whole wild fish and from by-product raw material. The fishmeal inclusion level is 30% and the fish oil inclusion is 6%, with 100% of fishmeal and 50% of fish oil sourced from by-products from tuna fisheries, and the remaining 50% of fish oil originates from sardine and anchovy fisheries. The Feed Fish Efficiency Ratio (FFER) is moderate (1.014), meaning that

1.014 mt of wild fish are needed to produce the fish oil required to produce one mt of farmed barramundi. The sustainability of the source fisheries is also moderate and scores a 4.14 out of 10. Combined with the FFER, the Factor 5.1 – Wild fish use score is 5.01 out of 10. The net protein loss of -75.16% is high and results in a score of 2 out of 10 for Factor 5.2 – Net protein gain or loss. The feed footprint is low with approximately 12.99 kg of $CO_2$-eq per kg of harvested protein, resulting in a score of 7 out of 10 for Factor 5.3 – Feed footprint. Altogether, the three factors combine to give a final score of 4.75 out of 10 for Criterion 5-Feed.

# Criterion 6: Escapes

**Impact, unit of sustainability and principle**

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

**Criterion 6 Summary**

| Escape parameters | Value | Score |
|---|---|---|
| F6.1 System escape risk | 4 | |
| F6.1 Recapture adjustment | 0 | |
| F6.1 Final escape risk score | | 4 |
| F6.2 Competitive and genetic interactions | | 4 |
| **C6 Escape Final Score (0-10)** | | **4** |
| Critical? | YES | **Yellow** |

**Brief Summary**

Marine net pen production systems are open and vulnerable to escapes, but multiple escape prevention methods are employed including strategic farm siting, size grading with appropriate mesh size, and a detailed Escape Management Protocol system that emphasizes training, decision models, and action items. While a single large escape (>5% of the holding unit) has occurred in the last ten years, it was due to a stochastic event (Typhoon Damray) which prompted the operating company to adapt the construction and design of the net pens to prevent future occurrences. It was reported that nearly all escapees were recaptured by local fisherman, though this could not be confirmed. No such escapes have occurred in the five years since and as such, the adaptations made justify a lower level of concern for open systems with effective best management practices for design, construction, and management of escape prevention. Besides this event, escape events appear minimal from 2010-2018. The accounting of barramundi at stocking and harvest is within the error/variability of the accounting machine and model for all years except 2016, confirmed by third-party certification audits. If it is assumed that the reason for the difference between stocking and harvest of barramundi is due to trickle losses and not statistical error, then the total number of barramundi that may have escaped over these years could be up to 10,524, a number considered unlikely to cause population level impacts to wild species. Overall, the escape risk concern is moderate and the score for Factor 6.1 Escape Risk is 4 out of 10.

Should barramundi escape from net pens, they may cause competitive and/or genetic impacts to wild species. There is limited data or literature readily available that evaluate or document the genetic risk or lack thereof between native, wild barramundi and farmed stock in Vietnam, though it is apparent that farm stock are multiple generations removed from the wild and have been selected for favorable traits. Despite this, the farm is located at least 800 km from suitable spawning grounds and there is no evidence that escapees have successfully spawned with wild barramundi. Documentation of other marine organisms such as fish, coral, crustaceans, invertebrates etc. inhabiting Van Phong Bay were unavailable in the Environmental Impact Assessment (2012) beyond noting the location of coral reefs proximal to the current operation, some of which appear to be <1 km from production areas (see Figure 10 in Factor 3.1). No information is available regarding the health of these reefs, though it is assumed that these areas host numerous species of fauna. Given the carnivorous nature of barramundi, it is considered possible that escapees may predate upon and/or compete for resources with fish, crustaceans, and other organisms that they interact with. However, given the limited number of escaped fish over the entire lifetime of the farm, any competitive, predatory, and/or genetic impacts that may occur from escapees are unlikely to affect the population status of wild species. As a result, the concern for 6.2 Competitive and genetic interactions is moderate and scores a 4 out of 10.

Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6 – Escapes.

**Justification of Rating**

This criterion assesses the risk of escape (Factor 6.1) with the potential for impacts according to the nature of the species being farmed (Factor 6.2). The potential for recaptures is a component of Factor 6.1. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

**Factor 6.1. Escape risk**

As a production system, marine net pens are open to the environment and are inherently vulnerable to escape events. Some factors that may contribute to such unforeseen events include inclement weather, damage inflicted on nets by predators or saboteurs, equipment failure, poor handling and human error. However, escape risks can be mitigated by the implementation of effective Best Management Practices (BMPs). The sole operating company farming barramundi in marine net pens in Vietnam is located in coastal Vietnam where extreme weather events such as tropical monsoons, typhoons, and storm surges are typical. It is not required for farmers to document and publish escape events in Vietnam, and there are no independent organizations tracking escapees, so data are limited to accounting information provided by the company, as well as their BAP and ASC certification audits.

A thorough accounting of escapes is difficult but is estimated by counting total number of fish at stocking and harvest using a fish counting device and incorporating this into a model that considers additional sources of losses (such as cannibalism and mortalities). From 2010 to 2018, estimates of the total number of fish at harvest and stocking were provided. Knowing the exact proportion of any loss that is due to cannibalism vs. escapes is challenging, but an estimated 6%

cannibalism is assumed for each year given juvenile barramundi behavior. Also, the counting machine has an estimated ±3% estimated error/variability. Incorporating these adjustments finds the expected harvest number (estimated number of fish at stocking and adjusted for expected mortality and cannibalism) as compared with the actual harvest number to be within the ±3% estimated error/variability for all years from 2010 to 2018 except for 2016. In 2016, the amount of barramundi that escaped is estimated to be roughly 25,000 individuals and was confirmed by the operation (personal communication Goldman, 2020). The cause of the escape event was a severe typhoon (Typhoon Damray), which tangled net pen gridlines and damaged farm infrastructure, allowing for farm stock to escape (personal communication Goldman, 2020). It was reported that nearly all of the fish were re-captured by local fishermen that flocked to the area to harvest escaped stock from nearby lobster farms (personal communication, Goldman, 2019).

In addition, the operation in Van Phong Bay has been BAP certified since 2017, and ASC certified since 2019. The most recent audit for BAP (March 2020) and the ASC audit (June, 2019) were made available for this assessment. According to the BAP audit, there were two minor escape events that both occurred in 2018 – five fish escaped in one instance but were all recaptured with nets, and on a separate occasion one fish escaped but was also recaptured with a net. The ASC audit also states there were zero escapes from June 2018 to June 2019.

Besides the major escape event in 2016, escape events appear minimal from 2010-2018. The actual number of harvested barramundi is within the error/variability of the accounting machine and model for all years except 2016, and the BAP audit in 2020 verifies minimal and very minor escapes events from 2018-2020. If it is assumed the reason for the actual number of barramundi harvested being less than the predicted number of barramundi at harvest in 2010, 2014, 2017, and 2018 is due to trickle losses and not due to counting variability, the total number of barramundi that may have escaped over these years could be up to 10,524. This worst-case scenario of potential barramundi escapes appears low relative to the number of fish stocked, especially given a timespan from 2010 to 2019. However, impacts associated with recorded and potential escapes are assessed in Factor 6.2.

Preventative measures have also been incorporated to minimize escape events. The barramundi operation is strategically located in Van Phong Bay, Vietnam, which faces the South and the South China Sea. This area is protected from major wave heights (<2m), and wind (EIA, 2012). Net pens are anchored to a mooring system of steel anchors that are embedded in the sediment bottom with dynamic tension that allows for cages to move up and down with the tide (personal communication Goldman, 2020; EIA, 2012). In response to the reported escape event in 2016, net pens and the anchor system were adjusted to increase the holding capacity by replacing the anchoring system from concrete blocks to steel anchors, “increasing the strength of all grid components and converting from conventional Nylon to UMHWPE nets which are stronger and induce lower drag forces on the mooring system components” (personal communication Goldman, 2020). These improvements are expected to minimize any future issues (personal communication Goldman, 2020). Management measures include inspecting the condition of each net pen every day and performing routine maintenance every 10-20 days, and frequent scheduled inspections of moorings as documented in a mooring inspection report from 2018-2019 (BAP audit, 2020). Barramundi are graded prior to out-planting, with the farm employing a phased production size class strategy to match fish size with net mesh size to minimize escape opportunities. Mesh sizes are 12 mm for fish sizes of 50-200 g, 19 mm for fish sizes that are >= 200 g, 22 mm for fish sizes > 600 g, and 25 mm for fish sizes >= 1,400 g (BAP audit, 2020).

The farm has established an Escape Management Protocol that dictates the type of response to the observation of net damage or an escape event:

1. Scenario 1: small hole up to 10cm, evaluate netting integrity, notify, record the event, analyze occurrence use feedback to mitigate, and when harvesting -> compare to stocking
2. Scenario 2: medium hole 10-20cm, dive cage and count fish to estimate # of escapes, (all else is similar to scenario 2)
3. Scenario 3: large hole >20cm, evaluate netting integrity, estimate number of escapes, communicate to management, authorities, and certification agencies, recapture efforts are initiated -> local fisherman catch, quantify amount caught.

Overall, marine net pen production systems are open and vulnerable to escapes, but multiple prevention methods are employed including strategic farm siting, size grading with appropriate mesh size, management techniques, maintenance and a detailed Escape Management Protocol system that emphasizes training, decision models, and action items. When the only recent escape issue did occur, management actively adapted the design and construction of net pens to minimize the possibility of future occurrences. Combined this creates an escape risk management framework that goes beyond best management, and regulatory requirements. Besides the major escape event in 2016, escape events appear minimal from 2010-2018. The actual number of harvested fish is within the error/variability of the accounting machine and model for all years except 2016, and the BAP audit in 2020 verifies minimal escapes from 2018-2020. If it is assumed that the reason for the difference between stocking and harvest of barramundi is due to trickle losses and not statistical error, then the total number of barramundi that may have escaped from 2010 to 2019 could be up to 10,524. The cause of the 2016 escape event was due to a typhoon, but nearly all escaped barramundi were reportedly recaptured. There is no documentation of escape events in primary literature, or other sources and there is also no independent monitoring data that may evaluate escapes in the wild.

While a single large escape (>5% of the holding unit) has occurred in the last ten years, it was due to a stochastic event which prompted the operating company to adapt the construction and design of the net pens to prevent future occurrences. No such escapes have occurred in the five years since and as such, the adaptations made justify a lower level of concern for open systems with effective best management practices for design, construction, and management of escape prevention. Therefore, the escape risk concern is moderate, and the score is 4 out of 10.

**Recapture**
A large escape event occurred in 2016 with estimates of at least 25,000 individuals escaping. It was reported that nearly all of the fish were recaptured by the local fishermen, but without any further evidence or details, this information cannot be confirmed and is not robust enough to warrant a recapture adjustment. In 2018, BAP audits documented 2 escape events of five and one individuals escaping – all were recaptured with a net. Given the inability to confirm recaptures of the primary escape event, in addition to next to no escapes otherwise, there is limited justification for a recapture adjustment, and the final score for Factor 6.1 – Escape Risk is 4 out of 10.

**Factor 6.2. Competitive and genetic interactions**
Barramundi, *Lates calcarifer*, are native to the coastal waters of the Indian and Western Pacific Oceans, which includes areas as far north as Taiwan, south to the eastern Australian coast, east to Papua New Guinea, and as far west as the Persian Gulf (Greenwood 1976; Tucker et al. 2002; Hernandez-Jover et al. 2017). Preferred habitat includes coastal waters, estuaries, and lagoons with water temperatures of 20-30°C (Hernandez-Jover et al. 2017). Barramundi are serially hermaphroditic, demersal, catadromous, seasonal broadcast spawners that typically reproduce at estuary mouths at or near a full moon (Fulton-Howard, 2008; Moore, 1982; Hernandez-Jover et al. 2017). Considered opportunistic predators, barramundi will eat other barramundi, insects, crustaceans, zooplankton, fish, mollusks, and other organisms. Australian pelicans, file snakes and other barramundi are known to predate on barramundi as well (Fulton-Howard, 2008). Although not significant, there are some small capture fisheries of barramundi in the Mekong Delta area. Barramundi are not known to be found in the net pen production area of Van Phong Bay.

The nursery and grow out net pens in Van Phong Bay are supplied with barramundi from a captive native strain broodstock which are held in a land-based RAS facility. The broodstock are naturally spawned on the lunar cycle and the eggs are disinfected with ozone and transferred to a bio-secure RAS hatchery. The broodstock are up to three generations removed from wild populations (personal communication Goldman, 2019). Future broodstock are selected based on their performance such as growth rates and survival. (personal communication Goldman, 2020). As a result, it is likely that the broodstock are moderately phenotypically different and have been selected for beneficial characteristics (growth rate, disease resistance, etc.).

If barramundi do escape from the net pens, the risk that they may compete, predate, breed, disturb or other forms of impact to wild species, habitats or ecosystems is evaluated. Barramundi spawn in estuaries, and there are 130 estuaries along Vietnam's coast (Viet Thanh, 2013). It is estimated that there is 1 estuary per 25 km of coastline (Viet Thanh, 2013). However, the nearest suitable spawning ground is approximately 800 km from the farm location as habitat degradation from coastal habitat conversion due to shrimp farming, and coastal urbanization have altered the immediately surrounding estuaries (personal communication Goldman, 2019). Primary literature about the status of wild barramundi stocks in Vietnam could not found, so it is challenging to evaluate the risk or potential impact barramundi could have on wild populations if they escape, though there are no known populations of wild barramundi in Van Phong Bay. Given the low number of documented escapes and the distance to suitable spawning ground, it is unlikely that escapes from Van Phong Bay would congregate in spawning locations in significant enough numbers to cause a negative impact on wild stocks with respect to introgression and/or disruption of spawning events.

Documentation of other marine organisms such as fish, coral, crustaceans, invertebrates etc. inhabiting Van Phong Bay were unavailable in the Environmental Impact Assessment (2012) beyond noting the location of coral reefs proximal to the current operation, some of which appear to be <1 km from production areas (see Figure 10 in Factor 3.1). No information is available regarding the health of these reefs, though it is assumed that these areas host numerous species of fauna. Given the carnivorous nature of barramundi, it is considered possible that escapees may predate upon and/or compete for resources with fish, crustaceans, and other organisms that they interact with. However, given the limited number of escaped fish over the entire lifetime of the farm, any competitive or predatory impacts that may occur from escapees are unlikely to affect the population status of wild species.

Overall, barramundi are native to Van Phong Bay, and the active breeding program has likely resulted in phenotypic differences from the wild populations. The risk of these barramundi escaping from the net pens and impacting wild species is unclear as data are limited, but the risk is likely low. As a result, the concern for competitive and genetic interactions is moderate and the final score for Factor 6.2 – Competitive and genetic interactions is a 4 out of 10.

**Conclusions and Final Score**

Marine net pen production systems are open and vulnerable to escapes, but multiple escape prevention methods are employed including strategic farm siting, size grading with appropriate mesh size, and a detailed Escape Management Protocol system that emphasizes training, decision models, and action items. While a single large escape (>5% of the holding unit) has occurred in the last ten years, it was due to a stochastic event (Typhoon Damray) which prompted the operating company to adapt the construction and design of the net pens to prevent future occurrences. It was reported that nearly all escapees were recaptured by local fisherman, though this could not be confirmed. No such escapes have occurred in the five years since and as such, the adaptations made justify a lower level of concern for open systems with effective best management practices for design, construction, and management of escape prevention. Besides this event, escape events appear minimal from 2010-2018. The accounting of barramundi at stocking and harvest is within the error/variability of the accounting machine and model for all years except 2016, confirmed by third-party certification audits. If it is assumed that the reason for the difference between stocking and harvest of barramundi is due to trickle losses and not statistical error, then the total number of barramundi that may have escaped over these years could be up to 10,524, a number considered unlikely to cause population level impacts to wild species. Overall, the escape risk concern is moderate and the score for Factor 6.1 Escape Risk is 4 out of 10.

Should barramundi escape from net pens, they may cause competitive and/or genetic impacts to wild species. There is limited data or literature readily available that evaluate or document the genetic risk or lack thereof between native, wild barramundi and farmed stock in Vietnam, though it is apparent that farm stock are multiple generations removed from the wild and have been selected for favorable traits. Despite this, the farm is located at least 800 km from suitable spawning grounds and there is no evidence that escapees have successfully spawned with wild barramundi. Documentation of other marine organisms such as fish, coral, crustaceans, invertebrates etc. inhabiting Van Phong Bay were unavailable in the Environmental Impact Assessment (2012) beyond noting the location of coral reefs proximal to the current operation, some of which appear to be <1 km from production areas (see Figure 10 in Factor 3.1). No information is available regarding the health of these reefs, though it is assumed that these areas host numerous species of fauna. Given the carnivorous nature of barramundi, it is considered possible that escapees may predate upon and/or compete for resources with fish, crustaceans, and other organisms that they interact with. However, given the limited number of escaped fish over the entire lifetime of the farm, any competitive, predatory, and/or genetic impacts that may occur from escapees are unlikely to affect the population status of wild species. As a result, the concern for 6.2 Competitive and genetic interactions is moderate and scores a 4 out of 10.

Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6 – Escapes.

# Criterion 7: Disease; pathogen and parasite interactions

**Impact, unit of sustainability and principle**

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

**Criterion 7 Summary**

Risk-Based Assessment

| Pathogen and parasite parameters | Score | |
|---|---|---|
| C7 Disease Score (0-10) | 6 | |
| Critical? | YES | YELLOW |

**Brief Summary**

Overall, the open nature of net pen barramundi farms means that fish are readily exposed to pathogens and parasites occurring in the waterbody, on wild fish, or on other natural hosts. There is some documentation of clinical disease on the farm, but through effective biosecurity management and vaccination, clinical disease frequency and severity as well as resulting mortality all appear very low. There is no documentation of transmission of diseases from farmed barramundi to the surrounding marine ecosystem. Therefore, the concern for Disease Risk is Low-moderate and scores a 6 out of 10.

**Justification of Rating**

As disease data quality and availability is moderate (i.e., Criterion 1 score of 5 out of 10 for the Disease criterion), the Seafood Watch Risk-Based assessment was used.

The open nature of net pen barramundi farms means that fish are readily exposed to pathogens and parasites occurring in the waterbody, on wild fish, or on other natural hosts. If farmed fish are infected, pathogens and parasites may be amplified within the net pens, and farms can act as temporary unnatural reservoirs for a variety of pathogens and parasites, which have the potential to transfer to wild fish (Hammell et al. 2009). Therefore, the risk of disease occurrences on farm and the potential impact of transmission to wild species is assessed.

Bacterial, fungal, viral, and parasitic diseases may occur throughout the barramundi life cycle. According to the Van Phong Bay operation, monogenean flukes, iridovirus/red seabream iridovirus (RSIV), streptococcus, and vibriosis are the pathogenic issues the operation experiences and treats (personal communication Goldman, 2019).

Vibrio bacteria species and specifically, *Vibrio harveyi*, are found in Vietnam and can lead to vibriosis, a significant disease that can impact barramundi production. Symptoms of vibriosis include hemorrhages, and ulcerations of the skin, fin and tail and can also impact internal organs (Hernandez-Jover et al., 2017). Reported cumulative mortality due to outbreaks of *V. harveyi* for Vietnamese barramundi is up to 40% (Dong et al. 2017). Scale drop and muscle necrosis syndrome (SDMN) is another disease resulting from *Vibrio harveyi* infection (Mohamad et al. 2019) and can cause “necrotic muscle with infiltration of massive immune-related cells, hemorrhage and blood congestion in the brain, collapsed kidney tubules and epithelial cells sloughing” (Dong et al., 2017). For the Van Phong Bay operation, vibriosis primarily affects juvenile fish and typically arises during the first 45 days of transfer into nursery net pens (personal communication Goldman, 2019).

Another bacteria found in Vietnam that can lead to disease is the Streptococcus genus, causative of streptococcosis (Hernandez-Jover et al., 2017). According to Hernandez-Jover et al. (2017) symptoms include “erratic swimming (such as spiralling or spinning); loss of buoyancy control; lethargy; darkening; uni or bilateral exophthalmia; corneal opacity; haemorrhages, ascites; and ulcerations (Yanong and Francis-Floyd, 2002).” There are potentially a wide range of hosts as transmission occurs horizontally, but wild barramundi may be a “a reservoir for infection when cohabiting in sea cages.” (Jerry, 2013 from Hernandez-Jover et al., 2017). At the Van Phong Bay operation, streptococcosis may affect fish throughout its life cycle (personal communication Goldman, 2019).

Fish are vaccinated against *Streptococcus iniae* and *Vibrio* spp. with a unique, trivalent autogenous vaccine. The operating company reports that this trivalent vaccine offers largely strong life cycle protection against these pathogens, with relative percent survival (RPS) in the mid-90s noting that “vast majority of the losses [occur] during the nursery stage and period following transfer to the sea cages.” (personal communication Goldman, 2020).

The virus family Iridoviridae include three genera that affect vertebrates: Ranavirus, Lymphocystivirus and Megalocytivirus (Kurita and Nkajima., 2012; Subramaniam et al., 2012; Dong et al., 2017). Within the genera Megalocytivirus is the red sea bream iridovirus (RSIV) and infectious spleen and kidney necrosis virus (ISKNV) (Dong et al., 2017; Kurita and Nkajima, 2012; Subramaniam et al. 2012; Dong et al. 2017; Dong, 2015; Suebsing et al. 2016; Shi et al, 2010; Miyata et al, 1997; Sudthongkong, et al. 2002).

Both red seabream iridovirus (RSIV) and Infectious spleen and kidney necrosis virus (ISKNV) can lead to red sea bream iridoviral disease (RSIVD) (Hernandez-Jover et al. 2017). Although RSIV infection may occur at any point in the barramundi life stage, juvenile fish are at higher risk, and transmission is horizontal via water column with outbreaks more likely to occur at water temperatures over 25°C (Hernandez-Jover et al. 2017; World Organization for Animal Health (OIE), 2016). Depending on the species and a number of other variables, mortality rate of RSIVD can range from 0 to 100% (USDA, 2013). Mortality rates for this disease were not provided by the Van Phong Bay net pen operation, though it was stated that RSIV usually affects juvenile barramundi between 3-30 grams and is effectively managed with vaccination and a proprietary technique (Personal communication Goldman, 2019).

Monogenean flukes are parasites that "infects the gills and skin of marine and freshwater fish" (Palmeiro, B., 2013). Transmission occurs primarily by contact from fish to fish (Palmeiro, B., 2013) as flukes move "directly from host to host" (Reed et al, 2012). Stress, and poor environmental conditions can "predispose fish to infection" (Palmeiro, B., 2013). Symptoms may include lethargy, change in swimming behavior, scale loss, color variation, swollen and pale gills, mucus, ulcers, and hemorrhages; large numbers of flukes on fish skin and/or gills may result in significant damage and mortality (Palmeiro, B., 2013; Reed et al. 2012). For barramundi production in net pens in Van Phong Bay, monogenean flukes have been reported to affect fish <250 grams at nursery net pens (personal communication Goldman, 2019). It is effectively treated with a freshwater and/or formalin bath (personal communication Goldman, 2019; Palmeiro, B., 2013). The mortality rate due to monogenean fluke parasites in nursery/grow out pens is less than 3%.

The frequency of these disease occurrences in Van Phong Bay and the severity of outbreaks is unknown, though overall mortality rates are reported low. Given the vaccinations and effective disease management protocols (detailed below), suitable year-round water quality (see Criterion 2 - Effluent) and a relatively low stocking density (<20 kg/m3), it is likely that clinical disease frequency and severity is low. Although the mortality rates for every disease that affects the farm are not known, a BAP audit indicates that grow-out survival on the farm is 97.5% for the year 2019 (BAP audit, 2020). Furthermore, the Network of Aquaculture Center in Asia releases quarterly reports on animal disease occurrences. From 2015 to 2019, there were no disease incidences reported in Vietnam for barramundi.

To help reduce the risk of disease outbreaks, net pen operations in Van Phong Bay employ a fish health management framework developed by an aquaculture veterinary specialist (personal communication Goldman, 2019; BAP audit, 2020). This includes stocking at relatively low densities (<30 kg/m3), observing fish behavior, and regularly sampling fish for pathogens and disease in an in-house lab (personal communication Goldman, 2019). This is done at least two times a week for net pen cages. If clinical signs are observed, samples are sent to internal or external government or private laboratories for diagnostic confirmation (personal communication Goldman, 2019). A biosecurity management plan also helps to exclude the introduction and spread of diseases. In the case of a biosecurity breach or observation of disease, staff are alerted, isolation is implemented if necessary, materials are disinfected, and the proper management of diseased individuals proceeds (personal communication Goldman, 2019). All fish planted in nursery and grow out net pens are sourced from a bio-secure RAS hatchery owned by the company where standard marine fish hatchery practices are implemented. Other ongoing biosecurity measures include restricting personnel access, routinely disinfecting equipment and materials, and only using one dock for outgoing travel/material to net pens, and one dock for incoming travel/material from net pens (personal communication Goldman, 2019).

The responsibility of enforcing these fish health management strategies is delegated to directors and farm managers, coordinated by the Biosecurity Officer. Success is dependent on all individuals following the management plan. As such, education and training for all employees is a key component (personal communication Goldman, 2019).

Literature on the transmission of disease from barramundi net pen production in Van Phong Bay to wild marine organisms is limited. The operation in Van Phong Bay is actively researching this topic, but there are no findings available at the time of writing this assessment. By design, open net-pen culture systems are inherently vulnerable to the transmission of pathogens between cages and also between wild and farmed fish stocks. It is, however, challenging to quantify such pathogenic exchanges and scant empirical evidence of these has ever been documented (Krkošek 2017). To date, there is no evidence of any disease transmission occurring from farmed barramundi to wild species in Vietnam. Hernendez-Joyer et al. (2017) highlighted the potential impact of common barramundi diseases such as “1) Red sea bream iridoviral disease (RSIVD); 2) Infectious spleen and kidney necrosis virus (ISKNV); 3) Scale drop syndrome (SDS); 4) Pot belly disease (PBD)” to wild populations in an assessment of Australian barramundi farms. The study found that the “Introduction of these diseases into the wild was a concern due to the lack of effective control measures available to eradicate the diseases” (Hernendez-Joyer et al, 2017) indicating the importance of farm management to minimize these diseases on farm. In Vietnam, the fish health management strategy along with the biosecurity measures implemented by the operating farm appear to be effective in controlling disease on-farm, and as such, effectively reduce the risk of disease transmission to the wild.

**Conclusions and Final Score**

Overall, the open nature of net pen barramundi farms means that fish are readily exposed to pathogens and parasites occurring in the waterbody, on wild fish, or on other natural hosts. There is some documentation of clinical disease on the farm, but through effective and robust biosecurity protocols, clinical disease frequency, severity, and resulting mortality all appear very low. There is no documentation of transmission of diseases from farmed barramundi to the surrounding marine ecosystem. Therefore, the concern for Disease Risk is Low-moderate and scores a 6 out of 10.

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

**Impact, unit of sustainability and principle**

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

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

**Criterion 8X Summary**

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

**Brief Summary**

The barramundi marine net pen farming industry in Vietnam is entirely reliant on domesticated, hatchery-raised broodstock, eggs, and juveniles. The final score for Criterion 8x – Source of Stock is 0 out of -10.

**Justification of Rating**

Due to the use of native domesticated broodstock (personal communication Goldman, 2019), marine net cage Vietnamese barramundi production is considered to be independent of wild barramundi fisheries for the supply of fish for production. The broodstock program is three generations removed from wild stock and has been closed from wild supplementation for about 5 years. Future broodstock are selected based on performance such as growth rates and survival (personal communication Goldman, 2020). Therefore, the score for Criterion 8x – Source of Stock is 0 out of -10.

**Conclusions and Final Score**

Because approximately 0% of farmed stock is dependent on wild broodstock/ wild fisheries, and 0% of farmed stock is dependent on endangered species, the final numerical score for Criterion 8X – Source of Stock is a deduction of 0 out of -10.

# Criterion 9X: Wildlife and predator mortalities

**Impact, unit of sustainability and principle**

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: 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**

| Wildlife and predator mortality parameters | Score | |
|---|---|---|
| C9X Wildlife and predator mortality Final Score (0-10) | **0** | |
| Critical? | NO | **GREEN** |

**Brief Summary**

Overall, deliberate lethal wildlife control is not used on the farm and there has been no death or injury to predators or wildlife since the start of operation about 10 years ago. The operating company employs high quality nets with proprietary tensioning and small mesh to limit the ability of predators to grip, enter, and or become entangled with the net pens. Interactions with birds are not uncommon, but predation is rare and interventions have not been required. The final numerical score for Criterion 9X – Wildlife Mortalities is 0 out of -10.

**Justification of Rating**

As Wildlife and predator mortality data quality and availability is high (Criterion 1 score of 7.5 out of 10), the Seafood Watch Evidence-Based Assessment was utilized.

Net pen operations in Van Phong Bay implement a predator control plan to minimize interactions with predators and wildlife. This includes frequent net inspections, training all staff of what to do in case of an interaction, documentation of any interactions, as well as detailed report and documentation of all IUCN listed species in the area (personal communication Goldman, 2020; BAP, 2020). Structurally, net pens use high quality (>250 kg breaking strength) nets, implement a proprietary net tensioning system to ensure the panels remain tight, and small mesh sizes, all of which minimize the ability of predators to grip, enter, and or become entangled with the net pens (personal communication Goldman, 2019; Seafood Watch, 2014). There is no use of bird nets, streamers, noise deterrents, or predator nets. Any interaction that does occur is recorded by the operation. Wildlife hunting is also not allowed at the farm, and there is no take of any wildlife that is allowed by the operation.

Known interactions that are documented by the operation include rabbitfish, eagles, and seabirds (personal communication Goldman, 2019). Rabbit fish can be found grazing on debris that grows on the sea cages (personal communication Goldman, 2019). Eagles and sea birds do occasionally catch fish, but interactions are said to be so rare that there is no incentive to adopt preventative techniques (personal communication Goldman, 2019). A common concern with marine net pen farming is the entanglement of marine mammals in the ropes and gear of marine net pen operations. Van Phong Bay opens up to the South China Sea, which is a significant region for cetacean species with high species diversity (Li et al. 2020), but the frequency and number of whales entering Van Phong Bay is unknown. Overall, known occurrences with any predators or wildlife is minimal, and there have been no death or injury to predators over the roughly 10 years of operation (personal communication Goldman, 2019).

Furthermore, the barramundi net pen operation is BAP certified[5], and must adhere to its indicators such as: "No control, other than non-lethal exclusion, shall be applied to species that are listed as endangered or highly endangered on the IUCN Red List or that are protected by local or national laws." The current and most recent audit indicates full compliance with this indicator (BAP audit, 2020).

**Conclusions and Final Score**

Overall, deliberate lethal wildlife control is not used on the farm and there has been no death or injury to predators or wildlife since the start of operation about 10 years ago. The operating company employs high quality nets with proprietary tensioning and small mesh to limit the ability of predators to grip, enter, and or become entangled with the net pens. Interactions with birds are not uncommon, but predation is rare and interventions have not been required. The final numerical score for Criterion 9X – Wildlife Mortalities is 0 out of -10.

[5] the Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP) Finfish and Crustacean Farm Standard

# Criterion 10X: Escape of secondary species

**Impact, unit of sustainability and principle**

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- 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**

| Escape of secondary species parameters | | Score | |
|---|---|---|---|
| F10Xa International or trans-waterbody live animal shipments (%) | | 10 | |
| F10Xb Biosecurity of source/destination | | 10 | |
| **C10X Escape of secondary species Final Score** | | **0.00** | **Green** |

**Brief Summary**

Barramundi are native to Vietnam and Van Phong Bay. Broodstock are maintained in local hatcheries in the bay; thus, there is no risk of exotic pathogens being introduced by barramundi and all transfers of fish occur within the bay. The final score for Criterion 10X – Escape of secondary species is 0 out of -10.

**Justification of Rating**

<u>Factor 10Xa International or trans-waterbody live animal shipments</u>

The broodstock, hatchery, and marine net pen operations that produce barramundi are all located in Van Phong Bay. Therefore, there is zero percentage of production that is reliant on the ongoing trans-waterbody movement of broodstock, eggs, larvae, or juveniles.

Because 0% of production is reliant on international/trans-waterbody animal movements the score for Factor 10Xa is 10 out of 10.

**Factor 10Xb Biosecurity of source/destination**

As there are no international or trans-waterbody shipments of live animals, there is no risk of transferring organisms between ecologically-distinct environments. Thus, the score for Factor 10Xb is 10 out of 10.

The final score for Criterion 10X – Escape of secondary species is a deduction of 0 out of -10.

**Conclusions and Final Score**

Barramundi are native to Vietnam and the growing area, Van Phong Bay. The broodstock are maintained in local hatcheries; thus, there is no risk of exotic pathogens being introduced by barramundi farming. The final score for Criterion 10X – Escape of secondary species is a deduction of 0 out of -10.

# Overall Recommendation

The overall recommendation is as follows:

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

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

**Barramundi**
*Lates calcarifer*
**Van Phong Bay, Vietnam**
Net pens

| Criterion | Score | Rank | Critical? |
|---|---|---|---|
| C1 Data | 7.50 | Green | |
| C2 Effluent | 6.00 | Yellow | NO |
| C3 Habitat | 6.80 | Green | NO |
| C4 Chemicals | 8.00 | Green | NO |
| C5 Feed | 4.75 | Yellow | NO |
| C6 Escapes | 4.00 | Yellow | NO |
| C7 Disease | 6.00 | Yellow | NO |
| | | | |
| C8X Source | 0.00 | Green | NO |
| C9X Wildlife mortalities | 0.00 | Green | NO |
| C10X Introduced species escape | 0.00 | Green | |
| **Total** | **43.05** | | |
| **Final score (0-10)** | **6.151** | | |

OVERALL RANKING

| | |
|---|---|
| Final Score | 6.151 |
| Initial rank | Yellow |
| Red criteria | 0 |
| Interim rank | Yellow |
| Critical Criteria? | NO |

| FINAL RANK |
|---|
| **Yellow** |

## Acknowledgements

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

The author would like to thank the reviewers of this report who chose to remain anonymous.

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# Appendix 1 - Data points and all scoring calculations

| **Criterion 1: Data** | |
|---|---|
| **Data Category** | **Data Quality** |
| Production | 7.5 |
| Management | 7.5 |
| Effluent | 7.5 |
| Habitat | 7.5 |
| Chemical Use | 7.5 |
| Feed | 7.5 |
| Escapes | 5.0 |
| Disease | 5.0 |
| Source of stock | 10.0 |
| Wildlife mortalities | 7.5 |
| Escape of secondary species | 10.0 |
| **C1 Data Final Score (0-10)** | **7.500** |
| | Green |

Barramundi

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

**Select the species or "System" from the list** Barramundi

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

| **Criterion 2 - Effluent**<br>Risk-based assessment | |
|---|---|
| **2.1a Biological waste production** | **Data and Scores** |
| Protein content of feed (%) | 45.000 |
| eFCR | 1.610 |
| Fertilizer N input (kg N/ton fish) | 0.000 |
| Protein content of harvested fish (%) | 18.000 |
| N content factor (fixed) | 0.160 |
| N input per ton of fish produced (kg) | 0.000 |
| N output in each ton of fish harvested (kg) | 28.800 |
| Waste N produced per ton of fish (kg) | 0.000 |

| **2.1b Production System discharge** | **Data and Scores** |
|---|---|
| Basic production system score | 0.000 |

| | |
|---|---|
| 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) | 0.000 |
| 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 | 0 |
| 2.2b Enforcement of effluent management measures | 0 |
| 2.2 Effluent management effectiveness | 0.000 |
| **C2 Effluent Final Score (0-10)** | **n/a** |
| Critical? | No |

C3 applies to all species

| **Criterion 3: Habitat** | |
|---|---|
| **F3.1. Habitat conversion and function** | **Data and Scores** |
| F3.1 Score (0-10) | 9 |
| **F3.2 – Management of farm-level and cumulative habitat impacts** | |
| 3.2a Content of habitat management measure | 3 |
| 3.2b Enforcement of habitat management measures | 2 |
| 3.2 Habitat management effectiveness | 2.400 |
| **C3 Habitat Final Score (0-10)** | **6.800** |
| Critical? | No |

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

Single species

| **Criterion 4: Chemical Use** | |
|---|---|
| Single species assessment | Data and Scores |
| Chemical use initial score (0-10) | 8.0 |
| Trend adjustment | 0.0 |
| **C4 Chemical Use Final Score (0-10)** | **8.0** |
| Critical? | No |

Barramundi

| **Criterion 4: Chemical Use** | |
|---|---|
| All-species assessment | **Data and Scores** |
| Chemical use initial score (0-10) | 8 |

| | |
|---|---|
| Trend adjustment | 0 |
| **C4 Chemical Use Final Score (0-10)** | **8** |
| Critical? | No |

**Select the species or "System" again from the list** Barramundi

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

| **Criterion 5: Feed** | |
|---|---|
| **5.1 Wild Fish Use** | |
| **5.1a Forage Fish Efficiency Ratio (FFER)** | **Data and Scores** |
| Fishmeal from whole fish, weighted inclusion level % | 0.000 |
| Fishmeal from byproducts, weighted inclusion % | 30.000 |
| Byproduct fishmeal inclusion (@ 5%) | 1.500 |
| Fishmeal yield value, weighted % | 22.500 |
| Fish oil from whole fish, weighted inclusion level % | 3.000 |
| Fish oil from byproducts, weighted inclusion % | 3.000 |
| Byproduct fish oil inclusion (@ 5%) | 0.150 |
| Fish oil yield value, weighted % | 5.000 |
| eFCR | 1.610 |
| **FFER Fishmeal value** | **0.107** |
| **FFER Fish oil value** | **1.014** |
| Critical (FFER >4)? | No |

| **5.1b Sustainability of Source fisheries** | **Data and Scores** |
|---|---|
| Source fishery sustainability score | 4.141 |
| 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** | **5.010** |

| **5.2 Net Protein Gain or Loss (%)** | **Data and Scores** |
|---|---|
| Weighted total feed protein content | 45.000 |
| Protein INPUT kg/100kg harvest | 72.450 |
| Whole body harvested fish protein content | 18.000 |
| Net protein gain or loss | -75.155 |
| **Species-specific Factor 5.2 score** | **2** |
| Critical (Score = 0)? | No |
| Critical (FFER>3 and 5.2 score <2)? | No |

| **5.3 Feed Footprint** | **Data and Scores** |
|---|---|
| **GWP (kg CO2-eq kg-1 farmed seafood protein)** | **12.999** |

| | |
|---|---|
| Contribution (%) from fishmeal from whole fish | 0.000 |
| Contribution (%) from fish oil from whole fish | 1.360 |
| Contribution (%) from fishmeal from byproducts | 19.424 |
| Contribution (%) from fish oil from byproducts | 1.360 |
| Contribution (%) from crop ingredients | 58.337 |
| Contribution (%) from land animal ingredients | 15.431 |
| Contribution (%) from other ingredients | 4.088 |
| **Factor 5.3 score** | **7** |
| | |
| **C5 Final Feed Criterion Score** | **4.8** |
| Critical? | **No** |

**Select species again** Barramundi

| **Criterion 6: Escapes** | **Data and Scores** |
|---|---|
| F6.1 System escape risk | 4 |
| Percent of escapees recaptured (%) | 0.000 |
| F6.1 Recapture adjustment | 0.000 |
| F6.1 Final escape risk score | 4.000 |
| F6.2 Invasiveness score | 4 |
| **C6 Escape Final Score (0-10)** | **4.0** |
| Critical? | No |

Barramundi

| **Criterion 7: Disease** | **Data and Scores** |
|---|---|
| Evidence-based or Risk-based assessment | Risk |
| **Final C7 Disease Criterion score (0-10)** | **6** |
| Critical? | No |

Barramundi

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

Barramundi

| Criterion 9X Wildlife Mortality parameters | Data and Scores |
|---|---|
| Single species wildlife mortality score | 0 |
| System score if multiple species assessed together | n/a |
| **C9X Wildlife Mortality Final Score** | **0** |
| Critical? | No |

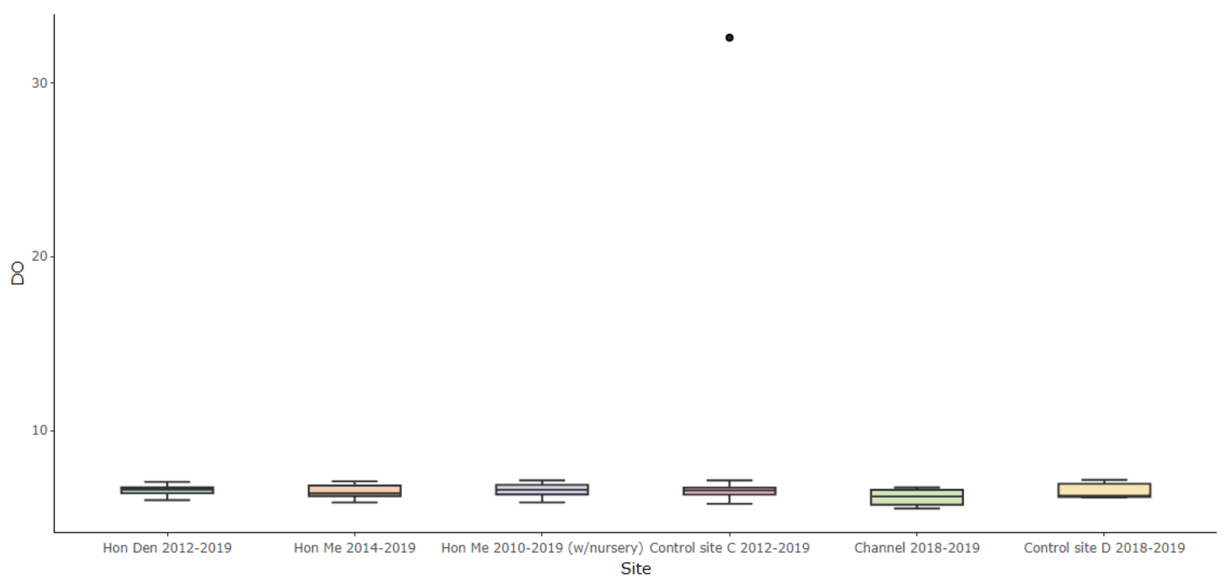
| Barramundi |
|---|

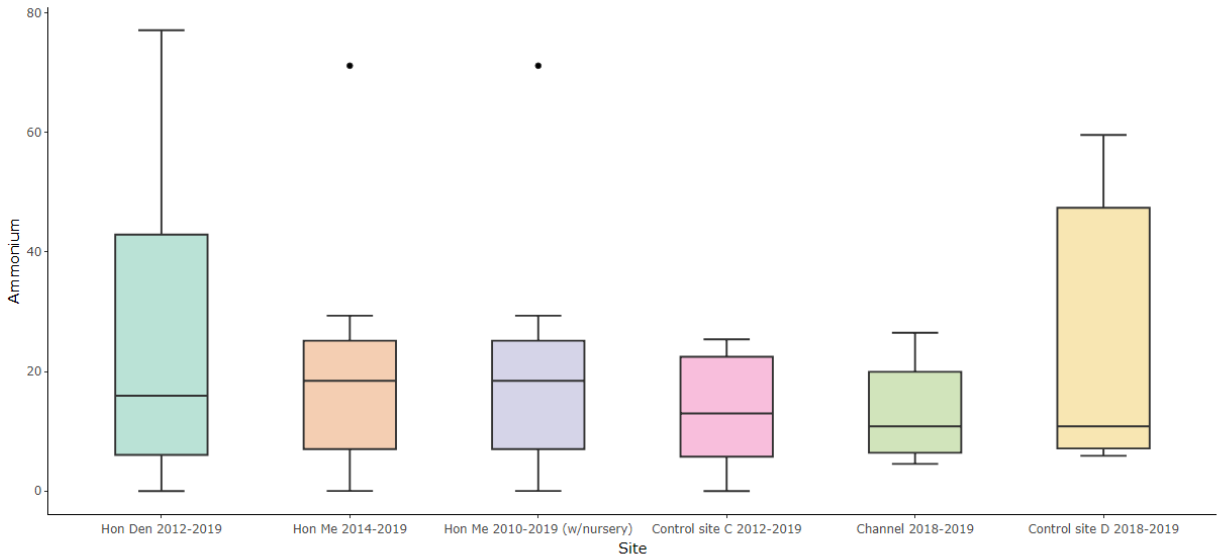
| Criterion 10X: Introduction of Secondary Species | Data and Scores |
|---|---|
| Production reliant on transwaterbody movements (%) | 0 |
| Factor 10Xa score | 10 |
| Biosecurity of the source of movements (0-10) | 10 |
| Biosecurity of the farm destination of movements (0-10) | 10 |
| Species-specific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

# Appendix 2 - Summary of water column and sediment measurements

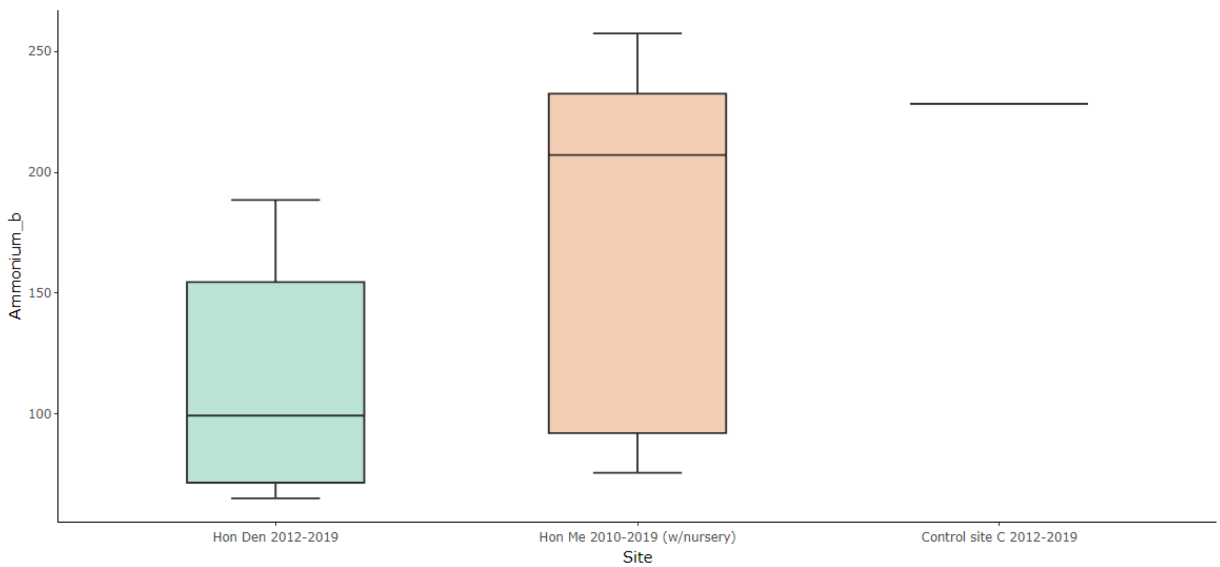
Water quality measurements are presented for water column and sediment from 2010 to 2019. Water column measurements were made for the following parameters: dissolved oxygen, ammonium measurements from 2015-2019, ammonium measurements from 2010 to 2013 (identified as ammonim_b), phosphate, sulfate, TON, TOP, and nitrate. Sediment measurements were made for the following parameters: B.O.D., ammonium b (2015-2019), ammonium (2010-2013), phosphate, sulfate, and redox. Data provided has inconsistent sampling methodology in time, place, parameters measured and low sample size. All measurements are aggregated to the site level over time and are presented in a box plot to visualize the range of results, and the median for each site.

### Water Column

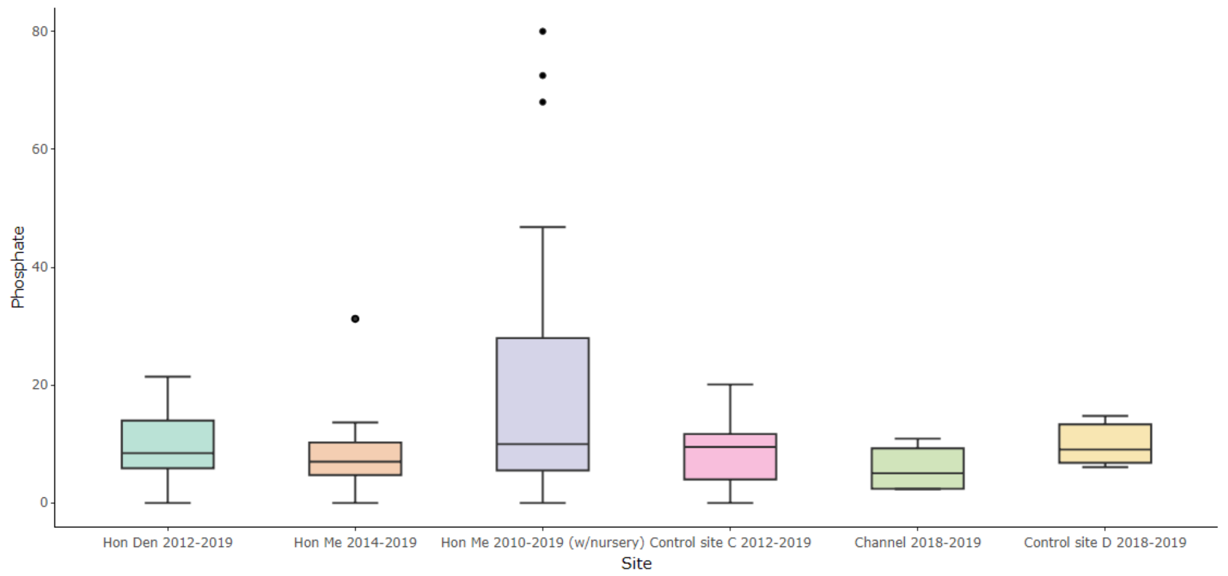


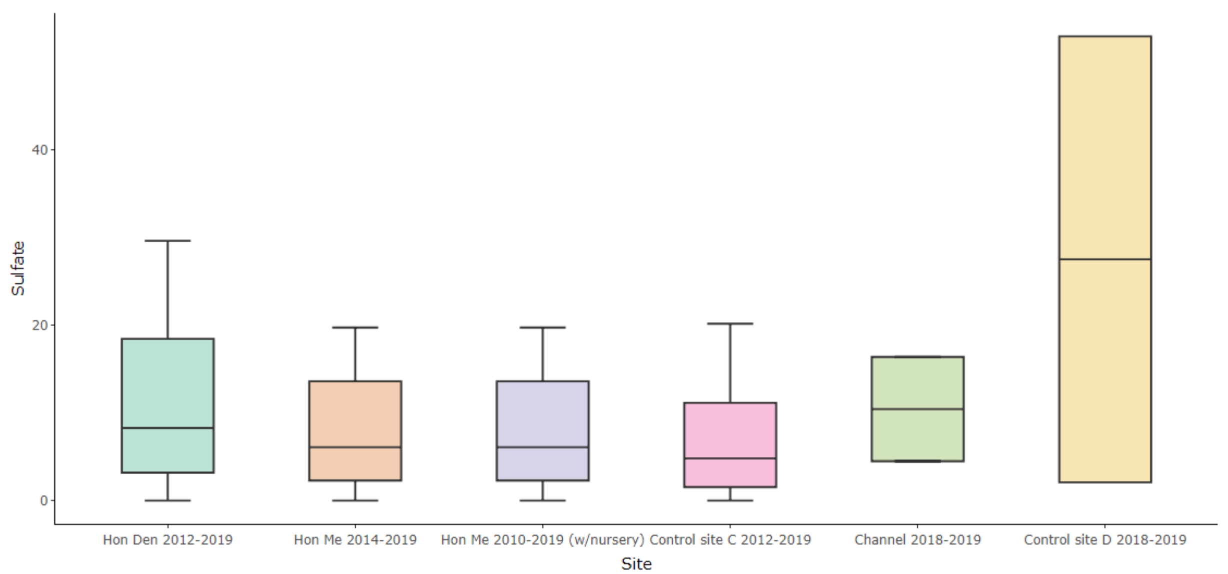


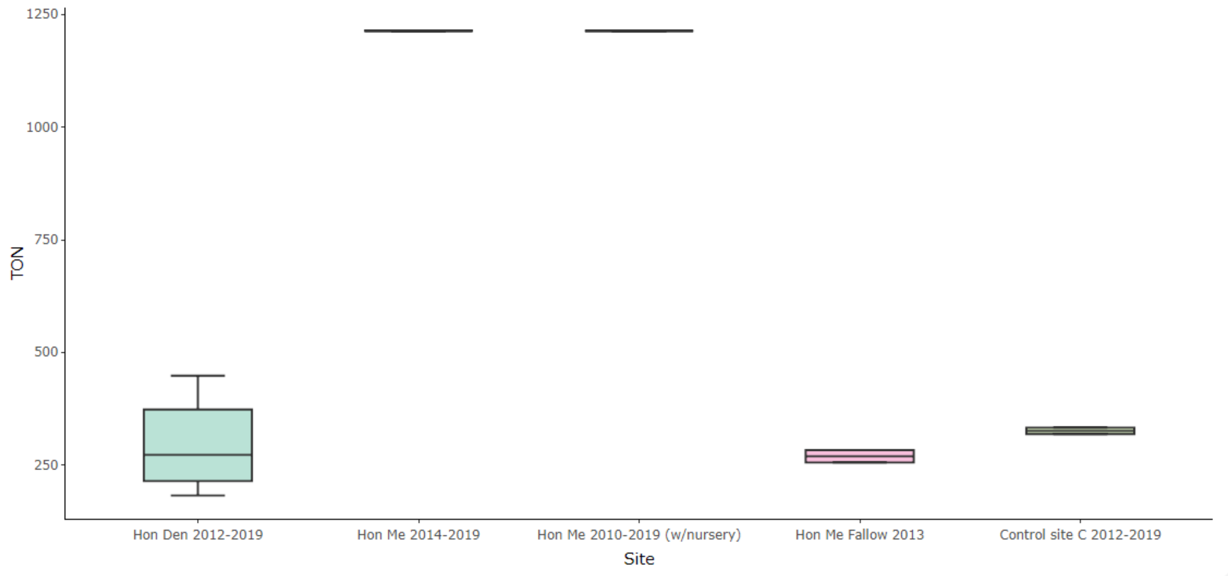
Ammonium
80
60
40
20
0
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site

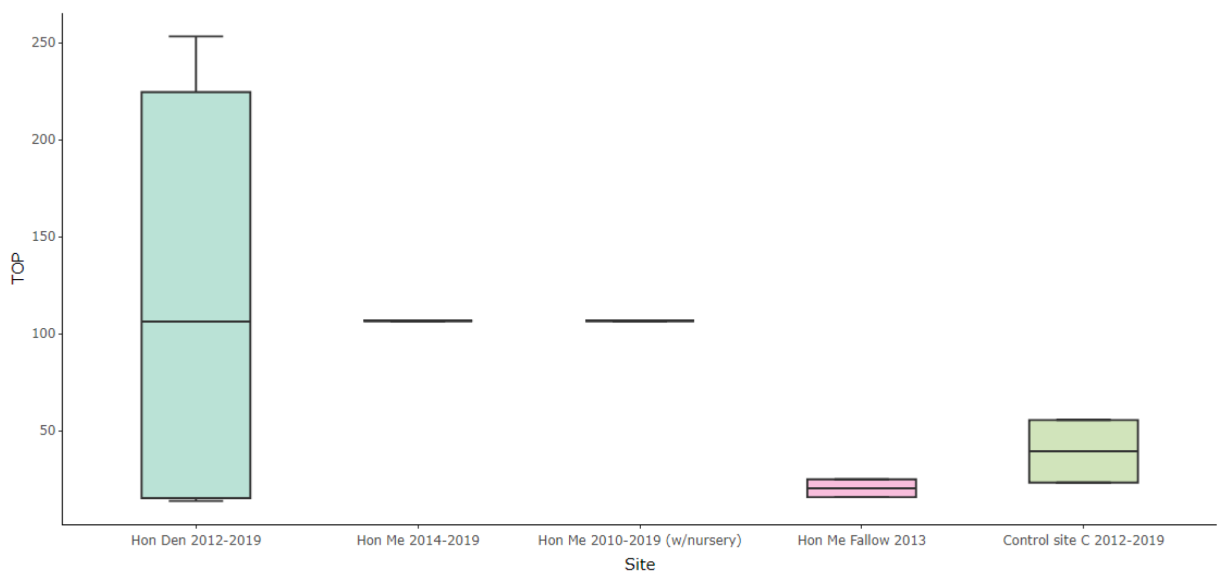



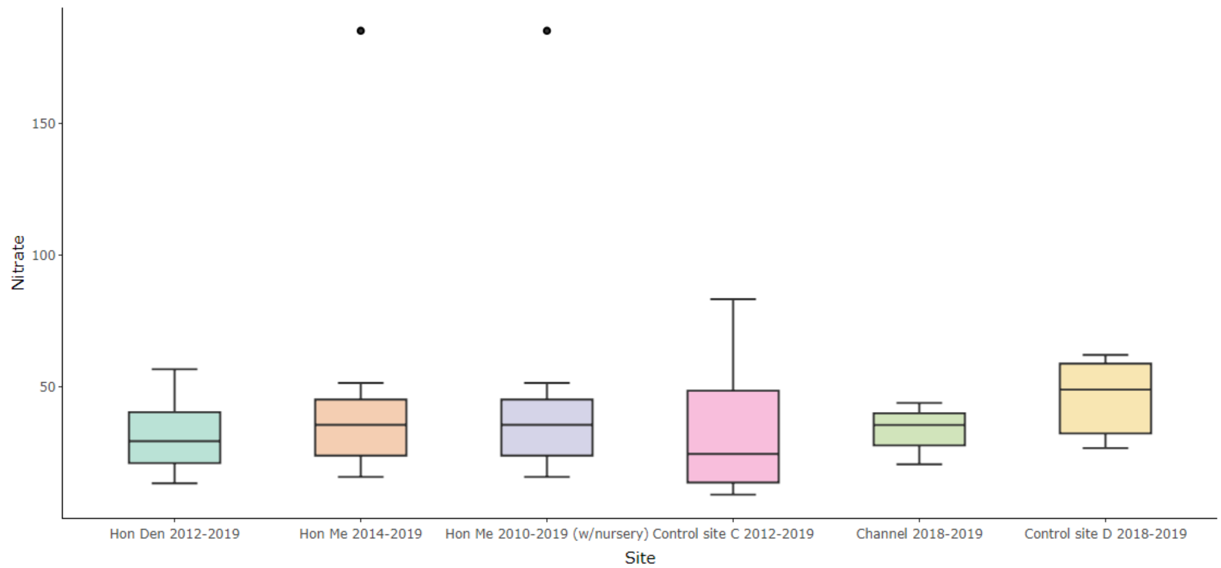
Ammonium_b
250
200
150
100
Hon Den 2012-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Site


Phosphate
80
60
40
20
0
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site

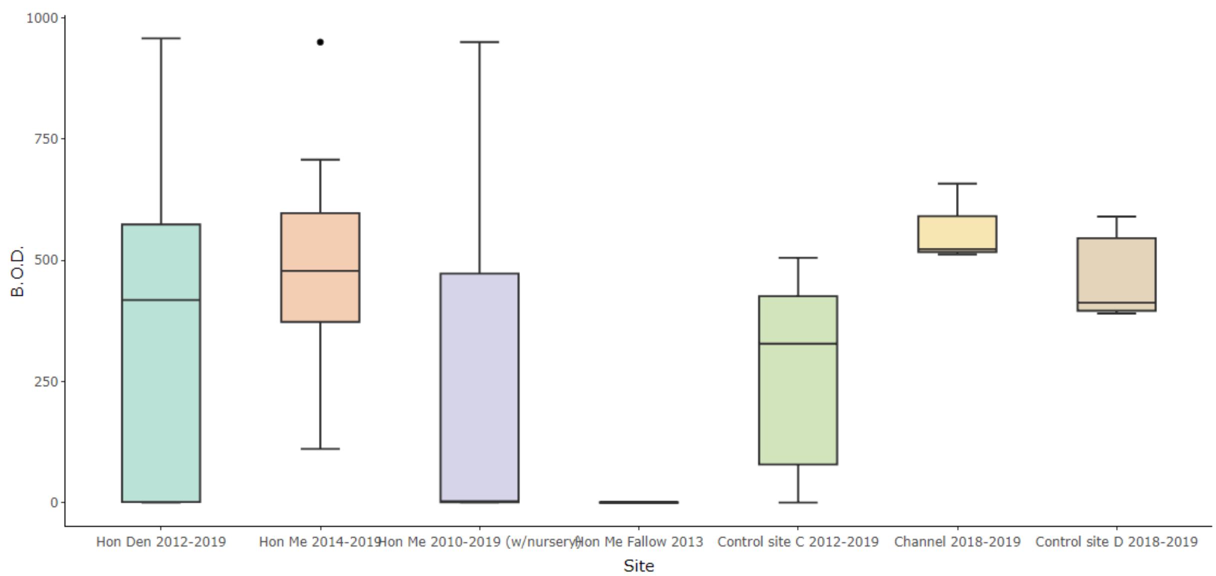

Sulfate
40
20
0
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site

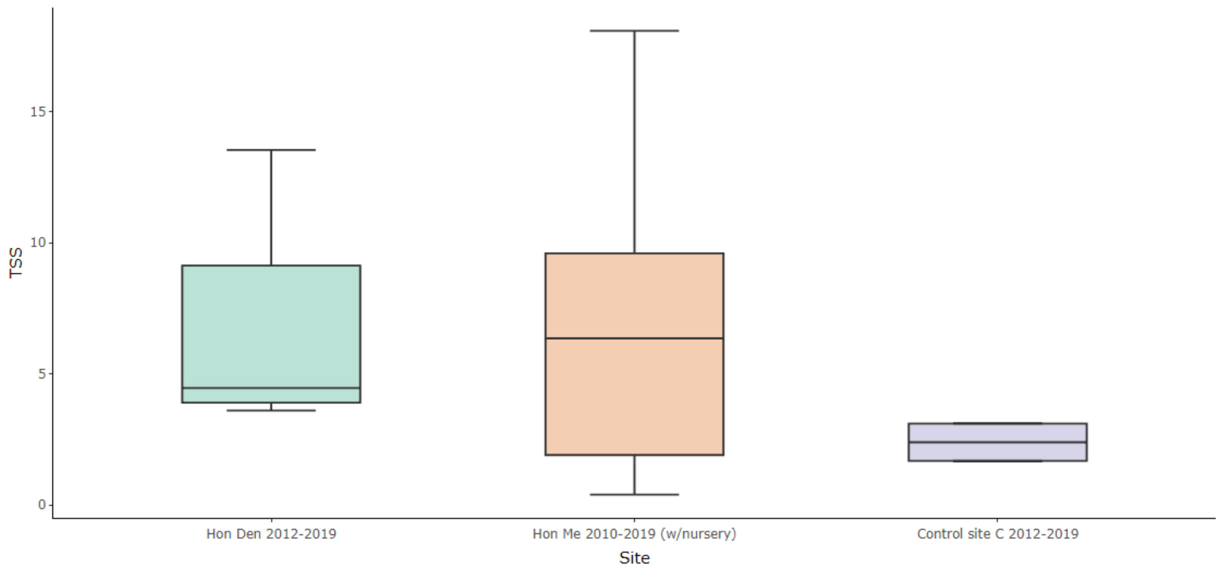

1250
1000
750
500
250
TON
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Hon Me Fallow 2013
Control site C 2012-2019
Site

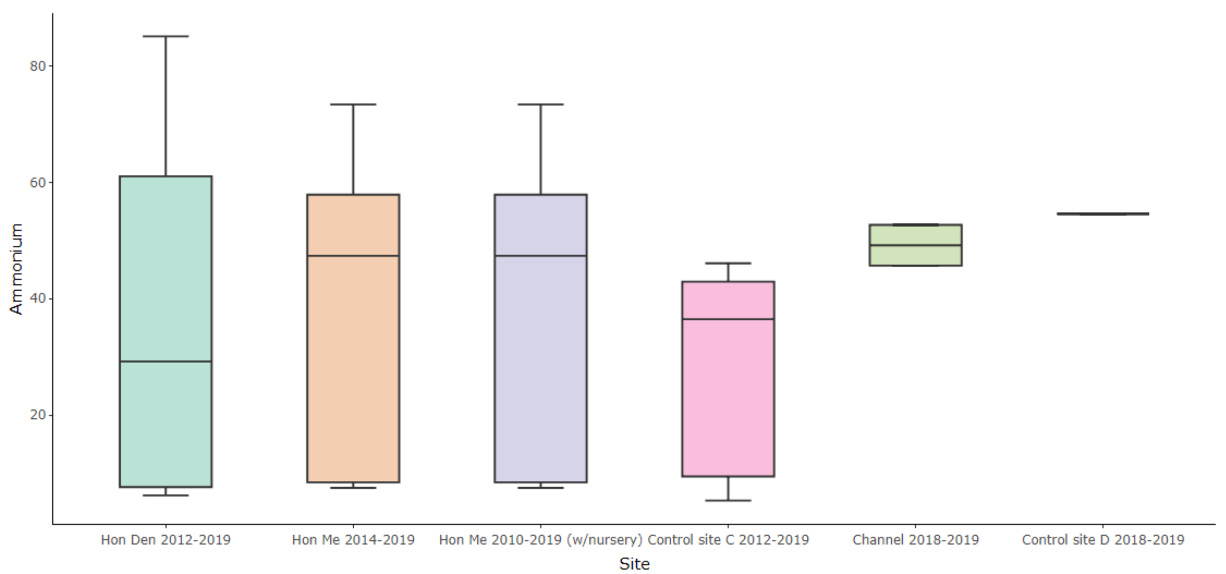

250
200
150
100
50
TOP
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Hon Me Fallow 2013
Control site C 2012-2019
Site

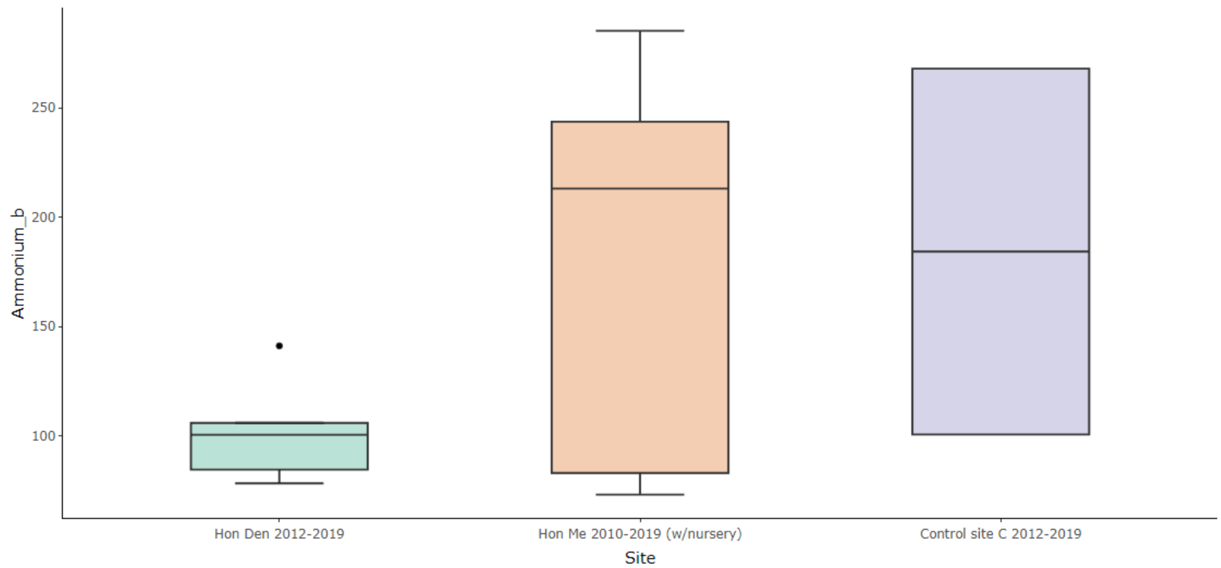

150
100
50
Nitrate
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site

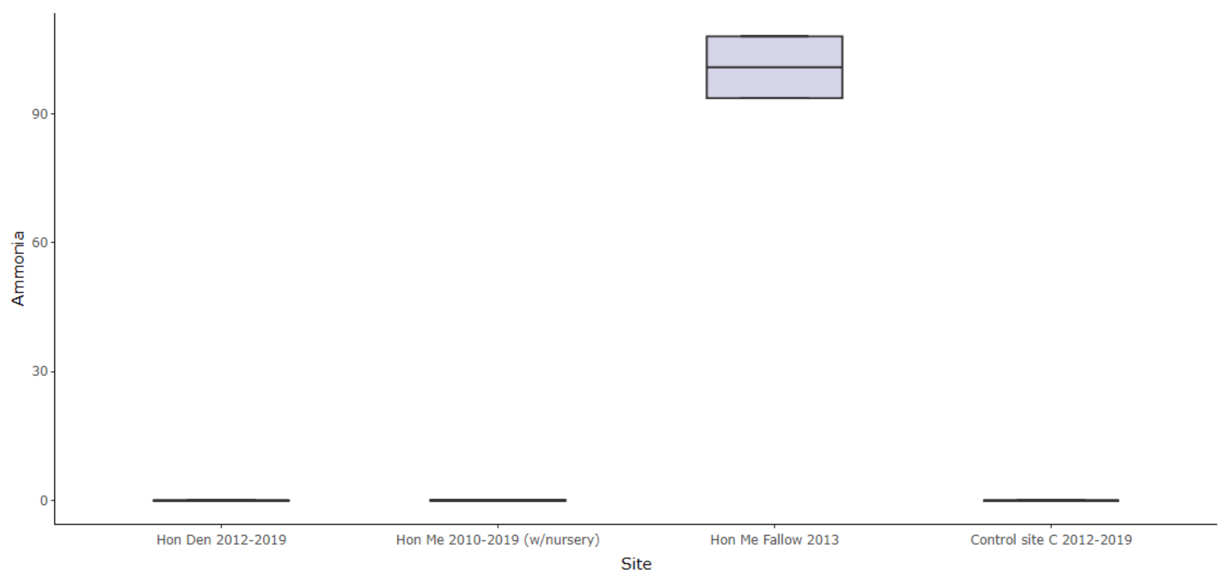
## Sediment

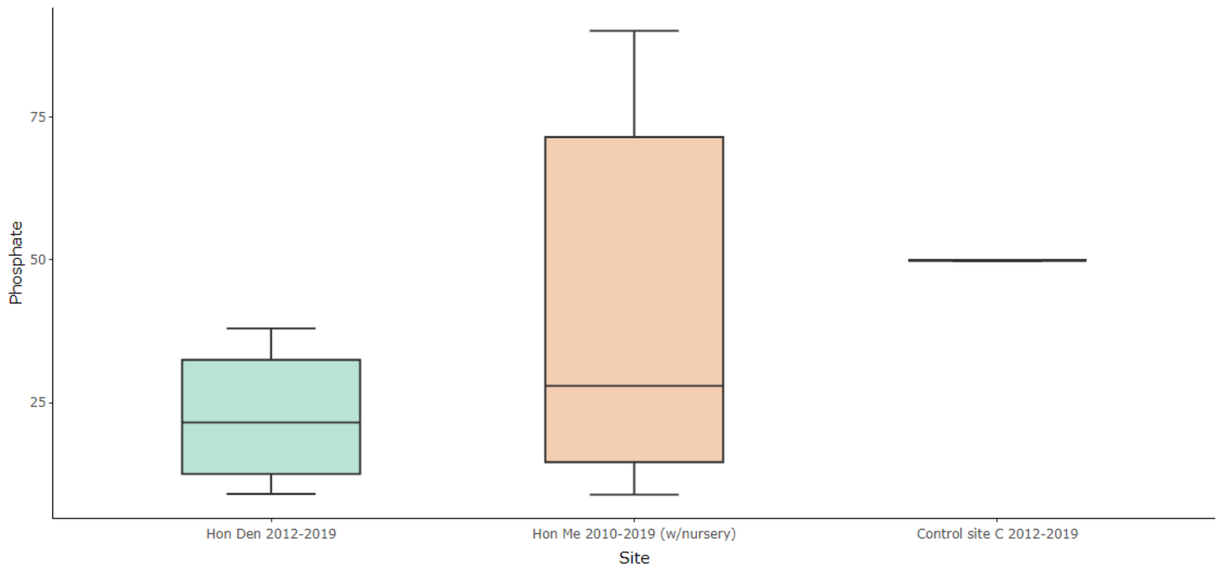

1000
750
500
250
0
B.O.D.
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Hon Me Fallow 2013
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site

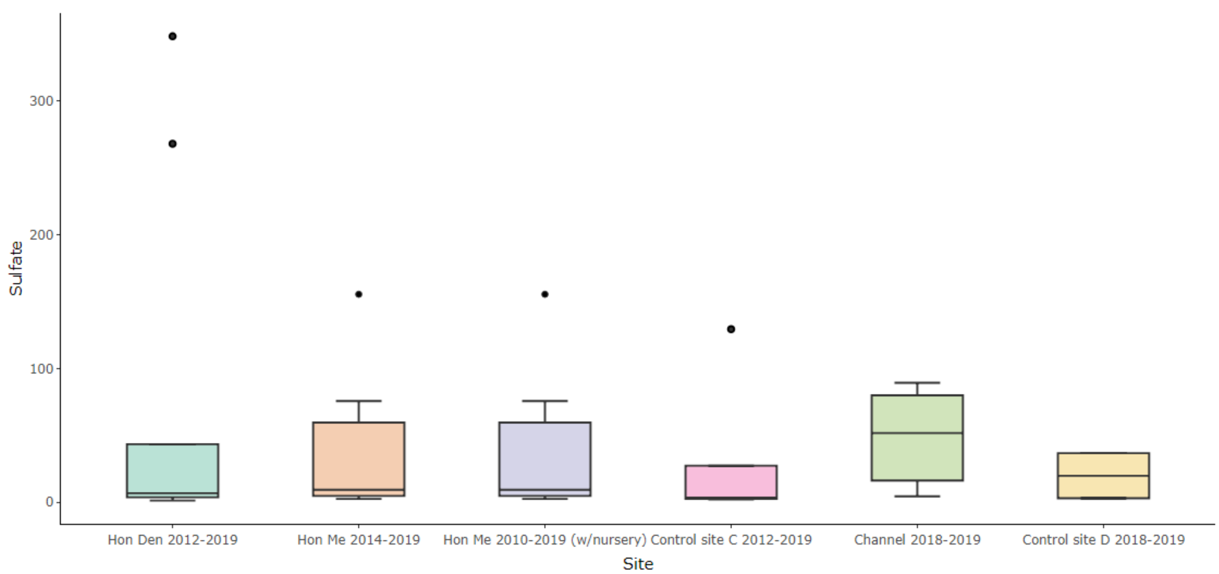

TSS
15
10
5
0
Hon Den 2012-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Site

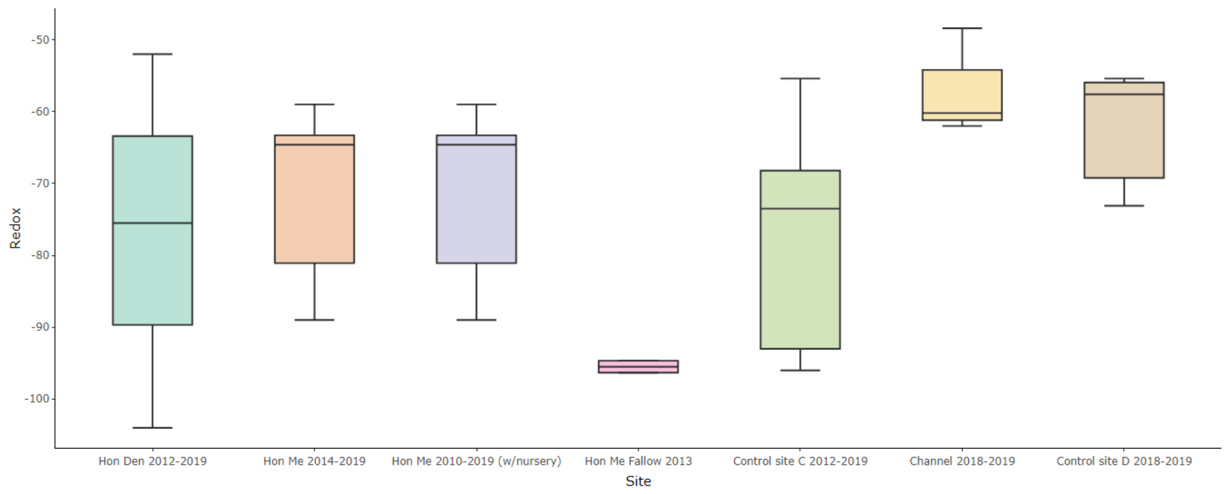

Ammonium
80
60
40
20
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site


250
200
150
100
Ammonium_b
Hon Den 2012-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Site


90
60
30
0
Ammonia
Hon Den 2012-2019
Hon Me 2010-2019 (w/nursery)
Hon Me Fallow 2013
Control site C 2012-2019
Site


Phosphate
75
50
25
Hon Den 2012-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Site


Sulfate
300
200
100
0
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site


-50
-60
-70
-80
-90
-100
Redox
Hon Den 2012-2019
Hon Me 2014-2019
Hon Me 2010-2019 (w/nursery)
Hon Me Fallow 2013
Control site C 2012-2019
Channel 2018-2019
Control site D 2018-2019
Site