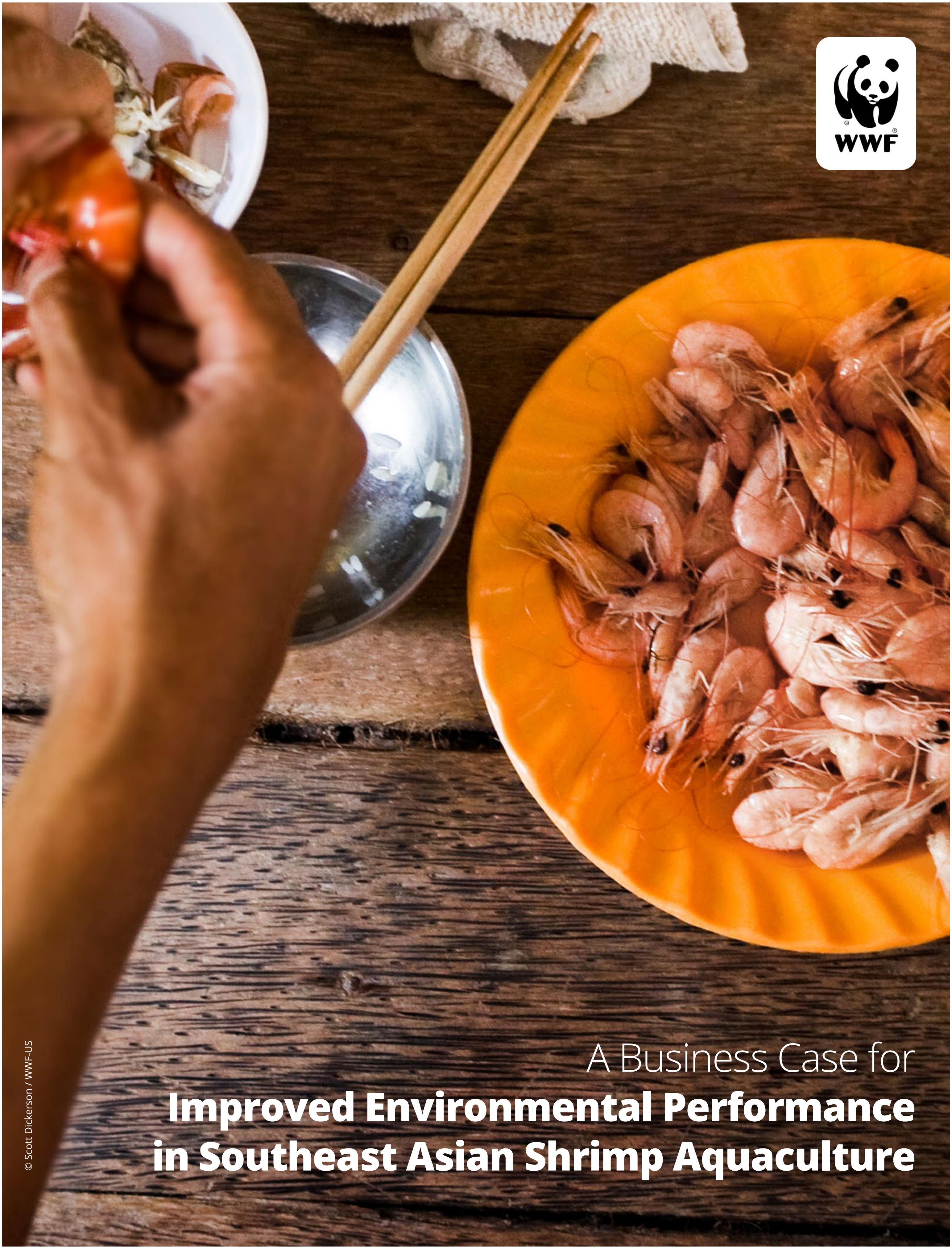

A Business Case for
Improved Environmental Performance in Southeast Asian Shrimp Aquaculture

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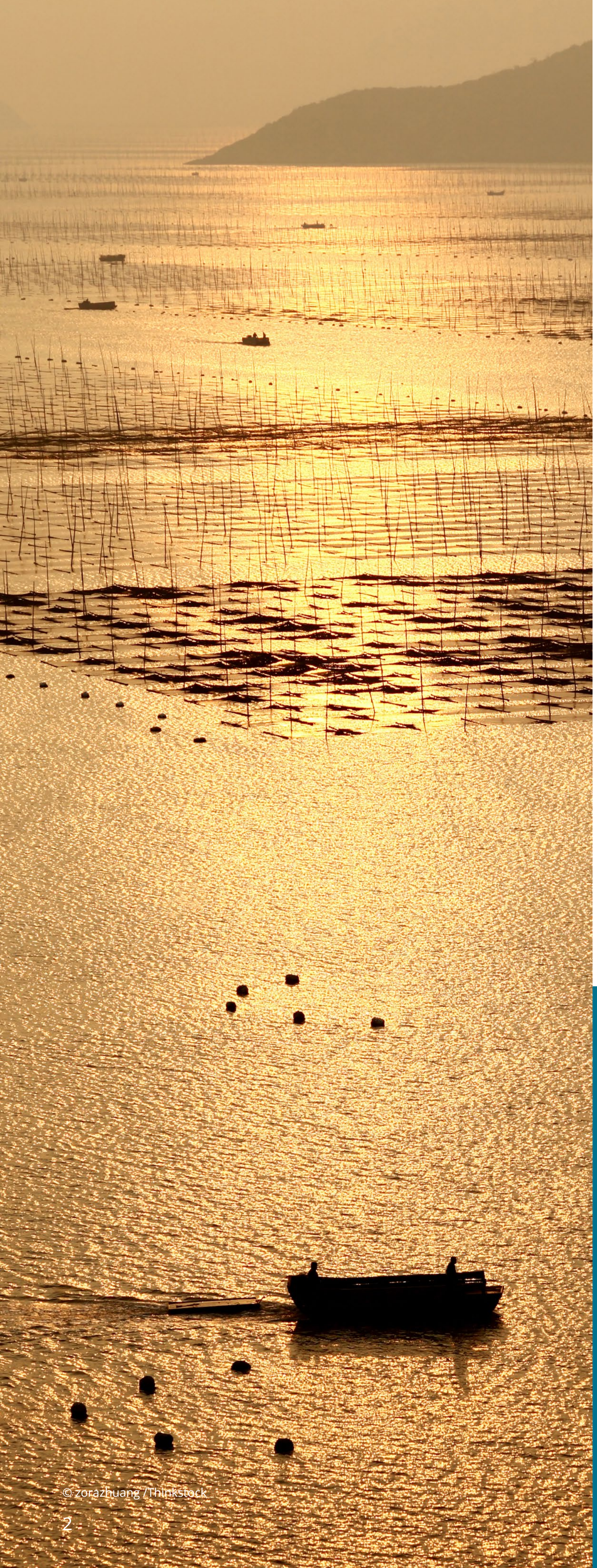

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FORWARD

Food production is the single largest driver of habitat conversion[i], yet clearly it is critical for humankind.

The challenge is to provide food that meets the nutritional requirements of the global population without sacrificing the biodiversity and ecosystem services that are vital for our planet's well-being. From farms to fisheries, every sector of the food system must accelerate efforts to reduce their environmental impact.

As nearly 90 percent of the world's fisheries are operating at or beyond their biological limits[ii], aquaculture is an increasingly important source of protein for a growing population. In fact, aquaculture, or the farming of aquatic organisms such as salmon, tilapia, and shrimp, is the fastest growing form of animal protein production in the world[iii]. And in 2014, more seafood was produced on farms than harvested from the wild[ii].

The future growth in seafood will come from aquaculture. However, in a world of shrinking supplies of natural resources, the aquaculture sector must become more efficient.

Aaron A. McNevin, Ph.D.
Director, Sustainable Foods

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WWF AND AQUACULTURE

World Wildlife Fund began working on aquaculture in the 1990s with a comparison of shrimp trawling and shrimp farming. This research found that although both producing and catching shrimp had significant impacts, shrimp aquaculture had the largest opportunity for improvement. Armed with these findings, WWF co-founded the Consortium on Shrimp Farming and the Environment in the late 1990s with the World Bank, the Food and Agriculture Organization of the United Nations, Network of Aquaculture Centres Asia-Pacific, and the United Nations Environmental Programme.

Through the Consortium, researchers examined shrimp aquaculture across the globe and found that just a handful of practices—such as siting, feed, and energy—contributed to the majority of environmental impacts. The Consortium released the International Principles for Responsible Shrimp Farming to highlight how the main impacts could be reduced. Focusing on the most important impacts of aquaculture production, WWF began the Aquaculture Dialogues, a series of multi-stakeholder roundtables designed to engage a critical mass of vested stakeholders to develop indicators and quantitative standards that minimize or eliminate impacts associated with the most important aquaculture species traded globally. These standards were handed off to the Aquaculture Stewardship Council (ASC) in 2010, which currently manages the certification of farms that comply with these standards for various aquaculture species.

WWF believes that ASC is the most credible aquaculture certification program. While not all shrimp farms can become ASC certified, all can improve their efficiency and performance.

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Overcoming environmental threats with economic incentive

Over a period of 40 years, shrimp aquaculture has contributed significantly to the degradation of natural resources and ecosystems. Coastal habitats that provide breeding grounds, food, and sanctuaries for both aquatic and terrestrial species have been cleared for shrimp farms, which funnel large amounts of nutrient and chemical wastes into coastal waters. The demand for fish meal in shrimp feed has led to the decimation of wild fisheries and, in some cases, egregious human rights abuses. Yet shrimp remains the most valuable traded seafood product in the world. What was once a rare treat is now commonplace as a snack in supermarkets and the centerpiece protein at all-you-can-eat restaurants. The wholesale price of shrimp has fallen from a high of approximately $15/kg in the mid-1990s to under $11/kg currently. As the industry continues to expand and prices drop, consumers will demand more shrimp.

Farmers can no longer externalize the negative impacts of shrimp farming as these issues directly and indirectly contribute to farm-level profitability and long-term viability. Thus, reducing these negative impacts would offer an economic benefit to shrimp farmers.

The environmental impacts and economic costs of shrimp aquaculture are concentrated on the farm and in the production of feed ingredients for shrimp feed. Major financial expenditures fall into ten categories: land, construction, electrification (the cost to bring electricity to the farm), equipment, juvenile shrimp or post-larvae (PLs), feed, energy, amendments, labor, and annual fixed costs (overhead). Many of these are related directly and indirectly to natural resources used to produce shrimp.

The relationship between the cost to produce shrimp and the use of natural resources is one of efficiency. Thus, there is a direct value proposition for shrimp farmers to use natural resources parsimoniously. WWF tested the value proposition – or the business case – for improved environmental performance with commercial shrimp farmers in Thailand and Vietnam over the course of two years and found a direct and positive correllation between environmental and economic performance. This publication describes the findings and implications of that work.

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SHRIMP FARMING

A general understanding of shrimp aquaculture at the farm-level is essential in understanding the impact of shrimp production as well as the greatest areas for environmental and economic gains.

Shrimp farms typically are characterized by their intensity level – production per unit area (in this paper, measured as metric tons of shrimp per hectare of farm). Extensive farms have a low production weight per unit area while intensive farms have a high production weight per unit area. Shrimp are typically raised in shallow ponds with depths between 1-2 meters (m). Extensive and semi-intensive ponds can have large surface areas – 5-20 hectares (ha) – while more intensive farming relies on smaller pond sizes between 0.5-5 ha. Construction of ponds and waterways around farms is accomplished with earth moving equipment. While it was initially thought that shrimp farms should be constructed in the intertidal zone in estuaries where wild shrimp are found, it later became evident that those areas were not best-suited for shrimp farming because of soil quality and difficulty in drying ponds between crops.

Shrimp farms are sited in areas that have access to brackish water. This water generally enters the shrimp farms either by tidal flow for farms located in the intertidal zone or with pumps when farms are located out of the intertidal zone. Water can be exchanged daily with the natural environment in the case of extensive or semi-intensive farms, or it may only be released at harvest for more intensive farms. Some producers will never release water from farms, rather choose to recycle it for future shrimp crops. The water at shrimp farms will accumulate more nutrients and organic matter at higher intensity levels. Intensive shrimp farm discharge can be concnetrated and cause localized water quality impacts such as decreased availibility of oxygen for aquatic life. However, all shrimp farms that discharge will facilitate nutrient loading of the receiving water body.

While some companies own and operate large shrimp farms, feed mills, shrimp hatcheries, and processing facilities, the majority of shrimp farms in the world are not vertifically integrated with other components of the supply chain. Thus, shrimp farmers typically have two main inputs that they purchase from other actors in the supply chain –PLs from hatcheries and feed from animal feed manufacturers. Some extensive shrimp farms will not use any feed or only apply it at later stages of growth.

Shrimp farm laborers can be household members, contracted workers or permanent employees. The larger and more intensive the farming operation, the greater the labor force necessary. Farm workers will manage stocking and harvest of ponds, feeding, water quality monitoring and health management. Optimal management facilitates high rates of survival and feed conversion, which maximizes growth and output.

Survival rates vary greatly because shrimp aquaculture has been prone to significant disease outbreaks. Survival can range from 0% when there is a total pond die-off to near 90% in the best cases. Because shrimp are so small when stocked it is often not possible to obtain precise numbers of shrimp stocked, which makes survival measurements variable.

The greater the intensity of production the greater the reliance on formulated feeds. At higher intensities feed makes up the largest single operating cost for farms. The Feed Conversion Ratio (FCR) is the amount of feed to produce a unit of shrimp. Depending on species cultured and intensity level, FCRs can range from less than 1 kg feed per kg of shrimp produced to above 2 kg of feed per kg of shrimp. Ideally, shrimp farmers seek to keep the FCR as low as possible to minimize feed costs.

Technolgical advancements in feed and aeration have allowed shrimp farmers to produce more shrimp than in the past. However, with greater intensity of production comes greater stress, and health issues may arise more frequently on more intensive farms. Chemical amendments may reduce stress, cure disease and improve water or soil quality in ponds, and can vary from the benign, such as agricultural limestone, to the controversial, such as antibiotics. There are also a host of other chemicals used to sterilize ponds before stocking in hopes of removing pathogenic organisms or their vectors. Probiotics or bacteria may be used with hopes to further promote shrimp health, water quality or soil quality.

Tropical climates provide the best conditions for high shrimp growth rates. When farmers use feed, shrimp can reach market size in as little as 3-4 months. In more extensive systems, shrimp require a longer culture period. Farmers can harvest multiple crops per year if the intensity of farming is high. When shrimp reach market size, most farmers will completely empty their ponds, capturing shrimp in the effluent water. Water is released back into the natural environment except in some cases where farmers have sought to retain and disinfect water for further use. Retaining water at shrimp farms requires water storage and sometimes treatment ponds that create greater land burdens. Harvested shrimp are either sold to brokers that will aggregate product from many farms and sell to a processing facility or, if farm production is high enough, the farm may sell directly to a processing plant.

Shrimp farmers will incur costs associated with the start-up and construction of a farm. Land prices will vary by country and whether owned outright or leased there will be ongoing fixed costs of lease or loan payments and land taxes. Additionally, farms may not be connected to electrical power grids and further upfront costs can be incurred for electrification. Other fixed costs include vehicles, pumps, aerators and other farm tools. Variable costs will be incurred through the procurement of feed, PLs and chemical amendments, the payment of workers, maintenance of equipment, and energy to operate aerators, pumps and vehicles.

Context

Nearly all shrimp farming occurs in subtropical and tropical coastal ponds. Developing or transitional economies account for almost all farmed shrimp production.

Of the 40 species of penaeid shrimp reported by the FAO, 14 species are farmed. Whiteleg shrimp and black tiger shrimp are the most important by volume and total value, globally.

The majority of farmed shrimp is produced in Southeast Asia, and while annual output of shrimp will vary by country, Thailand and Vietnam are consistently major production hubs (Fig. 1). According to the FAO, in 2014, whiteleg shrimp and black tiger shrimp aquaculture production in Thailand was 264,709 tons (t) and 17,067 t, respectively. For the same year, Vietnam produced 309,543 t and 168,906 t of whiteleg shrimp and black tiger shrimp, respectively.

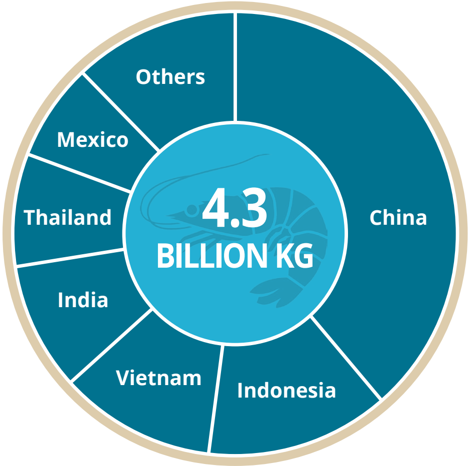

Figure 1. *Global shrimp aquaculture production and main producing countries*

The importance of the feed conversion ratio

The feed conversion ratio (FCR) is the amount of feed used per unit of shrimp produced. FCR is a measure of feed efficiency and can be one of the most important environmental and economic indicators for evaluating fed aquaculture operations.

Shrimp feed includes plant and fish meals. The natural resources to produce these ingredients are referred to as embodied resources. In some instances embodied resources can be greater than those used directly on the farm such as energy to run aerators or pump water. Land, water and energy are used to grow and process plants; energy is used to catch and process wild fish; the wild fish themselves represent a critical natural resource. Thus, FCR is also a measure of how efficiently farmers allocate and utilize natural resources embodied in feeds.

Approximately 3.6 million tons (t) of shrimp are produced using feed. An overall global decrease in FCR by 0.1 would embody 106,000 ha of land, 141 million cubic meters (m3) of water, 468,000 tons of wild fish and 3.6 million gigajoules (GJ) of energy. Moreover, the lower FCR would equate to savings from $85 to $110 million in Thailand and Vietnam at the farm-level.

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APPROACH

To establish any business case for improved farm performance, it is important to assess fixed and variable costs of shrimp farming and identify where environmental gains coincide. Obtaining reliable information on farm production activities and environmental impacts was necessary to test the value propostion for reducing environmental impacts of shrimp aquaculture. To accomplish this, farm surveys were administered in the major shrimp producing provinces of Thailand and Vietnam (Fig. 2). The survey was comprised of 34 whiteleg shrimp (Litopenaeus vannamei) and five black tiger shrimp (Penaeus monodon) farms in Thailand and 28 whiteleg shrimp and 24 black tiger shrimp farms in Vietnam. The farms were selected to include the range in farm size, production intensity common in both countries and the proportions of whiteleg to black tiger shrimp produced in each country. WWF Vietnam and WWF Thailand aquaculture scientists visited and assessed each farm, compiling information on the farm size, equipment used, production input quantities and costs, and other production practices, such as stocking density, feeding rates, aeration rates, length of production cycle, number of crops used, and average size of shrimp harvested.

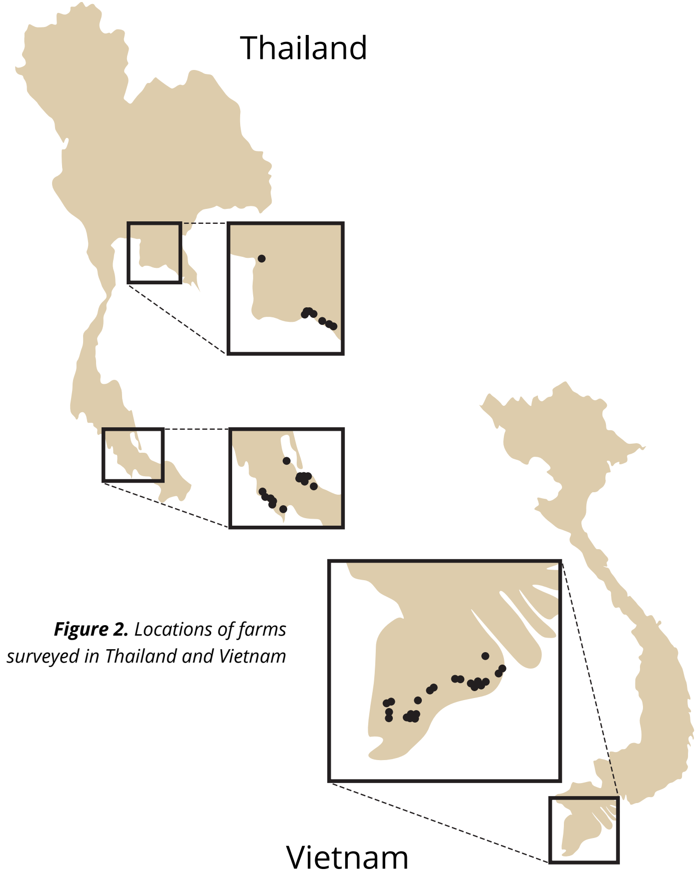

Figure 2. *Locations of farms surveyed in Thailand and Vietnam*

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THE BUSINESS CASE

Economic analysis of shrimp farms participating in this study revealed that operations with lower intensity had a distribution of costs different from farms producing at higher intensity. Additionally, more intensive farming was equated with larger amounts of shrimp produced. The analysis provided a breakdown in capital expenditures based on farm intensity, species and country (Figs. 3-5). Because there was only one intensity level observed at the black tiger shrimp farms surveyed in Thailand, analyses of different system types for this sub-set were not possible.

Across all farms, land, construction, electrification, equipment, energy and annual fixed costs followed a pattern of decreased cost share proportional to the decrease in intensity. This is likely because the dominant input of feed for more intensive farms is used to a lesser degree in less intensive farming systems. The cost share of PLs followed a similar pattern for whiteleg shrimp farming in both Thailand and Vietnam, but showed a pattern of decreasing cost share as production intensity decreased for black tiger shrimp in Vietnam. Of course, PL prices for black tiger shrimp are higher than whiteleg shrimp.

Feed inputs and labor as a percentage of total farm costs increased as production intensity increased across all farms. It is clear that more intensive farms rely greater on feed inputs and farm labor than do less intensive farms. Smaller farms had lower labor costs and in some instances there was no payment for labor as work was conducted by family members that share in the profits of shrimp sales.

The cost share of amendment applications did not follow a consistent pattern across all farms. In Thailand for whiteleg shrimp, the cost share of amendments was higher at the lowest and highest production intensities. For whiteleg shrimp production in Vietnam, the cost share of amendments decreased as intensity decreased. Vietnamese farmers culturing black tiger shrimp showed a trend of increasing cost share for amendments with decreasing intensity. Chemical amendments to ponds was shown to be a substantial cost, in particular, for whiteleg shrimp production in Vietnam with the highest percentages noted for the high intensity clusters.

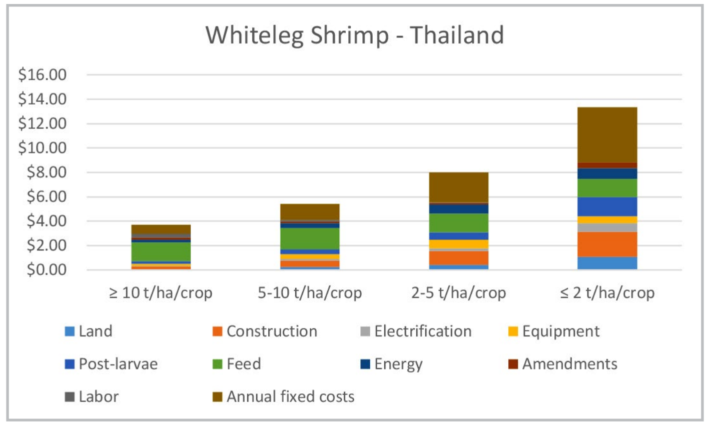


Figure 3. Cost of production separated by major budgetary categories at different intensities for whiteleg shrimp farmed in Thailand

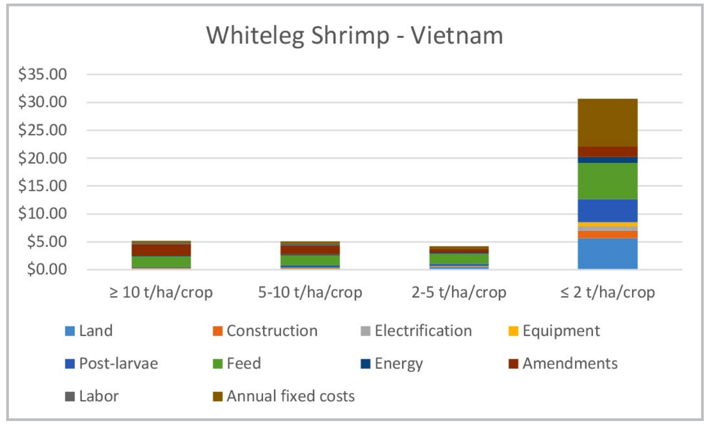


Figure 4. Cost of production separated by major budgetary categories at different intensities for whiteleg shrimp farmed in Vietnam

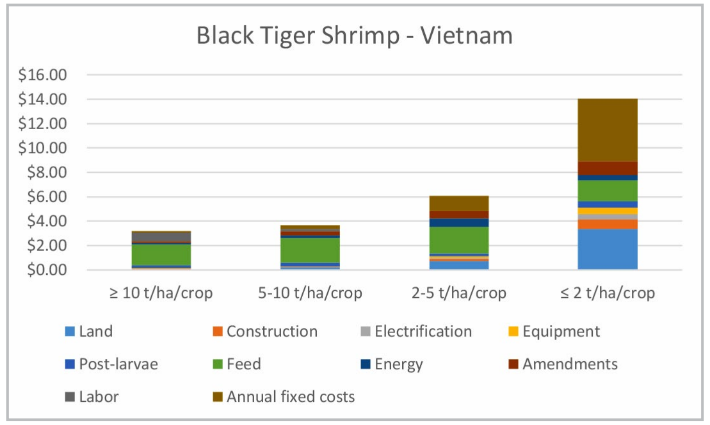


Figure 5. Cost of production separated by major budgetary categories at different intensities for black tiger shrimp farmed in Vietnam

It is noteworthy to point out that chemical expenditures at the highest intensity cluster for Vietnamese whiteleg shrimp production equaled the cost of feed. It should be noted that the primary amendments added to ponds in Vietnam were labeled as probiotics and vitamin supplements, not therapeutants.

Within each country and species type, the relative importance of the fixed costs associated with the investment in land, infrastructure, and equipment decreased as the intensity level increased. In Vietnam, the contribution of annual fixed costs to total costs decreased from 50% to 4% as intensity increased for black tiger shrimp and from 35% to 5% with whiteleg shrimp.

In Thailand, the contribution of annual fixed costs to total costs decreased from 46% to 20% as production intensity increased for whiteleg shrimp. This decrease in the relative importance of annual fixed costs demonstrates that with greater intensity of production comes a comparative advantage in the economies of scale.

The greatest economic gains from efficiency interventions would come from lowering FCR, increasing survival, decreasing energy use, and using less land (Table 1). Production output increases that are not related to efficiency require increasing the yield through intensification.

Table 1. Production cost changes with manipulation of key performance indicators (all other variables constant)
Monetary values are changes in total cost per ton of shrimp produced

	FCR change by 0.1	Survival change by 10%	Energy use change by 10%	Land value change by 10%	Yield change by 10%
VIETNAM					
Black Tiger Shrimp					
Low	$155	$626	$42	$341	$626
Medium	$155	$626	$78	$81	$626
High	$155	$626	$24	$19	$626
Very High	$155	$563	$11	$9	$563
Whiteleg Shrimp					
Low	$155	$655	$109	$576	$648
Medium	$155	$648	$15	$44	$648
High	$155	$648	$17	$22	$648
Very High	$155	$647	$11	$13	$648
THAILAND					
Black Tiger Shrimp					
Low	no feed	not calculable	$17	$1,578	$333
Whiteleg Shrimp					
Low	$122	$333	$98	$115	$333
Medium	$122	$333	$85	$76	$333
High	$122	$333	$46	$38	$333

The costs associated with the production of shrimp will vary depending on business model. However, findings show that farms producing at higher intensity will have lower breakeven points (Fig. 6) and better overall returns on investment. Of course, larger scale farms can leverage economies of scale to invest more in infrastructure and equipment that allow for intensification.

The economic value proposition for farmers to improve efficiencies and intensify is apparent, but the environmental implications of intensification cause debate around what farming model has the "least impact." While there are many ways and views on determining the environmental impact of a shrimp farm, the use of natural resources to produce a unit of shrimp is a good indicator of efficiency. If the greatest costs of shrimp production are associated with natural resource use, then there would be an inherent benefit in using natural resources more judiciously, thereby reducing pollution potential, increasing survival, decreasing feed and chemical use, etc.

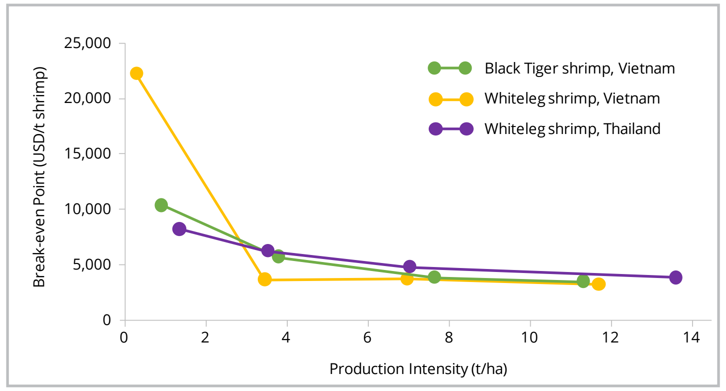
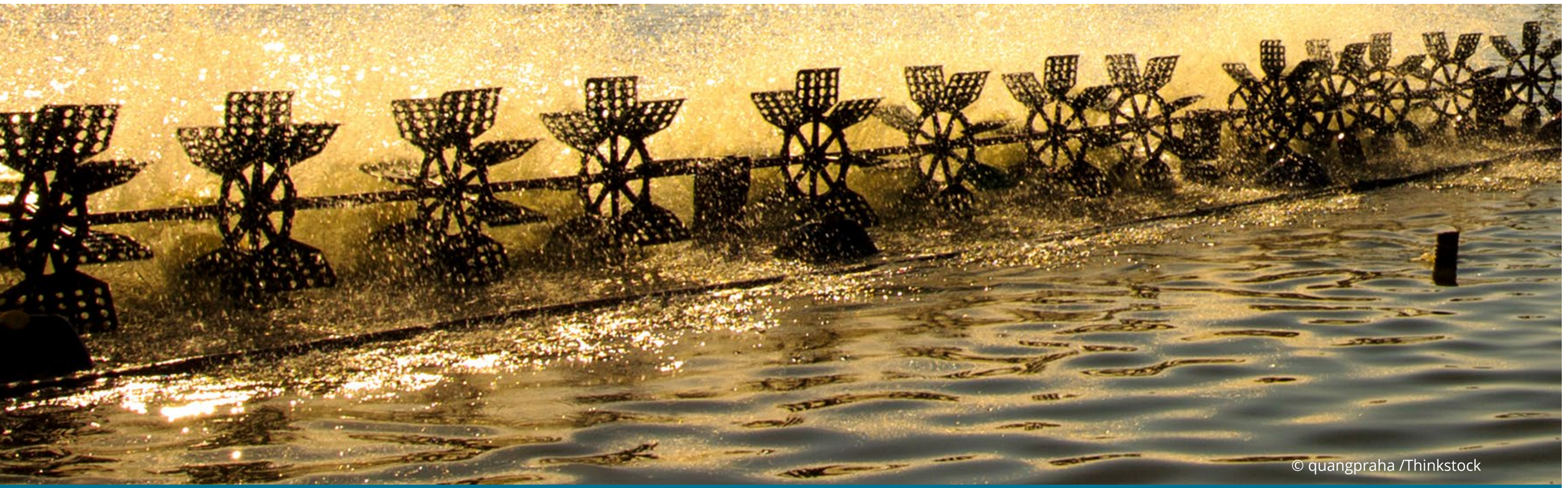


Figure 6. *Break-even point of producing one ton of shrimp as a function of production intensity*



NATURAL RESOURCE USE IN SHRIMP AQUACULTURE

Results of the farm-level assessments demonstrated that the greatest variability across farms could be attributed to the species produced (whiteleg shrimp vs. black tiger shrimp) and the intensity of production. Additionally, the majority of natural resources used for shrimp farming are either a result of direct on-farm resource use or embodied resources used to produce ingredients in shrimp feed.

Whiteleg shrimp aquaculture is typically more intensive than black tiger shrimp production. Farmers in Thailand were found to produce greater amounts of shrimp because they stocked ponds at higher rates and produced more crops per year than Vietnamese producers.

Black tiger shrimp farming is typically carried out in large ponds and can be managed with minimal inputs with the most extensive systems only stocking post-larvae (PL) with no feed and fertilizer additions. This management type was indicative of the sample of small-scale black tiger shrimp producers surveyed in Thailand. These producers were not able to identify their survival rates because they continually added more PL to ponds and continually harvested. This same protocol was practiced at a few farms in Vietnam, but the black tiger shrimp production in Vietnam appeared to entail more regimented management protocols and in some instances considerably more intense than what was found in Thailand.

LAND

Production intensity has the greatest impact on land use. For whiteleg shrimp, land burden per ton of shrimp declines rapidly with increasing intensity until production intensity reaches 5 t/ha per year. Land use per ton of shrimp produced decreases at a more gradual rate at production intensities greater than 5 t/ha. For black tiger shrimp production in Vietnam and Thailand, there was also a marked decrease in total land use that fell quickly as farm production intensity increased to about 5 5 t/ha per year after which land use declined more slowly with increasing intensity.

According to the Vietnam Directorate of Fisheries, shrimp farm area increased from 230,000 ha (56,000 t) in 1991 to 600,479 ha (304,257 t) in 2005, up to 652,613 ha (475,854 t) in 2015. Currently, whiteleg shrimp occupies 10% of total shrimp farming area but accounts for 52% of total shrimp production. Whiteleg shrimp was approximately 45% of total shrimp production in 2012 and increased to 70% of production in 2014.

According to the Department of Fisheries in Thailand, in 1980, land dedicated to shrimp farms was 26,036 ha with a total production of 8,063 t of shrimp. The land dedicated to shrimp production doubled by 2012 but the production output increased more than 66-fold to 540,000 t. Shrimp famers in Thailand are able to produce 34 times more shrimp per hectare now than in 1980. This does not take into account the land dedicated to terrestrial plant ingredients for shrimp feed, such as soy, corn, etc.

The footprint of natural resources used to produce feed is termed embodied resources, and those resources are added to the farm-level resources used to represent a combined resource use. The majority of whiteleg shrimp farmers use feed throughout the production period to promote shrimp growth, while black tiger shrimp farmers use varying amounts depending on intensity. Thus, whiteleg shrimp production has a considerably higher burden of land required for terrestrial plant ingredients than does black tiger shrimp production. However, the intensity of whiteleg shrimp production can be much higher than black tiger shrimp. Stocking rates for black tiger shrimp ranged from 0.5-50 PL/m^2 while whiteleg shrimp stocking rates had a much greater range from 3-125 PLs/m^2. The majority of land used to produce shrimp in Thailand was embodied land used to produce plant-based feed ingredients, while in Vietnam the land used to grow shrimp was greater than the embodied land in feed. Whether the majority of land used was represented as embodied or farm land, increased intensity resulted in an overall decrease in land use per ton of shrimp produced (Fig. 7).

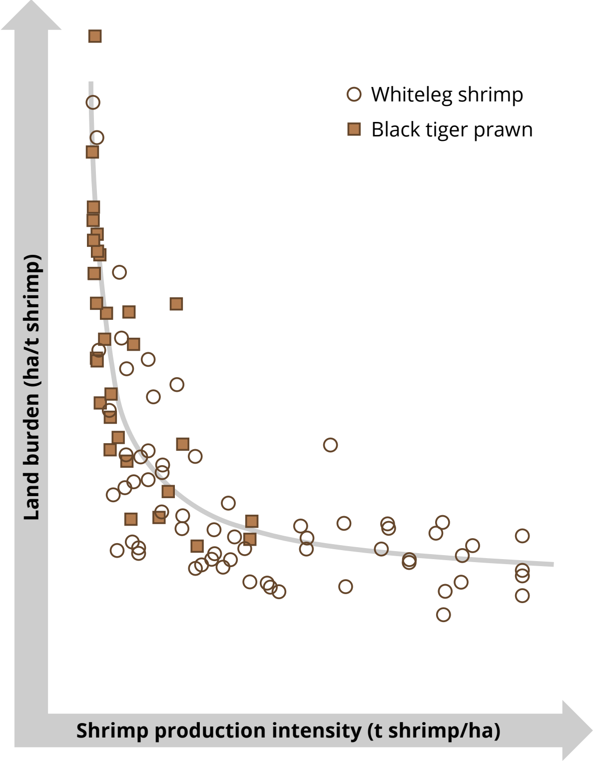


Figure 7. *Combined land use for shrimp production as a function of farm intensity*

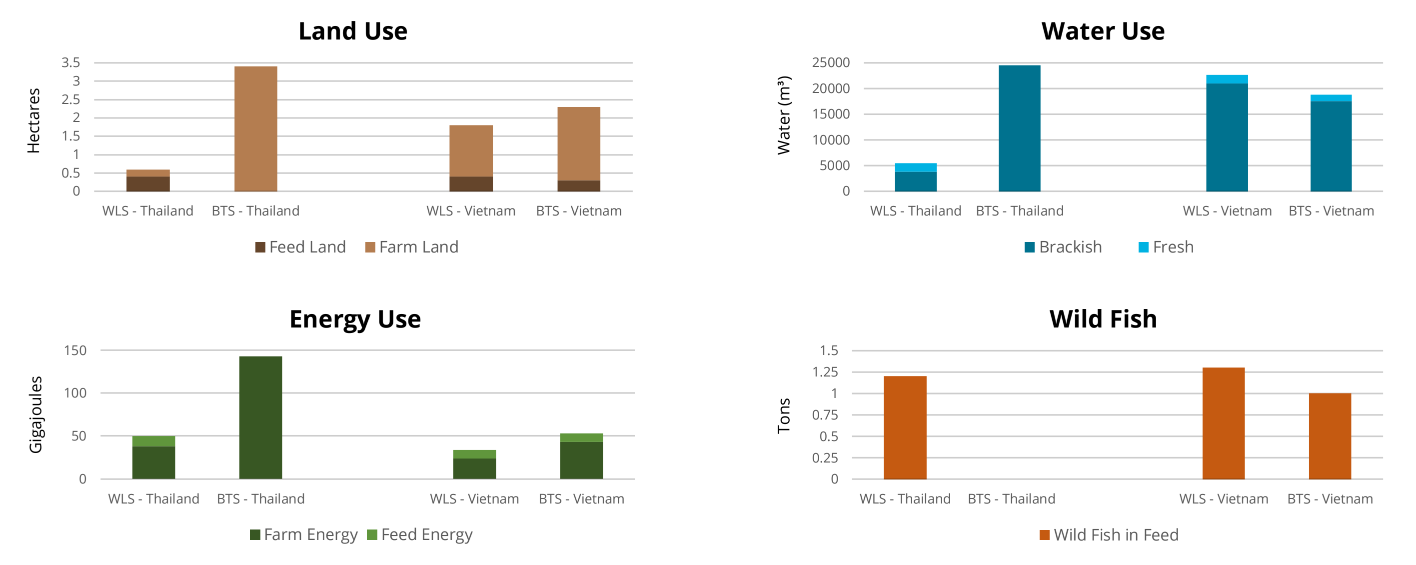


Figure 8. *Natural resource use to produce 1 ton of shrimp (WLS = whiteleg shrimp; BTS = black tiger shrimp)*

WATER

Freshwater is seldom used directly for shrimp farming. There are areas where shrimp farms are located in inland regions and salt is added to slightly saline or freshwater to allow for shrimp production, but this activity generates a relatively small proportion of shrimp produced. Moreover, there are serious implications for the salinization of freshwater aquifers by inland shrimp farms and many countries such as Thailand have halted expansion of this type of production or completely forbade it.

If feed is applied to any type of shrimp farm, embodied water in the feed ingredients will be used. The embodied freshwater use for feed ingredients is comprised of the water necessary to grow plants and to process wild fish into fishmeal for feed. Thus, there is a clear tradeoff of greater freshwater use with increasing intensity. Extensive farming of shrimp – most notably black tiger shrimp farming in intertidal areas – that do not rely on feed inputs will not have a freshwater burden.

Farm brackish water use at most whiteleg shrimp farms in both countries was less than 10,000 m³/t shrimp. However, on average, Thai shrimp culture used only about one-third as much water per ton of shrimp as did farmers in Vietnam, owing to two predominant factors: more intensive operations in Thailand used water more efficiently per ton of shrimp produced, and more farms in Vietnam exchanged water with outside sources, requiring greater farm water use. Black tiger shrimp farms used more brackish water per ton of production than whiteleg shrimp farms because of a lower intensity and greater reliance on water exchange; however, less freshwater is used because of a lower reliance on formulated feeds (Table 2).

In general, the more feed a farm uses, the larger it's freshwater footprint; however, feed efficiency is not the only factor included in the measure of freshwater resource efficiency. When intensity is increased, less freshwater is used per ton of shrimp produced than for lower intensity feed-based systems. Producers in Vietnam tended to have a lower FCR than in Thailand suggesting a greater feeding efficiency, but Thailand's production intensity was greater and allowed for more efficient use of freshwater in fed systems per ton of shrimp produced. Although greater intensity will use more freshwater resources, overall the total water use (brackish and fresh) decreased with increasing intensity (Fig. 9).

Brackish water use is not equivolent to freshwater use. Freshwater as a natural resource is much less abundant than brackish water. Moreover, freshwater is required for human survival and competition for this resource is high. Brackish water is only potable if it is desalinated, which requires treatement and can be costly. Nevertheless, brackish water is a natural resource and its quality can be degraded through the production of shrimp.

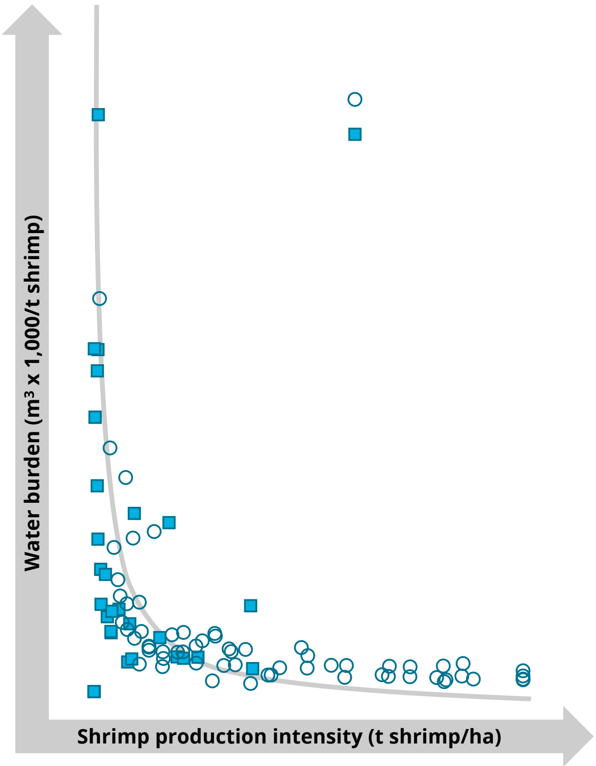


Figure 9. *Combined water (fresh and brackish) use for shrimp production as a function of farm intensity*

Receiving Water Resources

Aquaculture operations are dependent on the ecosystem services the surrounding environment provides to process farm waste. The receiving water body is the first natural water body that waste from aquaculture operations enter. They are a natural resource used not only because they often provide the water for shrimp ponds, but they also process wastes that farms discharge. Thus, if a particular receiving water receives wastes beyond the point it can assimilate them, oxygen will become depleted and fish death events can occur. However, because this water is also used to produce shrimp, impaired receiving water bodies negatively impact shrimp production. Further, receiving water bodies can also be a vector for disease as one farm discharging water with disease organisms can be taken up by an adjacent farm. Thus, there is a benefit to the producer if receiving water quality is maintained. However, this is a collective approach of all the water users in a watershed and is often beyond the control of any one individual farm. There is a trend in both Vietnam and Thailand to recycle water on the farm and not discharge any waste. This has been more of a necessity for biosecurity with numerous disease outbreaks on farms, but it also serves to reduce the pollution loads of receiving water bodies.

Table 2. Average Feshwater use (embodied in feed) at shrimp farms surveyed
Values are in m³ freshwater per ton of shrimp

Species	Thailand	Vietnam
Whiteleg shrimp freshwater use	1,660	1,730
Black tiger shrimp freshwater use	0	1,330

ENERGY

Combined energy use can be broadly divided into operational energy use on the farm, energy used for construction of the farm and embodied energy in feed ingredients. The operational energy used on farms is primarily for pumping and mechanical aeration. These activities maintain water quality and reduce stress on shrimp promoting greater survival and facilitating greater efficiency of production. Construction energy is captured as the amount of diesel fuel to move earth and construct the farms. This energy was amortized over a 30-year period for farms. Embodied energy is the amount of energy required to produce terrestrial plant ingredients, but also to capture wild fish and process them into fish meal for shrimp feeds.

Production intensity influences energy use, as more shrimp raised in a pond requires more energy to maintain water quality. One of the main sources of operational energy use is mechanical aeration to keep ponds oxygenated. Water exchange is another means to improve water quality by flushing waste from ponds. Water exchange in ponds constructed in intertidal regions is sometimes achieved with the flushing of ponds with tidal changes (filling ponds at high tide, and releasing water from ponds at low tide). Where farms are built above the high tide level, pumps are required to take in and release water from and to a natural water body.

The primary energy sources used on farms are electric and diesel. Electric energy is more efficient and often less expensive than diesel energy; however, in some shrimp producing regions, electrification grids are not established leaving few options other than diesel generators to power aerators and pumps. However, many farms with access to the electrical grid still use diesel pumps and generators because of the investments made into the equipment but also because diesel pumps can move water at a higher rate.

Energy is embodied in the production of feed, from the growth of plant materials such as soy to the harvesting of fish for fish meal. Reducing or eliminating feed at shrimp farms can reduce their overall energy use, but reducing feed beyond a certain point has the negative effect of reducing the output of shrimp, which results in a trade-off of the efficient use of land.

Operational energy use increases with greater production intensity. However, total energy per ton of shrimp decreases as production intensity increases (Fig. 10). Data from this study show that there is considerable room for improvement in energy use efficiency as variability in total energy use was great.

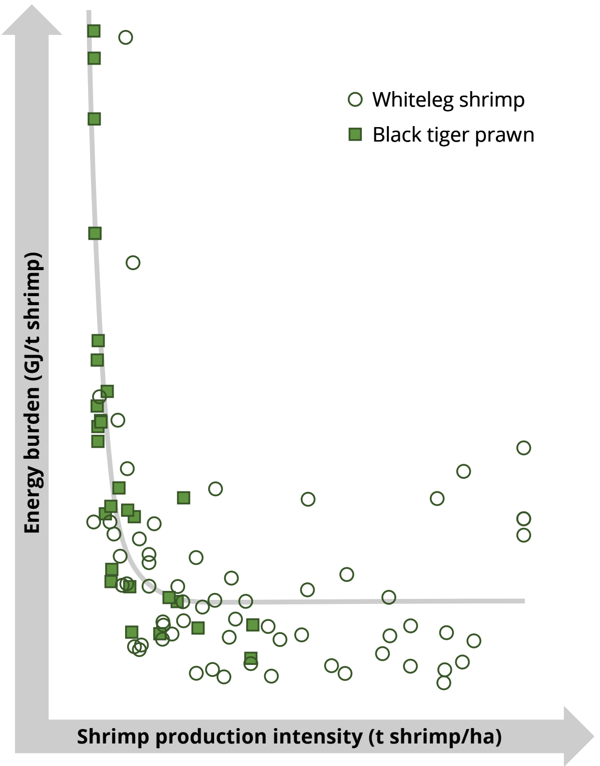


Figure 10. *Combined energy use (operational, construction and embodied) for shrimp production as a function of farm intensity*

Energy requirements of maintaining pond oxygen levels

Oxygen is used in ponds by micro-organisms to break down organic wastes. The greater the amount of organic waste, the greater the deficit of oxygen. Further, when photosynthesis ceases at night in the absence of sunlight, a greater amount of aeration is required to maintain adequate oxygen concentration in ponds.

Table 3. Average farm and embodied energy in feed from shrimp farms surveyed
Values are in GJ/ton of shrimp produced

	Whiteleg Shrimp		Black Tiger Shrimp	
	Thailand	Vietnam	Thailand	Vietnam
Operational energy	33	10	2	5
Construction energy	6	14	141	37
Embodied energy	12	10	0	10
Total farm/feed energy	51	34	143	52

WILD FISH

Wild fish use is higher in aquaculture than in any other animal protein production system, as the nutritional requirements of farmed fish are naturally found in wild fish. However, food production in general has shifted away from reliance on animals to feed other animals because of the ecological inefficiencies in energy transfer from one species to another. Thus, aquaculture is also moving away from using wild fish as feed. This is partially the natural progression of the industry, but more so there is an increased awareness that aquaculture cannot expand if it is dependent on limited and finite fish stocks; it simply doesn't make business sense to restrict the potential for growth. This is especially important given that nearly 90% of global fisheries are fully exploited or overfished, meaning that they are at best unable to yield more protein or at worst on the verge of collapse.

Typical shrimp feed has inclusion rates of 30-34% fish meal and 0-5% fish oil. While fish oil is difficult to replace in feeds, it is not essential in shrimp diets. Fish meal, however, can be replaced with commercially available plant meals and other protein alternatives. Thus, there is no nutritional rationale for retaining wild fish in shrimp feeds over other replacements. Of course, the substitution of plant-based proteins for fish proteins in shrimp feed will result in natural resource use impacts from the terrestrial production of those plants which gives rise to another trade-off.

Although black tiger shrimp feed typically contains a slightly higher fish meal content than feed for whiteleg shrimp, feeds for specific shrimp species maintain a fairly consistent fish meal inclusion rate. Other than deciding whether to use feed or not, the only variable that shrimp farmers control that affects the use of wild fish on farms is the FCR through better feed management strategies. Thus, except when feed is not utilized, there is no relationship between production intensity and the wild fish burden per ton of shrimp produced.

The amount of wild fish used to produce a unit of cultured shrimp or other fish is termed the fish-in:fish-out ratio (FI:FO). The FI:FO averages were similar across the whiteleg shrimp farms in Thailand and Vietnam. Black tiger shrimp farming is often accomplished with partial or no supplemental feeding, hence the lower FI:FO.

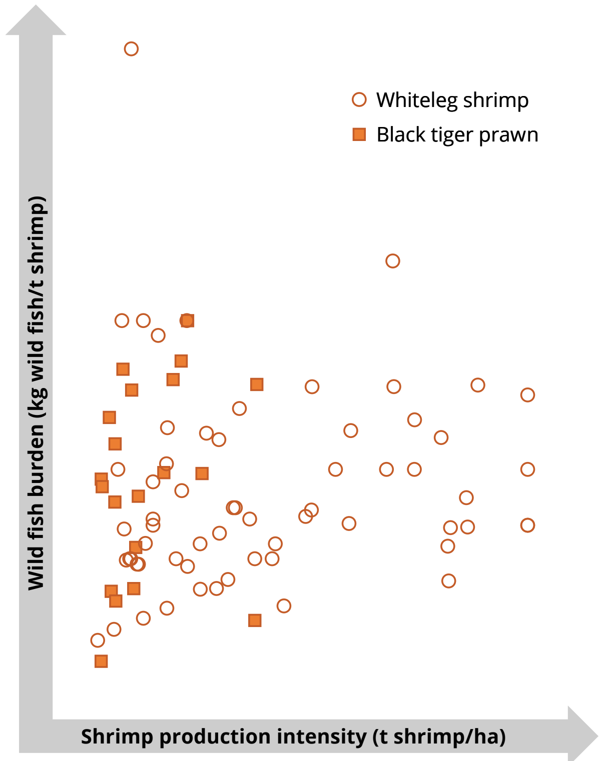
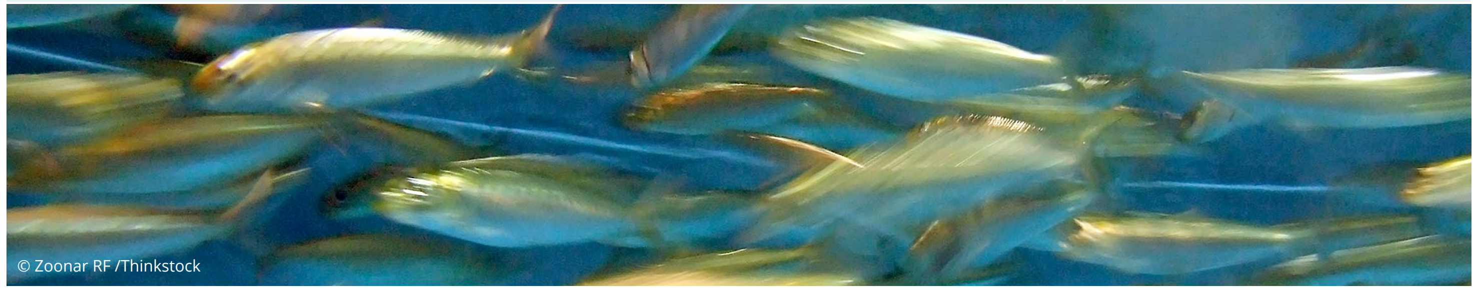


Figure 11. *Wild fish use for shrimp production as a function of farm intensity*

Table 4. Average fish-in:fish-out ratio (FI:FO) for farms survey

	Whiteleg Shrimp		**Black Tiger Shrimp**	
	Thailand	**Vietnam**	**Thailand**	**Vietnam**
FI:FO	1.2	1.3	0	1.02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Survival - It's not only revenue loss

Shrimp disease epidemics present a considerably level of risk for crop failures at shrimp farms. In Thailand, disease cut shrimp production in half in 2013. This represents a massive loss in revenue. The feed that was never converted to shrimp represents additional wasted and unaccounted resources. For example, if a 10-ha farm with a production intensity of 5 t shrimp/ha and an FCR of 1.2 suffered a drop in survival from 80% to 50%, it would represent a loss of 4.5 ha of land, 20,000 m^3 of freshwater, 15 tons of wild fish, and 160 GJ of energy—an overall loss of $5,000 in expenses per crop.

Table 5. Natural resources wasted would include:

Land - 4.5 ha	Fresh water - 20,000m^3
Wild fish - 15 tons	Energy - 160 Gj
The overall loss in revenue of the farm is $5,000	


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The economic implications of improper siting

Land values compose a greater percentage of the total cost of production at lower densities than at higher densities. However, most analyses of farm-level efficiencies assume optimal siting. In fact, improper siting of shrimp farms can have a much greater impact on long-term viability than operational efforts to improve management efficiencies.

The cost of clearing woody vegetation in Surat Thani Province, Thailand is approximately $4,032/ha. Construction of ponds in areas with high water tables requires additional excavating machine operation time for preparing the farm for appropriate drainage and for handling the wet soil. Thus, for wetland areas such as mangrove forests, the cost is typically 30% greater than for construction on former agricultural land. Organic matter content is high at sites with a high water table and embankments made from organic soils oxidize and decrease in volume over time resulting in costly repair efforts to stabilize pond integrity. In areas of sandy soils, top soil of better quality must be trucked in from another location at considerable expense to form an impermeable layer.

Potential acid sulfate soil (PAS) contains iron pyrite that oxidizes to sulfuric acid. Each 1% increment of pyritic sulfur requires about 50 t of liming material to completely neutralize a 1-ha pond. The pyritic sulfur content of PAS soils ranges from 1% to 5%, meaning that it requires 50 to 250 t of liming material per hectare, valued at $2,258 to $11,290. Thus, farmers can control costs just by avoiding acidic soils.

Poor siting increases risk of microbial activity in the bottoms of ponds, particularly with a high water table, PAS soil, or organic soil. This leads to deteriorated water quality, which stresses shrimp, increases risk of disease, reduces survival rates, and elevates FCR.

Pond bottoms can be lined, but the cost of lining an entire pond bottom is about $30,000 for a 1-ha pond which is greater than the cost to construct the pond.

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TRADE-OFFS

Business decisions require trade-offs. In shrimp aquaculture, many decisions have positive and negative implications on the use of natural resources. There is no "perfect" system that optimizes the use of all its resources. Representing these trade-offs in a clear and transparent manner is necessary to make informed decisions and to recognize the implications of these choices.

Converting land to aquaculture turns terrestrial or wetland ecosystems into aquatic ecosystems, a dramatic change that contributes significantly to climate change and the loss of wildlife habitat. Optimizing shrimp aquaculture to have the lowest land footprint requires farms to intensify. However, when farms intensify, more freshwater, energy and wild fish are used because of the need for larger amounts of feed and aeration. The aeration and embodied resources can be eliminated if feed is not used. If fertilizer is added to ponds in lieu of feed to stimulate natural productivity to serve as the nutrient source for shrimp, the embodied resources of feed are eliminated as well as the need for mechanical aeration. Of course, without aeration and feed, the productivity of ponds will decrease significantly thereby increasing the amount of land used to obtain a desired amount of shrimp.

The use of water is more complex than the use of land. When feed is utilized, there is a freshwater footprint. Without feed there is no freshwater footprint, but as explained, removing feed decreases the efficient use of land. Freshwater, however, is more valuable than brackish water as there are few uses of brackish water aside from aquaculture. As feed is reduced or eliminated, farms become less intensive. The less intensive the farms, the greater the reliance on brackish water flushing of ponds to maintain adequate water quality; large ponds used in semi-intensive and extensive farming are too large to efficiently aerate with mechanical aerators. Thus, more brackish water is used. Although fewer nutrients are added to these lower intensity ponds, the nutrients will be routinely flushed from ponds to maintain water quality, further justifying pond flushing. The quality of water is an important factor because highly concentrated effluents from intensive farms will add to the nutrient loading of the receiving water body, but may also cause serious localized water quality deterioration at the outfall of the farm. Less intensive systems will exchange more water than more intensive systems and can impart the same or even higher nutrient loads to the receiving water bodies as do intensive farms. Of course, lower intensity farming will not result in the release of highly concentrated effluent like that from intensive farms. Lastly it is important to note that more intensive farms are capable of not discharging any water from the farm, as they may treat the water and recycle it for use in another crop. The less intensive the production system the greater reliance on exchanging water from ponds to maintain water quality making it more difficult for these operations to close their system from discharge to the natural environment.

Energy is used to construct and repair farms and power mechanical equipment. It is also embodied in feed ingredient production or capture (in the case of wild fish). The combined energy to produce shrimp will increase as a farm intensifies – more feed, more aeration, more pumping, etc. However, the production output of a farm will increase through intensification such that the energy use per unit of shrimp will decline. Elimination of feed, aeration and pumping will push farms into the intertidal area to obtain the tidal flushing necessary to maintain pond water quality as there is no other means to flush water without energy. Semi-intensive farms outside of the intertidal zone will use large pumps to lift water into the farm to fill ponds but also run these pumps for periods of time to provide enough water to exchange pond water. Ponds are larger at lower intensity farms which requires greater earthwork for construction. Coupled with the energy for construction and the relatively low shrimp production, lower intensity farms often will have a higher energy demand per unit of shrimp produced.

Wild fish is a protein and nutrient source for shrimp. It is an ingredient in feed, thus a decrease in intensity would correspond to a decreased reliance on wild fish. Wild fish is only used for shrimp produced in systems where feed is applied. There is no wild fish burden for unfed shrimp aquaculture systems. The use of wild fish can be reduced or eliminated by using other protein sources, but there are also corresponding impacts for using those sources – plant meals have their own natural resource burdens for production. Replacement ingredients for fish meal in feeds is a growing area for research and businesses. The replacements that have been proposed to date still require natural resources to supply nutrients to a variety of organisms such as insects, bacteria and yeasts.

Though all natural resources are important, making more efficient use of land may have the most significant and far-reaching environmental consequences. Leaving habitat intact yields several benefits. First, it mitigates the impact of climate change, which is driven by the loss of forests, mangroves, and other carbon-rich ecosystems. Second, intact habitat—particularly coastal ecosystems such as mangroves—provides protection from predation and critical spawning and nursing grounds areas for fish and other organisms.

Preserving habitats also protects biodiversity. Most human-modified habitat such as agriculture and forestry tend to have less biodiversity. Thus, by using existing lands more efficiently, such as by intensifying shrimp farms, it would not be as destructive to biodiversity as would expanding the area for shrimp culture into relatively pristine regions. Of course, intensive farm expansion will require more land dedicated to feed ingredient production and if this agricultural land expansion extended into natural habitat such as undisturbed grassland or forest, the additional land might be similar in biodiversity to land upon which shrimp farms could be built. Nevertheless, there would likely be less conversion of areas with high ecosystem quality to areas of lower ecosystem quality through intensification than through expansion of less intensive production.

What is realized in weighing the various trade-offs of different shrimp production systems is that there comes a point when a value judgement is necessary. No one particular natural resource is more important than another absent context. If the focus of a particular initiative is to do away with wild fish in feeds at all costs, it can be done, but in doing so the value of wild fish is put above the natural resources used to produce the ingredients to replace it. If the elimination of energy and freshwater use is the priority, the elimination of feed will result in lower producing systems requiring more land than an intensive system to produce a unit of shrimp. Beyond the scope of this work, these trade-offs can be put in the context of what food to eat – shrimp vs chicken. Further analyses could be related to protein and system, i.e., intensive shrimp vs. free range chicken.

The rise of the organic foods movement among consumers has fostered demand for more extensively grown foods without the use of many chemicals, such as antibiotics. However, in shrimp aquaculture, organic farms use more than twice as much land and energy, and more than four times as much water as intensive operations per unit of shrimp produced—yet only about one-third of the feed.

Table 6. Natural resources used for the production of 1.6 ton of shrimp by organic standards at the maximum allowable production density and by conventional intensive aquaculture

	Organic	Intensive
Land (ha)	1.0	0.44
Water (m^3)	10,075	2,173
Energy (GJ)	62	30
Wild fish* (tons)	1.14	3.39

*Maximum fish meal inclusion is 20% and maximum allowable FCR is 0.8

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RECOMMENDATIONS

Shrimp are not essential to the human diet—no single food is. Rather it is the nutrients we obtain from these foods that are most critical. Nutrients that are the same as those found in shrimp can be obtained from other foods. Of course, the other foods will come with specific impacts as well that are being traded for the impacts of shrimp produced through aquaculture.

Interventions to stop shrimp farming have failed because the consumer demand for shrimp is high and continues to grow. The changes in shrimp consumption over the years of aquaculture expansion have been troublesome, though. Just a few decades ago, shrimp were rare and expensive. It is now much more affordable and being treated as such – from all-you-can-eat buffets, to a hamburger topping, to a condiment in a salad. Shrimp takes natural resources to produce – coastal land, water, energy and wild fish. These natural resources are now externalities that must be incorporated to convey the true cost of producing shrimp.

The following recommendations are provided with a prioritization on the elimination of further converted coastal lands for shrimp aquaculture. The recommendations are separated by stakeholder group as they are not solely the responsibility of the shrimp farmers. The entire value chain shares in the burden of the environmental cost to produce shrimp.

Fishing sector in Asia

The Asian fishing industry which provides fish to be converted to fish meal for shrimp feed requires a drastic trajectory change. Fisheries have been so depleted in some regions of the world that the only profitable means for fishing is by enslaving people on boats. Better management and greater traceability is required to sustain fish stocks.

Shrimp feed sector

The continued inability of the Asian fishing industry to manage the fish stocks that make up the fish meal in shrimp feed suggests that the marine ingredient itself is a greater liability than the cost and implications of replacements for wild fish. The decimation of these fish stocks is embodied in the feed that is produced and transferred with the shrimp that eat these feeds. Fish meal that is composed of these over-exploited fisheries should be avoided until such time that the fishing sector can prove that the management of these stocks is feasible. Of course, it is clear from new innovations in the feed ingredient sector that the motivation of companies producing fish meal alternatives is higher than those that manage these fisheries.

Feed ingredients including the marine ingredients for shrimp feeds must be able to be traced back to the origin where it was produced or caught. Without this knowledge, there is no means to determine if the ingredients in the feed are at best produced responsibly and at least illegally produced.

With traceability a greater demand for quality of raw materials will be key to allow shrimp farmers to advance their feed efficiency capabilities.

Shrimp farmers

Shrimp farmers must be more efficient in their utilization of natural resources. Additionally, they must recognize that improvements over time will be required to become even more efficient. Of course, the improvements in efficiency will have a direct benefit on farm profitability such that as farms reduce natural resource footprints, their costs of production will decrease. Decreased FCR and increased survival coupled with intensification will decrease the natural resource footprint. Intensification conducted in a responsible manner is likely the only means to continue to increase shrimp output and maintain profitability.

Certification programs

Various certifications exist, but all require improvement in traceability and impact reporting. Certifications should be reporting their natural resource footprint such that buyers and consumers are assured that by supporting such verification processes they are using their purchasing power for beneficial purposes. Detailed information on the changes that are required in certification standards are provided in Table 9.

Buyers (retail and food service)

Buyers should seek Aquaculture Stewardship Council certification, and when not available, measure natural resource footprints to monitor improvement in suppliers over time. Additionally, traceability needs to become a pre-competitive issue. No claims are valid about shrimp supplies if there is no means for determining the location where the product was produced. Traceability should be a pre-requisite in choosing suppliers. Lastly, it is critical to not support certification programs that cannot provide traceability of farmed product as this only reinforces fraud and mislabeling.

Consumers

Consumers should seek out shrimp from farms certified by the Aquaculture Stewardship Council shrimp or, if it is not present, request it. Further, the environmental and social burdens of farmed shrimp demand more awareness to reduce food waste and temper consumption such that shrimp is not perceived as a commodity but rather a specialty item.

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Table 7. Business case indicators for conservation of natural resources utilized in shrimp aquaculture production compared with corresponding BAP and ASC standards and recommendations for inclusion

Where “None” is entered, there was no metric in the standard for this measure.

			Corresponding Quantitative Standards		
Business Case Indicator	**Units**	**Impact(s) Addressed**	**Best Aquaculture Practice (BAP)**	**Aquaculture Stewardship Council (ASC)**	**Recommended Value**
Fish In:Fish out Ratio	t wild fish/t shrimp	Wild fish use and conversion efficiency	Whiteleg shrimp: 1.2** Black tiger shrimp: 1.7**	Whiteleg shrimp: 1.35 Black tiger shrimp: 1.9	Whiteleg shrimp: 0.5 Black tiger shrimp: 0.9
Land Use*	ha/t farmed shrimp	Habitat conversion, land use efficiency	None	None	Whiteleg shrimp: 1.2 Black tiger shrimp: 1.8
Water Use*	m^3/t farmed shrimp	Water discharge, pumping energy use, pollution load	None	None	4,000 m^3/t shrimp
Recovery of Stocked PLS	# PL stocked/ # shrimp harvested	Health management, disease transfer, natural resource use efficiency	None	Unfed and non-permanently aerated pond systems - 25% Fed but non-permanently aerated pond systems - 45% Fed and permanently aerated pond systems - 60%	70%
Energy Use*	gigajoules/t shrimp	Climate change	None	None	35 GJ/t shrimp
Condition of Receiving Waters	Diurnal oxygen flux in receiving waters (Δ O2 mg/L)	Water pollution, environmental condition and cumulative impacts	None	≤ 65%	N/A
Feed Conversion Ratio	t feed/t shrimp	Feed efficiency, water pollution, waste, natural resource use efficiency	None	None	1

* Includes embodied resources used for aquaculture feed ingredient capture/production

** The BAP standard for wild fish utilizes a less conservative calculation for Fish-in:Fish-out. Recommendations in this table are based on the calculations for Fish-in:Fish-out from the ASC standard.

CONCLUSIONS

Shrimp aquaculture requires resources and can cause negative impacts such as land use modification, excessive water use, water pollution, over-exploitation of oceanic fisheries for fish meal and oil included in feeds, and carbon emissions associated with electricity and fuel use on farms. Means for conserving resources and lessening negative environmental impacts must be devised so that aquaculture may sustainably supply the future increase in demand for fisheries products.

Intensification appears to be the only approach to reducing use of land, water, and energy in shrimp aquaculture. This may not seem reasonable to those who support small-scale, low-input aquaculture. The reason that intensification saves resources is that much more land and water is used for producing each ton of shrimp or other aquaculture product when pond production intensity is low. For whiteleg shrimp, about 2 ha of land and 100,000 m^3 of water are needed to produce 1 t of shrimp by extensive culture, while at a pond production intensity of 30 t/ha per year, only 0.444 ha of land and 200 m^3 of water – including land and water embodied in feed – are needed to produce 1 t of shrimp. Putting this on a large scale, suppose in the future whiteleg shrimp production in Thailand and Vietnam (combined) increases 500,000 t to meet future demand. Achieving this increase by extensive culture would require 1,000,000 ha of land for new farms. However, the production increase could be achieved with no additional shrimp farm area by intensification. But, about 250,000 ha (at FCR = 1.5) of additional cropland would be necessary for feed ingredients. It seems prudent to save 1,000,000 ha of coastal habitat at the expense of increasing agricultural land by about 250,000 ha as long as forests, grasslands and other biodiverse habitats are conserved.

The value proposition for shrimp farmers to improve their natural resources efficiency is apparent from the results of this study. The magnitude of this value proposition is different depending on the scale of production and the farm business model. Each farming management style has a maximum level of efficiency in which it can operate, and each management style has significant cost savings that can occur with improved performance.

Accountability and efficiency needs to become a pre-competitive aspect of shrimp aquaculture moving forward. Conversion of natural habitat for shrimp farm expansion must cease and the footprint of shrimp needs to be reduced. A “more with less” approach must be institutionalized and conventional thinking on what constitutes “responsibly-produced shrimp” needs to be challenged to foster continuous improvement. The responsibility for these changes rests with the entire value chain of shrimp from feed ingredient suppliers to consumers.

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