Seafood Watch
Seafood Report

MONTEREY BAY AQUARIUM

U.S. Farmed Shrimp

Pacific white shrimp
Litopenaeus vannamei

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Final Report
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About SFA®, Seafood Watch® and the Seafood Reports

This report is a joint product of the Sustainable Fishery Advocates (SFA) and the Monterey Bay Aquarium Seafood Watch® program. Both organizations evaluate the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. In doing so, SFA applies the definition of sustainable seafood and the method for its evaluation and presentation developed by the Seafood Watch program at the Monterey Bay Aquarium. Seafood Watch defines sustainable seafood as originating from species, whether wild-caught or farmed that can maintain or increase production into the long-term without jeopardizing the structure or function of affected ecosystems.

SFA makes its sustainable seafood recommendations available to the public through these reports and its FishWise® program. FishWise® is a patented, educational program that provides information on sustainability, catch method, and origin of seafood found at retail outlets. The program seeks to educate consumers, restaurants, distributors, and retailers on sustainable fishery issues, with the goal of decreasing unsustainable fishing practices, while improving the livelihoods of people who fish, fish populations and ocean ecosystems. The body of this report synthesizes and evaluates current scientific information related to each of five sustainability criteria. For each criterion, research analysts at SFA seek out relevant scientific information from the following information sources (in order of preference): academic, peer-reviewed journals, government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. The report then evaluates this information against Seafood Watch's conservation ethic to arrive at a seafood recommendation of "Sustainable/Best Choices", "Some Concerns/Good Alternative", or "Unsustainable/Avoid". The detailed evaluation methodology is available at Seafood Watch's website (http://www.mbayaq.org/cr/cr_seafoodwatch/sfw_aboutsfw.asp) and is also available upon request from SFA. The methodology reflects the common view of SFA and Seafood Watch® of the long-term sustainability of the species and the common methods by which it is currently caught or grown.

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 Report. Each report 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". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, 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 Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use these seafood reports in any way they find useful. For more information about SFA please contact SFA at postmaster@sustainablefishery.org or call (831) 427-1707. For additional information about Seafood Watch®, visit www.seafoodwatch.org or call 1-877-229-9990.

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I. Executive Summary

Shrimp aquaculture in the United States (U.S.) focuses primarily on the production of non-native *Litopenaeus vannamei* (Boone 1931), the Pacific white shrimp. The U.S. is the largest market for shrimp globally, but domestic aquaculture currently accounts for less than 0.1% of global *L. vannamei* production.

A large proportion of U.S. shrimp farms use best practices to guide site selection, water quality/effluent management and farm operations. However, the domestic industry is currently struggling to compete with low-cost shrimp from Asia and South America, which are preferred by U.S. consumers. Domestic production has fallen from a high of approximately 13 million lbs in 2003 to just over 4 million lbs in 2008.

Data for 2008 indicate that more than 87% of the total weight of marine shrimp farmed in the U.S. comes from operations engaging in low-level (1–3%) daily water exchange between farms and coastal systems. The vast majority of production from exchanging systems occurs in Texas (>99%). Small numbers of zero-exchange recirculating systems and inland ponds can be found throughout the country.

In the U.S., producers are currently working with feed manufacturers to decrease fishmeal inclusion rates through the use of more plant proteins (e.g., soy concentrate or microalgae). The U.S. farmed shrimp industry has an average fishmeal inclusion rate of around 15% in feeds, which is reported to be decreasing rapidly. Some farms now report inclusion rates as low as 5–7%. Use of marine resources is ranked “Moderate” based on a mean wild-fish-in-to-farmed-fish-out ratio (WI:FO) of 1.35:1, which results in part from the higher feed conversion ratios associated with producing larger shrimp. Escape and disease are moderate concerns for coastal shrimp farms, but pose a very low risk in zero-exchange recirculating and inland systems. While escaped *L. vannamei* have been detected in Texas and South Carolina and are periodically collected from commercial shrimp trawls, no permanent feral populations are known to exist. Common shrimp diseases such as Taura Syndrome (TSV), Whitespot Syndrome (WSSV) and Yellow Head Virus (YHV) can be transmitted between *L. vannamei* and at least three native shrimp species that are all commercially fished in U.S. marine waters. Susceptibility to these diseases varies by species. *Litopenaeus setiferous* appears to be more vulnerable than either of the two *Farfantepenaus* species. Surveys in the Gulf of Mexico have shown sporadic occurrence of WSSV, but there is no evidence that aquaculture-related viruses have become established in wild shrimp populations—other crustacean species still await testing. While ingestion of escaped and infected *L. vannamei* is a plausible mechanism for disease transfer between wild and farmed shrimp, the most likely mechanism is currently thought to be non-farm uses of diseased imported commodity shrimp. Commodity shrimp currently pose a biosecurity threat to both U.S. farmed shrimp and wild stocks. Strong farm-level management in the U.S. is directly related to strictly enforced federal, state and regional regulations that address water quality, effluent discharge, chemical use, the farming of exotics, site selection and monitoring frequency. These measures, along with the use of disease resistant strains and strict biosecurity protocols, have generally resulted in effective prevention and quarantine of pathogen outbreaks on farms. Broader legislation is needed to address the disease risks associated with the movement and disposal of commodity shrimp.

The U.S. farmed shrimp industry is rapidly changing in terms of protein sources, feed inclusion rates, cultured species (changes between shrimp and other non-shrimp organisms within farms) and as a consequence of the current economic climate. Establishing a centralized, up-to-date repository of industry information using creative mechanisms to provide transparency without compromising the proprietary needs of producers is one way that the U.S. industry could be more appropriately recognized for many of its progressive practices.

Overall recommendations vs. specific production system recommendations

The U.S. farmed shrimp industry is divided into three sectors that differ by production method: zero-exchange recirculating farms, inland pond farms and exchanging coastal farms. Meaningfully different risks are associated with each of these production systems. Therefore, in many sections of this report, rankings for each production method are presented separately. When information is available, we strongly encourage consumers and seafood buyers to select products based on the production system involved. Since this information is not consistently available, we have also provided a ranking for the U.S. industry as a whole, based on how the majority of shrimp (by weight) are produced. Industry initiatives to produce labels detailing production methods could also allow distinct market recognition for all zero-exchange and inland farms.

SINGLE OVERALL U.S. FARMED SHRIMP RECOMMENDATION

If information on production methods is not available, the overall ranking for U.S. farmed shrimp is as a **Good Alternative**. Data for 2008 indicate that over 87%[1] of the total weight of marine shrimp farmed in the U.S. came from operations exchanging waters (1–3%) with coastal systems daily for at least part of the growing season. The vast majority of production from exchanging systems occurs in Texas (>99%)[1], although two other such farms have been confirmed to operate in Hawaii and South Carolina. Just under three quarters of all U.S. shrimp currently comes from two exchanging Texan facilities called Bower Shrimp Farms and St. Martin Shrimp Farm. A number of smaller producers throughout the U.S. use recirculating systems or grow in inland ponds where discharge does not reach coastal waters. However, current market labels do not make it possible for consumers to distinguish between shrimp farmed using different production methods.

RECOMMENDATION BASED ON PRODUCTION SYSTEM

U.S. farmed shrimp (Zero-exchange recirculating systems and inland ponds) is ranked as a **Best Choice**. These operations use moderate amounts of wild forage fish, but avoid the two main impacts from shrimp farming in the U.S. by preventing viable escapes and eradicating/strongly diminishing the potential for disease transfer.

[1] Calculation details are given in Appendices III–VI.

U.S. farmed shrimp (Exchanging systems) is ranked as a **Good Alternative**. Farms that exchange water with coastal systems use moderate amounts of wild forage fish, have episodic escapes, operate with a moderate risk of disease transfer to wild shrimp and may be sited in or adjoining vulnerable coastal wetlands

Table of Sustainability Ranks – U.S. Farmed White Shrimp (*Litopenaeus vannamei*):

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Use of marine resources		√		
Risk of escaped fish to wild stocks	√ Zero-exchange recirculating and inland systems	√ Exchanging systems		
Risk of disease and parasite transfer to wild stocks	√ Zero-exchange recirculating and inland systems	√ Exchanging systems		
Risk of pollution and habitat effects	√ Zero-exchange recirculating and inland systems	√ Exchanging systems		
Management effectiveness	√			

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if >3 criteria are of Low Conservation Concern (Green) and the remaining criteria are not of High or Critical
- A seafood product is ranked as a **Good Alternative** if the five criteria "average" to a Moderate Conservation Concern (Yellow) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if >2 criteria are of High Conservation Concern (Red) OR if one or more criteria are of Critical (Black)

Overall Seafood Recommendation:

U.S. farmed shrimp (general):

Best Choice	[Good Alternative]	Avoid

OR

Zero-exchange recirculating and inland systems:

[**Best Choice**]	Good Alternative	Avoid

Exchanging systems:

Best Choice	[Good Alternative]	Avoid

II. Introduction

Biology: Pacific White Shrimp (*Litopenaeus vannamei*)

The Pacific white shrimp, *Litopenaeus vannamei* (formerly *Penaeus vannamei*), is a marine crustacean belonging to the order Decapoda and the family Penaeidae. The body is translucent but often has a bluish-green hue due to the presence of pigmented chromatophores (molecules evolved to collect/reflect light). *Litopenaeus vannamei* (Figure 1) can reach 230 mm (9 inches) in length and are restricted to eastern Pacific waters ranging from Sonora, Mexico to Tumbes in northern Peru (Figure 2) (Farfante and Kensley 1997). The preferred habitat of *L. vannamei* ranges from muddy shore bottoms down to depths of 72 m (235 feet) (Dore and Frimodt 1987). The anatomy (Figure 3) and life history (Figures 4 and 5) of *L. vannamei* are similar to other members of the family Penaeidae.

Figure 1: *Litopenaeus vannamei* (http://www.ag.auburn.edu/fish)

Weight at first maturity averages 20 g for males and 28 g for females and is usually obtained between six and seven months of age. Female *L. vannamei,* weighing 30 to 45 g, spawn 100,000 to 250,000 eggs that are approximately 0.22 mm in diameter. Hatching occurs approximately 16 hours after fertilization.

The growth and survival of *L. vannamei* post-larvae are strongly dependent on temperature and salinity. When reared at temperatures of 20, 25, 30 and 35˚C and salinities of 20, 30, 35, 40 and 50 parts per thousand (ppt), survival and growth reach a joint optimum at around 28–30˚C and 33–40 ppt. Juvenile survival is severely compromised at low salinities and high temperatures (Ponce-Palafox *et al.* 1997).

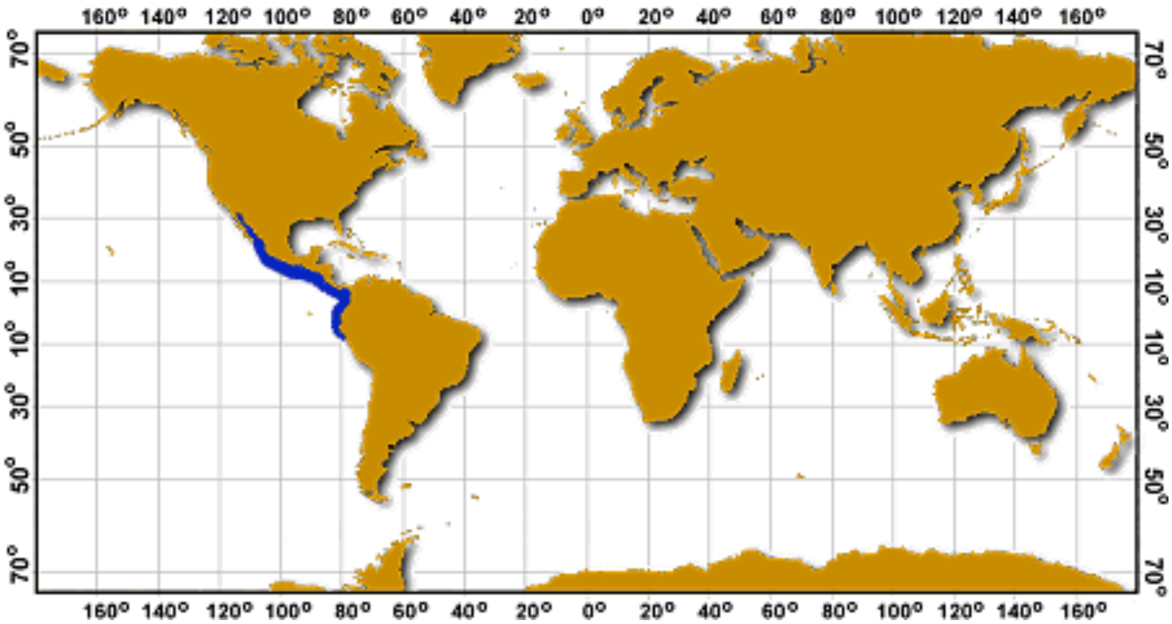

Figure 2: The native geographic range of *L. vannamei* in the wild from Holthuis, L.B. 1980. FAO species catalogue. Vol.1. Shrimps and prawns of the world. An annotated catalogue of species of interest to fisheries (FAO Fish. Synop. (125) V.1: 261; www.fao.org).

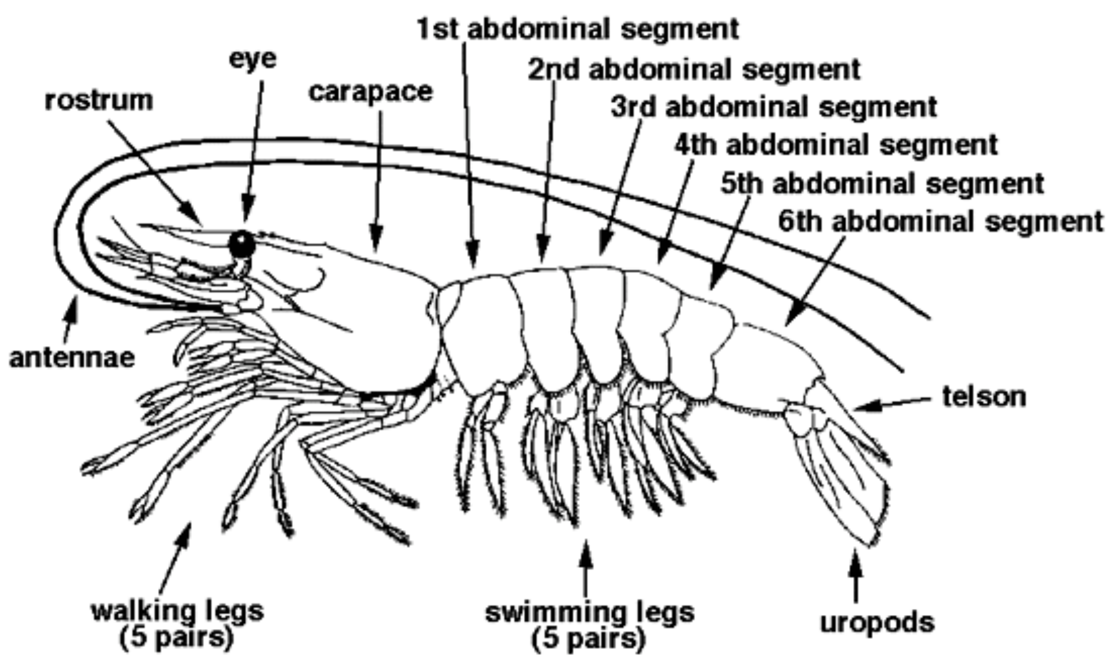

Figure 3: Basic shrimp anatomy. Courtesy of South Carolina Department of Natural Resources.

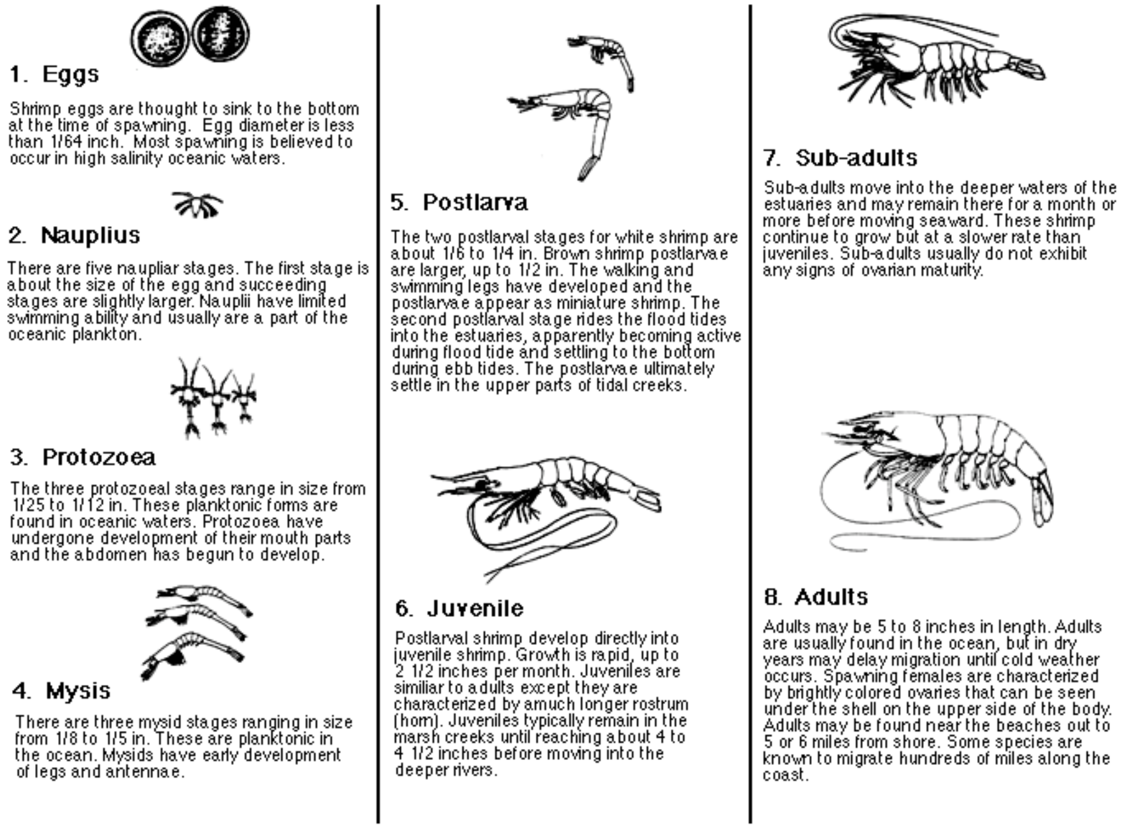

Figure 4: Penaeid shrimp life-history. Courtesy of South Carolina Department of Natural Resources.

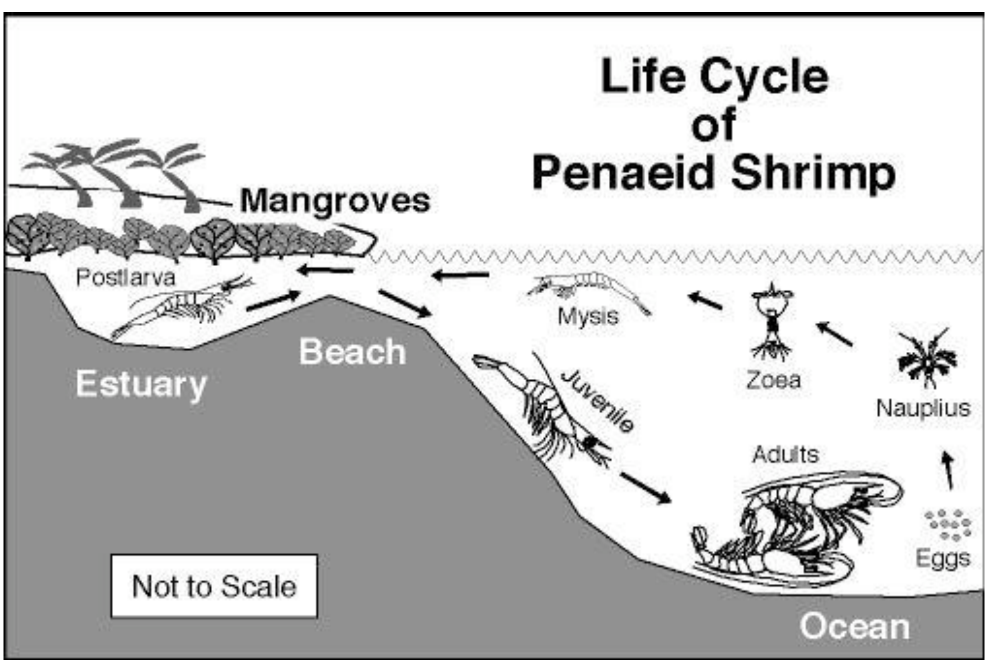

Figure 5: Diagrammatic representation of Penaeid shrimp life history.

Farming methods

Litopenaeus vannamei inhabits waters that range in salinity from 1 to 40 ppt (Bray *et al.* 1994) and is the most commonly cultured shrimp in the world (Josupeit 2008b). In the western hemisphere, *L. vannamei* is typically grown in ponds with salinity concentrations ranging from 0.5 (Samocha *et al.* 2001) to 28.3 ppt (Smith and Lawrence 1990, Saoud *et al.* 2003).

When the industry began, shrimp farmers predominantly utilized coastal flow-through technology, however, there was a shift away from this method during the 1990s (Treece 2002). Currently, operations in the United States raise shrimp using three different production methods:

- **Exchanging systems**: are located coastally, stock semi-intensively and practice water exchange techniques to maintain water quality.
- **Inland pond systems**: draw on ground water sources to fill their ponds. They do not practice water exchange but do produce effluent, which is either discharged to local freshwater sources or used as irrigation for crops.
- **Recirculating zero-exchange systems**: use either filtered, treated seawater or create their own salt water by adding minerals to freshwater. They do not discharge any effluent.

Development of the U.S. industry

Litopenaeus vannamei is not native to North America and was brought to South Carolina in 1985 in post-larval form for commercial aquaculture (Sandifer 1988). Domestic shrimp production began in Hawaii, where disease-resistant strains were bred and maintained in quarantine on the Island of Oahu by the U.S. Department of Agriculture's United States Marine Shrimp Farming Program (Treece 2008). Since 2005, broodstock has been produced in Texas, Hawaii and Florida (USDA NASS 2006).

Growout operations (normally for consumption) have traditionally been concentrated in Texas more than any other state. This concentration has only intensified in the last decade as growout production in other states has diminished both overall and in relation to Texas. In 2008, over 87% of production came from Texas (of which 99% came from exchanging farms, by weight, Appendix V), 4% came from Alabama and 2.6% came from Hawaii and Florida, with South Carolina, Kentucky, Maryland and Arizona making up the remainder (Treece 2009b) (Figure 6).

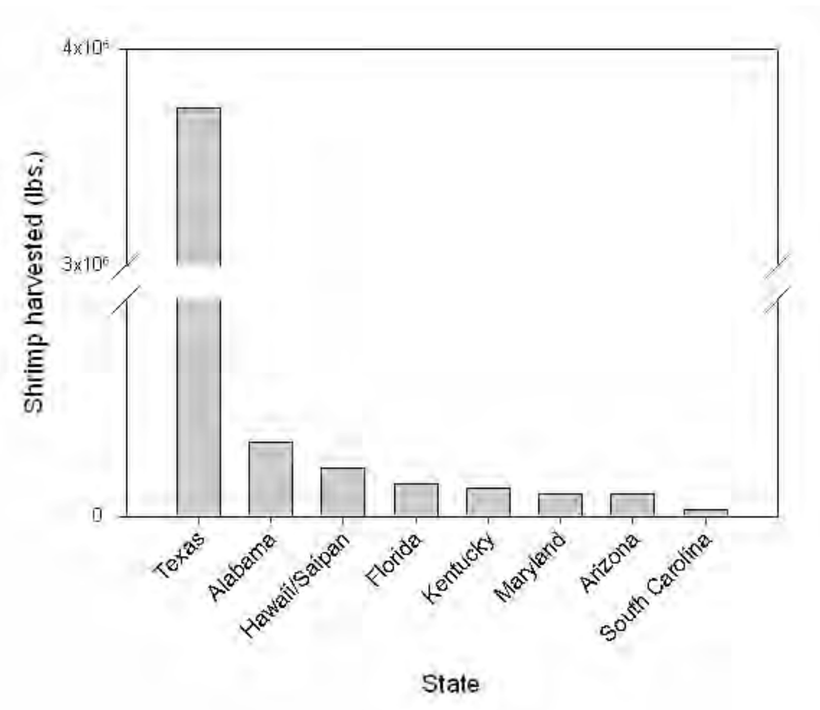

Figure 6: Shrimp production by state, in millions of pounds, 2008.
Note break in the y-axis from 500,000–3,000,000 lbs.

Production trends

Total saltwater shrimp aquaculture production in the U.S. is currently more than twice what it was at the industry's inception, although production has varied substantially through time. The industry reached peak production in 2003, when levels were greater than six times initial production, but outputs have declined since (Figure 7). In 2007, the U.S. produced 2,278 metric tons of *L. vannamei* (<0.1% global production by weight) worth $10,046,000 or 0.1% of the global total value (FAO 2009).

Texas is currently the state producing the most shrimp in the U.S, with outputs increasing substantially between 1987 and 2006 (Figure 8). When production peaked in 2003, Texas farmed a record 9 million pounds of *L. vannamei* (70% of U.S. domestic production) valued at $18 million. In 2004, production dropped to 7.94 million pounds, then to 6.83 million pounds in 2005, 5.0 million pounds in 2006, and 3.4 million pounds in 2007. Production increased slightly in 2008 to 3.7 million pounds (Treece 2008, Treece 2009b). The reduction in 2004 is thought to have resulted mainly from infection by Taura Syndrome Virus (TSV) coupled with decreasing shrimp prices. The overall decline since 2003 is thought to be a result of low farm-gate prices (the price farmers receive for their product from buyers) due to competition from imports and rising operation costs (Treece 2008).

Value

Litopenaeus vannamei is a high value aquaculture species. In Texas, *L. vannamei* was estimated to to be the fourth most valuable aquaculture species after catfish, red drum and hybrid striped bass in 2007 (Treece 2008). However, since 2002, average farm-gate prices for *L. vannamei* have been \$3.00/lb, \$2.00/lb and \$1.00/lb for shrimp in the 30 g, 20 g and 10 g weight ranges, respectively, and the overall value of the crop has been steadily decreasing (Figure 9) (Treece 2008).

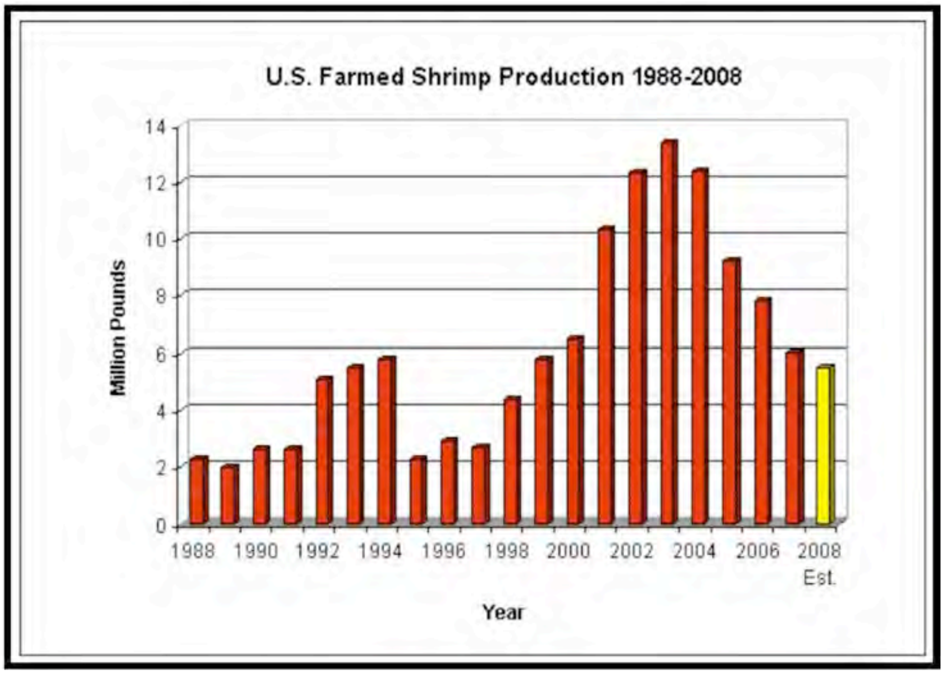

Figure 7: U.S. shrimp production, 1988–2008 (Treece 2008).

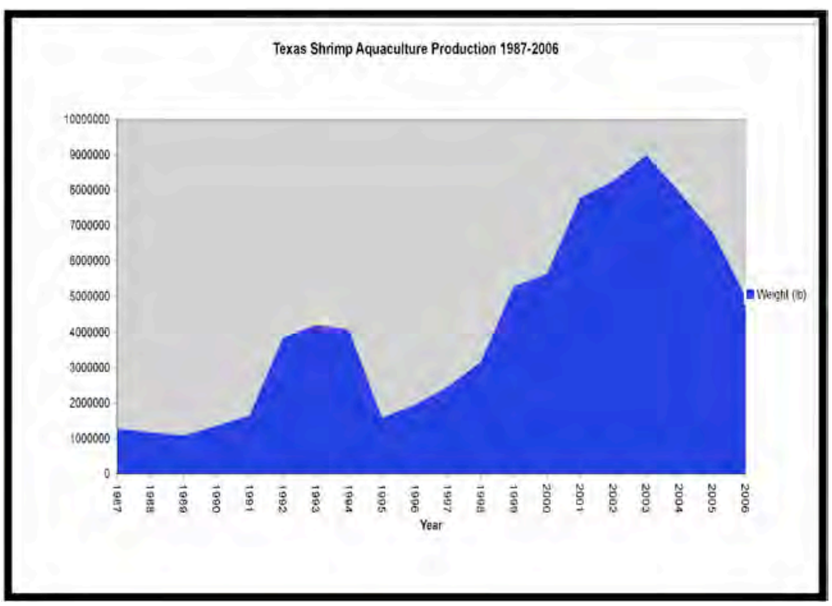

Figure 8: Total aquaculture shrimp production in Texas, 1987–2005 (Treece 2008).

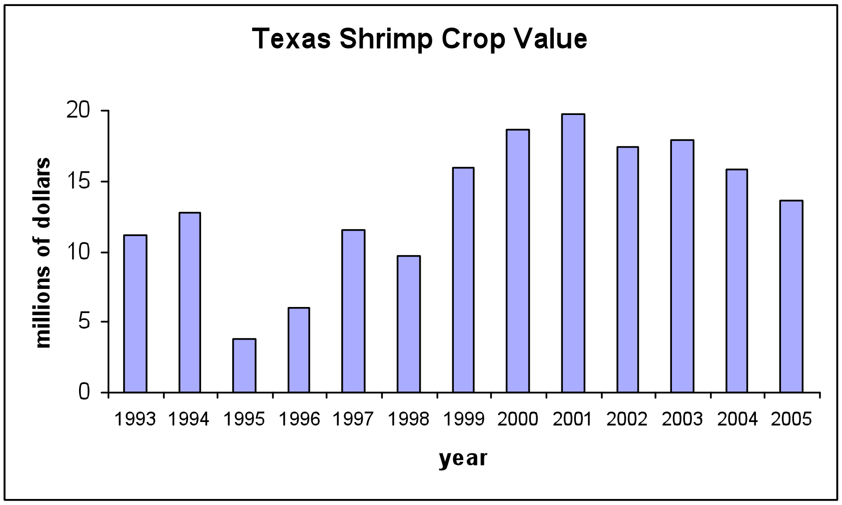

Figure 9: Total aquaculture shrimp value in Texas, 1993–2005 (Treece 2008).

Availability of science

Due to its global commercial importance, there is abundant literature on *L. vannamei* in the form of scientific journal articles, reports, books and websites. Information is available on many aspects of *L. vannamei* aquaculture, from the biology of the species to cultivation techniques to disease susceptibility. Scientific information specific to the production of *L. vannamei* generally comes from academia and industry since these two sectors often work closely to improve the efficiency and quality of aquaculture products. As a result. research on *L. vannamei* is both publicly and privately funded.

Information pertaining specifically to the U.S. farmed shrimp industry is less abundant, most likely because domestic production is so small relative to worldwide volumes. Information on the composition of feeds used in U.S. aquaculture—specifically their fishmeal and fish oil inclusion rates—is very scarce: these data tend to be proprietary and closely guarded by the feed companies. There is also a paucity of information documenting the production methods in use by different farms and the relative efficacy of legislation and best management practices.

Market information

Common and market names

Litopenaeus vannamei is sold as West Coast (or Pacific) white shrimp, camarón blanco or langostino. Names used by the Food and Agriculture Organization of the United Nations (FAO) include: whiteleg shrimp, crevette pattes blanches and camarón patiblanco

Seasonal availability

Coastal farms perform only one harvest annually, which usually takes place in October (Ostrowski, June 2007). The harvest is never later than the first week of November when cold snaps can occur that would kill the animals. Any shrimp not sold fresh are frozen and sold throughout the remainder of the year (Jaenike June 2007). Several inland intensive farms perform multiple harvests throughout the year (Marvesta Shrimp Farms 2009).

Product forms

Litopenaeus vannamei shrimp are sold head-on, head-off, Individually Quick Frozen (IQF), block (frozen in ice blocks) and fresh.

Table 1. Explanation of shrimp sizing (Seafood Business 1999).

	Count per pound		
Size name	**Green headless**	**Peeled**	**Cooked**
Extra Colossal	Under 10	Under 15	16/20
Colossal	Under 15	16/20	21/25
Extra Jumbo	16/20	21/25	26/30
Jumbo	21/25	26/30	31/35
Extra Large	26/30	31/35	36/40
Large	31/40	36/45	41/50
Medium Large	36/40	41/45	46/50
Medium	41/50	46/55	51/60
Small	51/60	56/65	61/70
Extra Small	61/70	77/75	71/80
Tiny	Over 70		

Shrimp count

Because shrimp vary in size, they are sold by count (number) per pound rather than by individual weight. This is expressed as a range. For example, a 16/20 count means it takes 16 to 20 shrimp of that size to make up a pound (Seafood Business 1999). The smaller the count, the larger the individual shrimp.

Import and export statistics

The United States is the largest market for shrimp globally (Johnson 2007). More than 85% of U.S. consumption met with imports, resulting in an annual trade deficit of more than $3.2 billion (University of Southern Mississippi 2008). Shrimp imports to the U.S. increased from 1997 to 2006 (Figure 10) until a sudden downward trend began in 2007 (Table 2), which was thought to be a result of the weakening dollar, the boom in oil prices, the slower economy, anti-dumping tariff disputes, reduction in some key production areas and a reduction in consumer confidence (Josupeit 2008a).

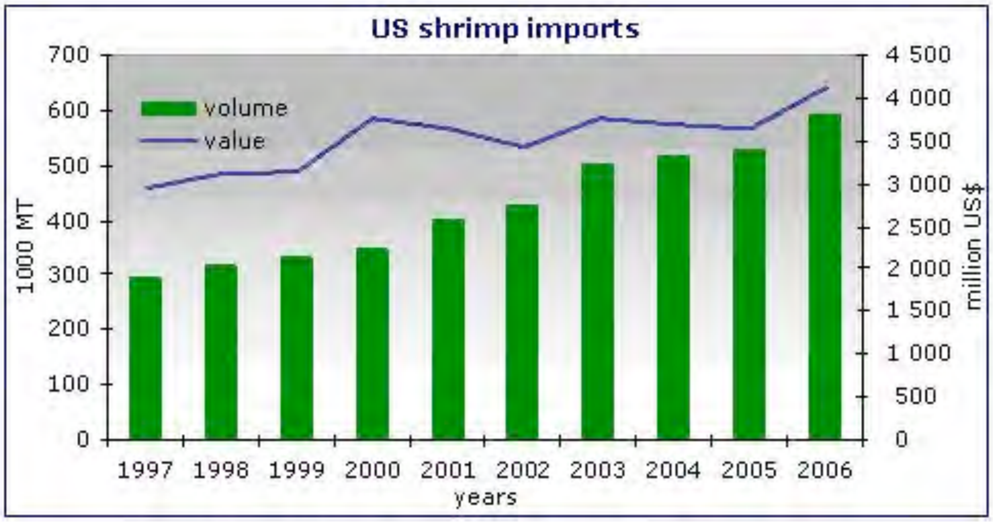

Figure 10: U.S. shrimp import volume (in metric tons) and value (in U.S. dollars) from 1997–2006 (Lopez 2007).

Increased foreign shrimp production (Figure 11) and imports into the U.S. over the past five years (Table 2, Figure 10) have lowered farm-gate prices and threatened the profitability of the U.S. marine shrimp farming industry. In response, the U.S. Marine Shrimp Farming Program (USMSFP) has aggressively pursued a strategy to provide next generation technologies, products and services that will improve competitiveness and create new opportunities for U.S. shrimp farmers (Ostrowski 2006).

Table 2. Volume of U.S. shrimp imports country by country (in 1000s of metric tons) from 2002 to 2007 (Josupeit 2008b).

Shrimp imports to the U.S. Origin	2002	2003	2004	2005	2006	2007
	1000s of metric tons of shrimp					
Thailand	115.1	133.2	132.1	160.9	193.7	188.3
Ecuador	29.7	34.0	37.5	49.6	59.4	59.1
Indonesia	17.4	21.7	47.0	52.6	58.7	59.1
China	49.5	81.0	66.0	45.2	68.2	48.4
Mexico	24.3	25.5	29.0	28.1	35.4	40.6
Viet Nam	44.7	57.4	37.1	42.9	37.1	39.3
Malaysia	1.5	1.3	12.7	17.2	20.3	22.8
India	44.2	45.5	41.0	35.7	27.3	20.8
Bangladesh	8.5	8.1	17.4	15.8	19.4	14.9
Venezuela	10.3	10.0	16.3	11.4	9.9	10.8
Guyana	9.7	11.4	8.4	8.6	7.8	8.9
Brazil	17.7	21.8	9.2	3.0	0.6	0.0
Others	56.7	53.6	63.9	57.8	52.5	43.9
Total	429.3	504.5	517.6	528.8	590.3	556.9

Source: NMFS; GLOBEFISH AN 10129

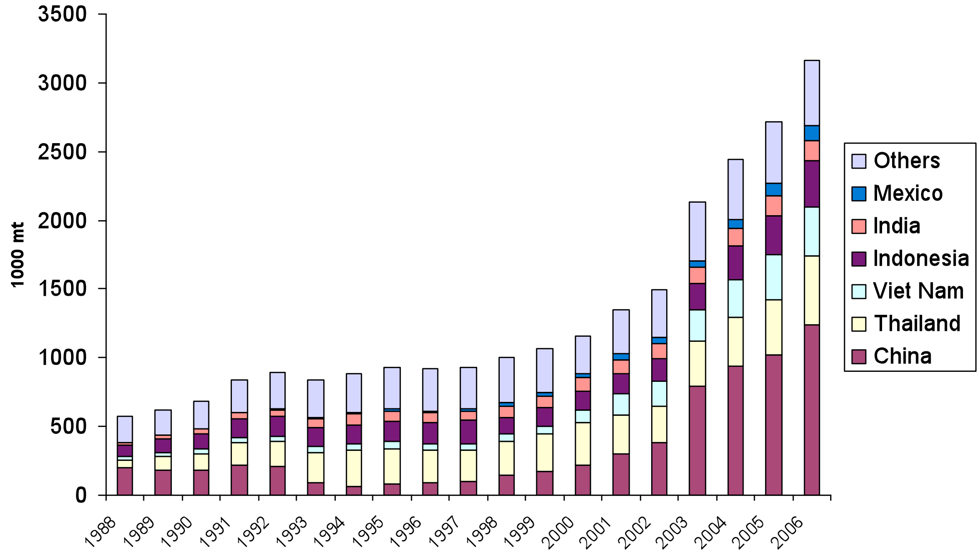

Figure 11: Global shrimp production 1988–2006 (Josupeit 2008b).

The U.S. has a diverse domestic aquaculture industry with exports primarily consisting of rainbow trout, Atlantic salmon, tilapia, catfish, freshwater crayfish and live mussels being shipped to Europe, North America, South America and Asia (Garrett *et al.* 1997). Most U.S. shrimp is consumed domestically, but farmers do occasionally export their product to Mexico or Canada if prices in these countries increase beyond the domestic market. Because of tariffs against U.S. shrimp, U.S. producers are unable to sell their product to the European Union (Jaenike, June 2007).

III. Analysis of Seafood Watch® Sustainability Criteria for Farm-Raised Species

Criterion 1: Use of Marine Resources

Nutritional requirements and feed production

Litopenaus vannamei is the most well-studied shrimp species with regard to nutrition and physiology (Cuzon *et al.* 2004). It is also a shrimp that maximizes growth in reduced protein environments due to its ability to make use of ambient, naturally occurring food sources such as plant matter and detritus (Gamboa-Delgado *et al.* 2003). When *L. vannamei* are grown semi-intensively, as they are in the U.S., high stocking densities decrease access to naturally occurring food items. Therefore, feeds with high protein content are needed to promote optimal growth and reduce mortality. The protein in aquaculture fish feeds normally comes from a combination of fishmeal derived from reduction fisheries and plant sources. Land animal by-product proteins may also be used. Major shrimp feed manufacturers in the U.S. include Cargill, Rangen, Zeigler and Burris Feed (Tacon May 2007). Obtaining information about shrimp feeds can be difficult due to the proprietary nature of information concerning feed composition.

Understanding nutritional requirements is central to the development of improved hatchery approaches and growout techniques for shrimp. Commercial feeds traditionally used for growout contain 30–50% protein. Culture strategy (Table 3) and species-specific nutritional requirements (Table 4) both determine the fraction of protein in feed (Forster *et al.* 2002).

Most *L. vannamei* in the U.S. is grown in semi-intensive systems with stocking densities of 100,000 to 300,000 individuals per hectare. Yields range up to 5,000 kilograms per hectare annually (Conklin 2003). At the least intense end of the farming spectrum, extensive culture has lower stocking densities (≤25,000 post-larvae per hectare), lower yields (<500 kg per hectare annually) and tends to use less feed and/or feeds with a lower proportion of protein. In extensive culture, shrimp obtain some of their protein from prey occurring naturally in the culture ponds. Although less frequently used in the U.S., intensive culture can yield as much as 20,000 kilograms per hectare annually, but requires aeration, constant water exchange, feeds with very high protein content and high initial stocking densities (Conklin 2003) .

Litopenaeus vannamei is an efficient species for farming because it has lower and more flexible protein requirements than both the tiger prawn *Penaeus monodon* (Fabricius, 1798) and the blue shrimp *Litopenaeus stylirostris* (Stimpson, 1874) (Velasco *et al.* 2000). It is also possible to successfully substitute as much as 75% of the diet of *L. vannamei* with soy protein concentrate (Forster *et al.* 2002). However, to exclude fishmeal and oil from shrimp diets entirely, an alternate source of DHA omega-3 fatty acids (required for optimal shrimp growth) must be included in the feed. These DHA omega-3 fatty acids are essential for shrimp growth since crustaceans only have a limited ability to synthesize them *de novo* (Gonzalez-Felix *et al.* 2003).

Table 3. Suggested protein levels for various culture strategies. Data from (O'Keefe 1998).

Culture system	Protein requirement (whether derived from fishmeal and/or other sources)
Extensive	25% – 30%
Semi-intensive	30% – 40%
Intensive	40% – 50%

In recent years, two primary factors have been attributed to changes in shrimp feed composition: the variable price of feed containing high quality protein (derived from forage fisheries) and the environmental impacts of such fisheries:

> "As the shrimp farming industry has exploded from a minor producer of shrimp to one of global importance, several factors have stimulated efforts to find alternatives for marine protein sources in manufactured shrimp feeds. Undoubtedly, price is the key reason to look for alternatives. The supply and price of high quality fishmeal, as well as shrimp and squid meals, can vary dramatically from year to year. There is also a general concern of the potential negative impact that fishmeal production might have on natural fisheries because of the use of single species fisheries models that do not fully account for the ecosystem effects of the fisheries (Naylor *et al.* 2000). Because of its attractive amino acid content, availability and relatively affordable price, soybean meal and soy concentrates have received increasing attention as replacements for marine animal meals" (Conklin 2003).

Table 4. Suggested protein requirements for various shrimp species. (1) (Venkataramiah *et al.* 1975, Zein-Eldin and Corliss 1976) (2) (Wu and Dong 2002) (3) (Colvin 1976, Boonyaratpalin 1998) (4) (Colvin and Brand 1977) (5) (Pedrazzoli *et al.* 1998) (6) (Deshimaru and Kuroki 1975, Deshimaru and Yone 1978) (7) (Chen, 1993a in (Shiau 1998) in(Conklin 2003).

Species name	Common name	Protein requirement (whether derived from fishmeal and/or other sources)
Farfantepenaeus aztecus	Northern brown shrimp	40% – 51% (1)
Fenneropenaeus chinensis	Chinese white shrimp	45% (2)
Fenneropenaeus indicus	Indian white shrimp	34% – 50% (3)
Litopenaeus stylirostris	Western blue shrimp	30% – 35% (4)
Litopenaeus vannamei	Western white shrimp	30% – 40% (5)
Marsupenaeus japonicus	Japanese kuruma prawn	52% – 57% (6)
Penaeus monodon	Giant tiger shrimp	40% – 50% (7)

The variable economics of fishmeal (and fish oil) are the result of a finite supply of wild forage fish stocks that are facing substantial increases in demand from the global expansion of aquaculture. In 2006, it was estimated that 68.2% of total global fishmeal production (3,724,000 metric tons) and 88.5% of total global fish oil production (835,000 metric tons) was consumed by the aquaculture sector (Tacon and Metian 2008), and these percentages are increasing (Figure 12). While feed efficiencies continue to improve, some researchers have suggested that projected aquaculture expansion will soon outstrip fish oil and fishmeal production, increasing the need to identify and develop alternative protein sources (Brown 2002, Naylor and Burke 2005).

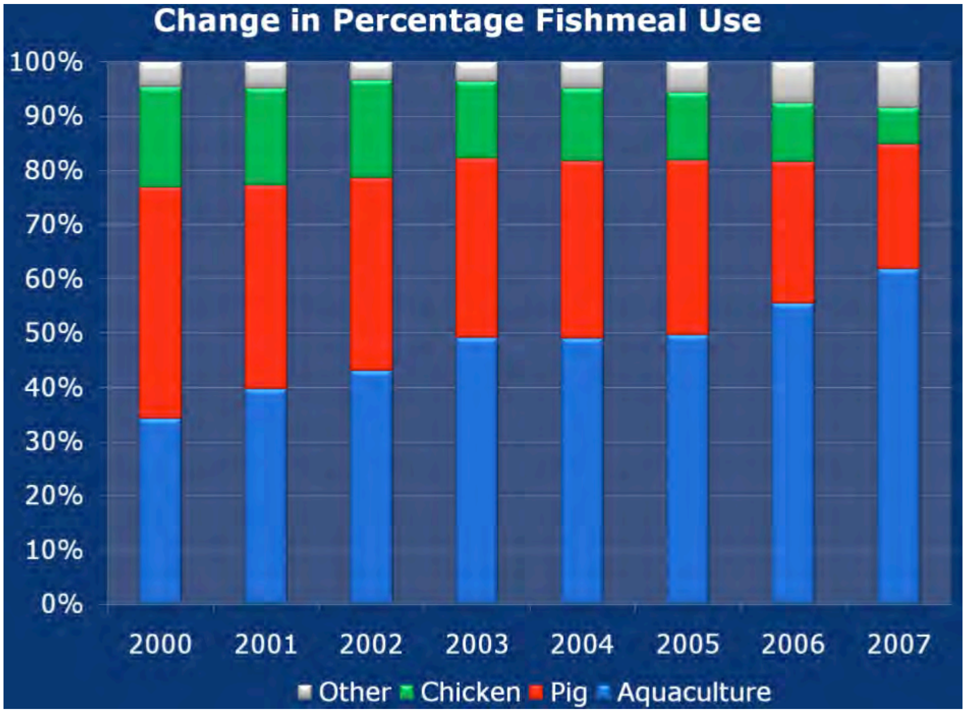

Figure 12: Change in percentage fishmeal use from 2000–2007 (Jackson 2009).

These two factors represent considerable economic as well as environmental incentives for making a transition from marine-derived protein meals to soy-based and other protein substitutes in the manufacture of feeds for shrimp aquaculture.

Alternative feed composition strategies

The aquaculture industry has begun to develop lower-cost feed formulations using alternative protein sources (Siccardi *et al.* 2006, Amaya *et al.* 2007). Although many plant proteins are suitable, soy-based products are one example of alternative protein sources currently being used in aquaculture feeds. Processing considerations have also been considered such as the removal of “anti-nutritional factors” to increase digestibility (Siccardi *et al.* 2006). Feed use efficiency has been discussed along with the potential development of a genetically modified soybean designed to suit aquaculture needs (Brown 2002). It has also been hypothesized that soy has substantial advantages over traditional protein sources used in feeds including improved effluent quality from aquaculture operations, and greater stability in soybean meal prices when compared to fishmeal (Brown 2002). However, fishmeal continues to have a nutritional advantage over soy, and replacing fish oil (also an important ingredient in feeds) with soy products would be considerably more difficult (Brown 2002). It may also be worth noting that at least 80% of U.S. soybean farmers cultivate genetically modified (GMO) soybeans (Traxler 2004).

Another alternative protein source tested as a substitute for fishmeal in *L. vannamei* diets comes from enzymatically hydrolyzed or steam-processed bird feathers, which are then combined in different ratios with soybean meal (Mendoza *et al.* 2001). Comparisons of a diet consisting of a 2:1 ratio of hydrolyzed feathers to soybean meal (20% of total diet) and a control diet containing 17.8% fishmeal revealed that growth, feed conversion ratios, digestibility and protein efficiency were similar among treatments over a 30-day period. This suggests that *L. vannamei* can be fed a diet containing 20% enzymatically hydrolyzed feathers and soybean meal without significant alterations to growth and feed conversion rates obtained with traditional fishmeal-based feeds (Mendoza *et al.* 2001).

Methods of producing DHA and EPA omega-3 fatty acids (normally provided by fish oil) from marine microalgae or genetically modified yeast grown in fermentation systems have been developed. A fishmeal and fish oil-free feed is therefore technically feasible and the shrimp display growth rates and final weights comparable to those achieved using commercial feeds that do contain fishmeal (Bullis June 2007). However, currently there are no U.S. shrimp farmers using this feed, most likely because it is more expensive than regular feeds.

Stock status of reduction fisheries[1]

Reduction fisheries (also called industrial or forage fisheries) refer to those fisheries in which the harvest is "reduced" to fishmeal and fish oil, primarily for use in agriculture and aquaculture feeds. The precise sources of fishmeal and fish oil can be difficult to determine due to proprietary reasons. Nevertheless, we do know that most forage fisheries are for small pelagic species that mature quickly, reproduce prolifically, are low on the food chain and are preyed on by higher trophic level animals such as piscivorous fish, seabirds and marine mammals. Forage species play a crucial role in marine ecosystems as they transfer energy from plankton to larger fishes, seabirds and marine mammals (Naylor *et al.* 2000, Alder and Pauly 2006) (MATF 2007).

Removing forage species from the marine ecosystem can therefore impact marine mammals and seabirds (Baraff and Loughin 2000) (Tasker *et al.* 2000, Furness 2003, Becker and Beissinger 2006). Fisheries targeting forage species can even reduce the productivity of other commercial and recreational fish that consume those species as prey (Walters *et al.* 2005). Similarly, forage fish are nutritious and could be used more efficiently by humans for direct consumption (Alder and Pauly 2006). There are multiple sources of uncertainty regarding these species' population sizes, so removal of forage species should err on the side of caution (NRC 2006). A healthy abundance of forage fish in our coastal marine systems is critical to the resilience of these systems in the face of the global climate and oceanographic changes we will face in the coming decades (IPCC 2007).

It is generally believed that the populations of fish targeted in most reduction fisheries are stable (Hardy and Tacon 2002, Huntington *et al.* 2004), although concerns have been raised about the potential for increased demand for farmed carnivorous fish by expanding industries (Weber 2003). In most cases, populations of forage fish are classified as fully exploited

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[1] Parts of this section are adapted from (Tetreault Miranda and Peet 2008) and can be found at http://www.montereybayaquarium.org/cr/SeafoodWatch/web/sfw_factsheet.aspx?gid=88

(Tacon 2005). Menhaden is thought to be one of the main fish used in U.S. feeds as a protein source. According to the Atlantic States Marine Fisheries Commission, the 2006 stock assessment showed that stocks are not considered to be overfished nor is overfishing occurring (ASMFC 2007). Marine Stewardship Council certification of forage fish populations used for reduction does not currently exist, but may be one mechanism to help assure the health of these stocks.

Sources of seed stock

Shrimp farming operations in the U.S. use only larvae produced from cultures grown in Hawaii, Texas and Florida (Treece 2008). These sources are typically marketed as Specific Pathogen Free (SPF) or Specific Pathogen Resistant (SPR). In other countries, the capture of wild *L. vannamei* postlarvae can be associated with severe environmental degradation and high bycatch of other species (Paez-Osuna 2001), but this practice is now mostly redundant on a commercial scale. These concerns are non-existent for shrimp aquaculture in the U.S. because all domestic farms stock their operations with post-larvae raised by other farms (Ostrowski June 2007).

Rates for WI:FO, inclusion and economic feed conversion

There are three major aspects of aquaculture feed that must be considered when determining a farm's economic viability and its impact on reduction fisheries: the amount of raw material (fishmeal and fish oil) for feed that can be extracted from wild fish (yield rate), the amount of fishmeal and/or oil in feeds (inclusion rate) and the efficiency with which feed is converted into farmed biomass (economic feed conversion rate).

For farmed *L. vannamei* in the U.S., we calculate the ratio of wild fish input to farmed fish output via the equation:

Yield rate of wild fish to fishmeal/oil	X	Inclusion rate	X	Feed conversion rate	=	Wild Fish Input: Farmed Fish Output (WI:FO)

Yield rate

Reduction is the process by which wild fish are processed into fishmeal and/or fish oil. The efficiency of this process is described by a yield rate, which can vary based on the species of fish, the season, the condition of the fish and the efficiency of the forage fish reduction plants (Tyedmers 2000).

Here, we use a fishmeal yield rate of 22%. This has been suggested by Tyedmers (2000) as a reasonable year-round average yield rate for menhaden. Yield rates of 22% for fishmeal are also consistent with global fishmeal yield values cited by Tacon and Metian (2008), who estimate fishmeal yields of 22.5%. A fishmeal yield rate of 22% means that 4.5 units of wild fish from reduction fisheries are needed to produce a single unit of fishmeal.

We also show calculations based on a fish oil conversion rate of 12%, or 8.3 units of wild fish to produce one unit of fish oil, which was suggested by Tyedmers (2000) as a representative year-round average for Gulf of Mexico menhaden. This yield rate is substantially higher than the global 5% oil yield averages suggested by Tacon and Metian (2008), corresponding to 20 units of wild fish for one unit of fish oil. However, to be consistent with previous Seafood Watch Reports, we will continue to use the Tyedmers (2000) value until a new definitive estimate is published. As the fish oil content of shrimp feed is low, the difference between these values does not affect the overall ranking for U.S. farmed shrimp (see WI:FO calculations below).

Inclusion rate

The result of a global survey undertaken between December 2006 and October 2007 suggests that the mean percentage fishmeal and fish oil included in compound shrimp feeds in the U.S. is 15% (range: 5–20%) and 4% (range: 1–8%), respectively (sample sizes not cited, Tacon and Metian, 2008). Here, we use these rates as the best values currently available summarizing inclusion of fishmeal and fish oil in feeds in the U.S. industry. There were no reports of feeds with inclusion rates higher than 15%[2], so we infer this to be a conservative estimate of the fishmeal inclusion rate from a conservation perspective.

Further independent estimates for inclusions rates in shrimp feeds used in the U.S. range from 6.5–25% fishmeal and 0–3% fish oil (Coutteau June 2007). Dr. Addison Lawrence, who has worked extensively with shrimp nutrition and formulates industrial feeds, uses an average fishmeal inclusion rate from 5–10% for shrimp production feeds and never more than 15% (Lawrence, November 2008). In the U.S., shrimp farms claim to be actively reducing their inclusion rates. For example, in 2007, Harlingen Shrimp Farms, Ltd. (Texas) claimed to have reduced their fishmeal inclusion ratio from 25% to 15% (Jaenike June 2007) and this year (2009) Marvesta Shrimp Farms aim to reduce their feed from the current 15% to 6.5% (Fritze, December 2008).

Economic feed conversion rate

The economic feed conversion rate (eFCR) is generally defined as the ratio of total feed weight used to the net production output (total weight gained by the stock) over one or more farming cycles[3].
This calculation is expressed as:

Feed Weight/(Final Stock Wet Weight – Starting Wet Weight) = eFCR[4]

[2] Based on communications with two U.S. shrimp farmers and an academic who formulates feeds for the U.S. industry.
[3] This is in contrast to biological feed conversion rates, which simply examine the capacity for a particular species to metabolize feed and convert it into biomass, without accounting for the mortality and average losses over a farming cycle.
[4] Although this calculation is of critical economic importance when determining which feeds provide optimal growth for the price, FCRs alone are a poor tool for measuring environmental impact, which is best accomplished using overall WI:FO (also know as FFER or feed fish equivalence ratio). FCRs are problematic if they are used to infer the

Globally, compound shrimp feeds were estimated to have an eFCR of 1.7 in 2007, and this is predicted to fall to 1.4 by 2020 (Tacon and Metian 2008). However, estimating eFCRs is challenging because the values depend on multiple factors including size of shrimp farmed, farming conditions (e.g., use of feed trays (Jory *et al.* 2001)), stocking densities, escapes and individual survivorship. For example, large shrimp grow less efficiently than smaller shrimp (Wyban *et al.* 1995) such that smaller size-class shrimp (e.g., 15 g per individual) have lower eFCRs than larger size classes (e.g., 30 g per individual) (Jaenike June 2007). The use of "average" eFCRs is further complicated by the fact that individual ponds produce shrimp of varying sizes such that a given eFCR corresponds to a range of size classes.

In this report, we used a mean eFCR value of 2.0 for the U.S. farmed shrimp industry obtained from surveys conducted by Tacon and Metian (2008). The only other estimate for the eFCR of most U.S. shrimp feeds that we could obtain came from Dr. Peter Coutteau (INVE, Belgium—a company manufacturing aquaculture feeds) and was cited as 1.3–1.6 (Coutteau, June 2007). For the purposes of this report, we use the environmentally conservative estimate of 2.0.

Overall WI:FO calculations

Fishmeal

(Tyedmers, 2000; Tacon and Metian, 2008)
(4.5 kg wild fish/1 kg fishmeal) X (0.15 kg fishmeal/1 kg feed) X (2.0 kg feed/1 kg shrimp)
=1.35 kg wild fish/1 kg shrimp

Fish oil

(Tyedmers 2000)
(8.3 kg wild fish/1 kg fish oil) X (0.04 kg fish oil/1 kg feed) X (2.0 kg feed/1 kg shrimp) =
0.66 kg wild fish/1 kg shrimp

(Tacon and Metian 2008)
(20 kg wild fish/1 kg fish oil) X (0.04 kg fish oil/1 kg feed) X (2.0 kg feed/1 kg shrimp)
= 1.60 kg wild fish/1 kg shrimp

Since reduction fisheries produce both fishmeal and fish oil from the same fish, it is necessary to estimate whether fishmeal or fish oil is limiting for the production of a particular species. For shrimp, fishmeal rather than fish oil is the limiting part of feed. Therefore, the overall WI:FO estimated for U.S. farmed shrimp is 1.35. For the sake of completeness, we

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conversion of biomass from one form to another because they compare dry weight of feed to wet weight of stock produced (stock weight gain). Therefore, the units of comparison are not consistent and underestimate the true amount of biomass that goes into the system relative to the output. Second, since FCR is a weight-based metric, it cannot account for differences among feeds that vary in either the amount of fish in feed (inclusion rate) or differences in the proportion of fish oil to fishmeal within individual feeds, where fish oil tends to require more fish to produce per unit weight than fishmeal.

have also shown the U.S. farmed shrimp WI:FO using two different estimates of fish oil yield rate.

It is worth noting that feed without any ingredients derived from forage fish would yield WI:FO values of zero.

Synthesis

The best values currently available for inclusion rates in the U.S. suggest a mean of 15% fishmeal and 4% fish oil for compound feeds, along with an eFCR of 2.0 (Tacon and Metian 2008). The resulting WI:FO using these numbers together with a broadly accepted yield rate of 4.5kg wild fish to fishmeal (Tyedmers 2000) is 1.35, which equates to a “moderate” use of marine resources. Using the alternative calculations based on Tacon and Metian’s (2008) oil yield figures would not affect this “moderate” ranking.

There are some U.S. operations reportedly using fishmeal inclusion rates as low as 5% (Tacon and Metian 2008) and with this value the resulting WI:FO becomes 0.45, which equates to “low” use of marine resources. Such values represent the low end of inclusion rates in the U.S. but are currently possible. Given continuing improvements in feed formulations and the U.S. market demand for large shrimp (high eFCRs), the most straightforward way for the U.S. shrimp farming industry to minimize their WI:FO ratio will likely be to continue to reduce forage fish inclusion in feed by using plant proteins and algae-based fish oil alternatives. With the current values for eFCR and yield rates, an inclusion rate of less than 12% fishmeal would result in a “low” use of marine resources. Access to yield rates from the specific reduction fisheries used in U.S. feeds together with inclusion rates for U.S. farm formulations would allow re-evaluation of the WI:FO values for U.S. shrimp.

Use of marine resources rank:

Low Moderate High

Criterion 2: Risk of Escaped Fish to Wild Stocks

Texas was responsible for approximately 87% of U.S. shrimp production in 2008 (Treece 2009b) and over 99% of the shrimp produced in Texas came from exchanging farms. All shrimp production in the state is regulated by the Texas Parks and Wildlife Department. Most farms operate with daily water exchanges of about 1–3% (Gregg, March 2009)(Appendix I), mainly by relying on recirculating systems (Treece 2002).

There are six potential negative impacts of escaped farmed fish, whether native or non-native: colonization, genetic impacts, competition, predation, habitat alteration and disease impacts. These risks can be reduced via proactive measures such as careful selection of sites for farms, species and systems; training of personnel; and development of contingency plans and monitoring systems (Myrick 2002).

Endemism and escape

Litopenaeus vannamei is not native to the U.S., but comes from the eastern Pacific waters ranging from Sonora, Mexico to Tumbes in northern Peru.

There are records of *L. vannamei* escaping from shrimp ponds, but a total of only 11 events have been recorded in government invasive species databases since 1990 (Perry 2009). Some caution is warranted here because, unless there is a known escape event, the measurement of escapes depends on commercial fishermen reporting catches. However, there is no evidence of established populations in the wild. The last *L. vannamei* found in wild U.S. continental[5] waters was in 1998, and most recorded landings occurred in the early 1990s (Perry 2009)—perhaps related to the transition between open flow-through and largely contained systems in coastal ponds in the mid-1990s (Treece 2002). In South Carolina, two exotic occurrences of *L. vannamei* have been recorded in the North Edisto River mouth (Charleston County) and in coastal waters (Wenner and Knott 1992). In Texas, six individual non-native *L. vannamei* were collected from the Gulf of Mexico off Brownsville (Cameron County), Matagorda Bay, Laguna Madre (north of Arroyo Colorado), Port Mansfield (Willacy County) and at Palacios (Matagorda County) (Balboa *et al.* 1991, Howells 2001). The last and only time an escape was identified in Hawaiian waters was in 1994. In Puerto Rico, one escape was noted in a canal connecting commercial aquaculture operations to La Plata River (Perry 2009).

A second non-native shrimp, the black tiger shrimp *Penaeus monodon*, has been officially recorded 27 times in at least six states including Alabama (n=2), Hawaii (n=1), Florida (n=4), Louisiana (n=1), South Carolina (n=7), North Carolina (n=10) and Georgia (n=2) (Fuller 2009). However, at present, no *P. monodon* are reared on U.S. farms or in U.S. research facilities, and there are no known established populations in U.S. waters. Conversations with research facilities and experts on the Atlantic seaboard near the North Carolina coast indicate that these collections are believed to have come from animals that escaped from farms in the

[5] One escaped *L. vannamei* was found in a drainage canal in Puerto Rico in 2006 in an area heavily predated by tarpon and egrets.

Caribbean, and are not relevant in terms of evaluating either disease or escape from U.S. farms.

Preventing escape

Exchanging farms pose the highest risk of escapes due to their relatively frequent discharges of water. However, in Texas, where the majority of exchanging farms are located, to avoid escape from farms during daily water exchanges with coastal waters, the Texas Parks and Wildlife Department (TPWD) enforces a rule calling for all water outflow to be triple-screened using varying mesh sizes according to animal size. Water intake must also be double-screened (500 and 250 micron mesh size) using screen bags made from either nylon or polypropylene. During the earlier stages of the farming process, a 500 micron mesh with 1/4 inch mesh backing and mesh netting on the outside is utilized (Jaenike, June 2007). Farms often do not exchange water until shrimp have passed the advanced juvenile stage and are sufficiently large to be retained by 1/4 inch mesh screening (Jaenike, June 2007).

At harvest time, a 3/8 inch mesh is used for the first screening, followed by a 1/2 inch mesh and finally another 1/2 inch mesh netting on the outside. Farms are also required to have a hurricane protection plan. If there is the threat of a hurricane, water levels in the ponds are lowered to contain rainwater and reduce the chance of wind damage to earthen levees. Additionally, all discharge pipes must be secured (Jaenike, June 2007).

The Hazard Analysis and Critical Control Point program, administered by the U.S. Food and Drug Administration, requires the TPWD to inspect exotic shrimp farm operations for diseases and viruses at least twice per year. Part of this inspection covers screens and harvest equipment to make certain they are escape-proof (HACCP 2007).

Inland ponds do discharge effluent, but they do not practice water exchange so the risk of shrimp escaping is negligible except for once per year, at harvest (USDA-Natural Resources Conservation Service and Auburn University 2003c) when ponds are drained and shrimp are captured as they leave the pond via the discharge water (Teichert-Coddington 2002). In many instances this discharge, rather than being discharged into a water body, is used to irrigate crops such as wheat, sorghum, cotton, alfalfa and olives (King *et al.* 2002). Moss (2002) describes the risk of escape of non-indigenous species from inland shrimp aquaculture as irrelevant.

Zero-exchange recirculating systems avoid the issue of escape altogether because there is no discharge of water, with all effluent being reincorporated into the system (Allen, April 2009; Fritze, December 2008).

Colonization potential

Escapes of non-native species are of greatest concern when environmental conditions enable establishment. Studies indicate that *L. vannamei* survival and growth is optimal at temperatures of 28–30˚C and salinities of 33–40 ppt (Ponce-Palafox *et al.* 1997). The species' preferred temperature range is 26.1–31.4°C (Hernandez *et al.* 2006). Temperatures in inshore waters range from 11.6–30˚C along the Texas coast, from 8.8–28.8˚C in South Carolina and from 21.6–27.2˚C in the Hawaiian Islands (National Oceanic Data Center 2009). Therefore, U.S. waters adjacent to shrimp culturing regions all exhibit temperature regimes that fall within the temperature and salinity tolerances of *L. vannamei*. However, no areas maintain optimal conditions for the growth and survival of *L. vannamei*.

Of all locations in the U.S., sea surface temperatures in Hawaii are within, but still slightly below, the species' optimum conditions. In Hawaii there are no regular commercial shrimp fisheries that might detect regular escapes, although Hawaii does have commercial shrimp trap fisheries that have operated sporadically since the 1960s (National Marine Fisheries Service (NMFS) *et al.* 2008).

Juvenile *L. vannamei* cannot survive at salinities below 2 ppt (Laramore *et al.* 2007), so there is no potential for the establishment of wild populations in freshwater systems.

Other effects of escape (genetic impacts, competition, predation, habitat alteration)

No information could be found on the possible or actual interactions of escaped aquaculture shrimp with native shrimp populations such as hybridization or indirect competition for food and other resources.

Status of potentially affected wild shrimp

The shrimp populations in the U.S. Gulf of Mexico are currently ranked as "Healthy" in the Seafood Watch Report "Wild-Caught Warmwater Shrimp: Gulf of Mexico and U.S. South Atlantic Regions" (last updated June 20, 2007), as fishery managers have no concerns about stock sizes.

Synthesis

Inland farms and aquaculture operations (regardless of location) using zero-exchange recirculating systems pose little or no threat to adjacent environments resulting from escapes and rank as a "low" risk. Escapes have been known to occur from exchanging farms, as evidenced by the occasional detection of *L. vannamei* in U.S. coastal waters. It has not been shown how the transition from largely open flow-through systems in coastal farms prior to the mid 1990s toward current practices focused on recirculation with minimal exchange have altered the risk of escapes, but it has likely been greatly diminished. There is currently no evidence that *L. vannamei* has established independent populations in U.S. waters, but the greatest risk that this could happen exists in Hawaii where the last and only escape was detected in 1994. Based on the facts that *L. vannamei* is a non-native species, escapes have been reported and the effects of interactions (both genetic and otherwise) with native shrimp species are unknown, exchanging aquaculture systems carry a "moderate" risk.

Risk of escaped fish to wild stocks rank:

Zero-exchange recirculating and inland systems:

Low Moderate High Critical

Exchanging:

Low **Moderate** High Critical

Criterion 3: Risk of Disease and Parasite Transfer to Wild Stocks

The risks for disease transfer between farmed animals and wild stocks is contingent on a number of factors: the potential for farming to amplify and retransmit disease to wild stocks, the likelihood of introducing pathogens to wild populations, the management of bio-safety risks and the susceptibility of wild stocks to infection. Here, we give an overview of the biological and historical information relevant to diseases affecting U.S. farmed shrimp, then examine the relative risks posed by different factors relevant to disease transfer.

Overview Information

Pathogens and Diseases affecting L. vannamei

Litopenaeus vannamei is known to be a vector for several viruses including *Baculovirus penaei* (BP), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Reo-like Virus (REO), Taura Syndrome Virus (TSV), White Spot Syndrome Virus (WSSV) and Yellow Head Virus (YHV). Of these, all but BP and REO are considered major penaeid shrimp viral pathogens in U.S. aquaculture operations (Dorf *et al.* 2005). In particular, WSSV can be highly lethal to farmed shrimp with mortality reaching 100% in some cases (APHIS 2007).

In addition to viruses, penaeid shrimp raised in aquaculture (including those raised in the southwestern U.S.) are known to carry a range of pathogens including bacterial, fungal, rickettsial, protozoan and metazoan infections (Lightner *et al.* 1983a, Lightner *et al.* 1983b, Lightner 1985, Lightner 1988, Brock and Lightner 1990, Brock 1992, Lightner 1993, Lightner 1996, Lotz 1997, Kautsky *et al.* 2000). Additionally, several noninfectious diseases exist that are caused by genetics, nutrition or extreme environmental conditions including toxins (Kautsky *et al.* 2000).

Currently, most U.S. shrimp farms reportedly use "disease-resistant" broodstock (discussed below). Furthermore, probiotics may be used on U.S. farms where the introduction of "friendly microbes" to farms during rearing has been shown to thwart harmful pathogens via competition (Moriarty 1998, Kautsky *et al.* 2000).

History of pathogen outbreaks in the U.S.

White Spot Syndrome Virus (WSSV)

Before November 1995, there were no documented cases of WSSV at U.S. shrimp farms: all previous outbreaks had been reported in Asia. In 1995, the first national occurrence of WSSV resulted in heavy losses to farms in South Carolina and Texas. Hawaii's first WSSV outbreak (Kaui'i Island) occurred in 2004 when the virus decimated the *L. vannamei* reared at Ceatech USA Inc., one of the largest farms in the state at that time (Hayworth 2004). A subsequent WSSV episode occurred at the same location (renamed Limaloa Farm) in 2008 (USMSFP 2008). Within three days of tissue samples from Limaloa Farm being sent for analysis, the Hawaii Department of Agriculture (HDOA) implemented an emergency quarantine prohibiting the movement of shrimp. The farm had reportedly already voluntarily halted shipments as soon as symptoms were first noticed (HDOA 2008).

Table 5. Biological summary of main shrimp viruses, with information on the presentation of the disease, transmissibility/mortality associated with outbreaks, and current geographic extent of the disease.

Common name	Abbreviation & Family	Description
White Spot Syndrome Virus (White Spot Syndrome Baculovirus Complex)	WSSV **Taxonomy**: Family = Nimaviridae, Genus = *Whispovirus*	**Virus**: WSSV is a rod-shaped double-stranded DNA virus. The virus has an outer lipid bi-layer membrane envelope, sometimes with a tail-like appendage at one end of the virion. **Presentation**: White spots on the shell of infected shrimp under scanning electron microscope appear as large dome shaped spots on the carapace measuring 0.3–3 mm in diameter. Smaller white spots of 0.02–0.1 mm appear as linked spheres on the cuticle surface. Chemical composition of the spots is similar to the carapace with calcium forming 80–90% of the total material. It has been suggested these spots derive from abnormalities of the cuticular epidermis. **Infection**: The disease is highly lethal and contagious, killing shrimp quickly. Outbreaks cause 100% mortality in most shrimp farm populations within three days. **Geography**: Currently known to be present in all shrimp growing regions except Australia.
Taura Syndrome Virus	TSV **Taxonomy**: First classified as a possible member of the family Picornaviridae. It was later reclassified in the Dicistroviridae family, genus *Cripavirus*. It currently belongs to that same family, but it is unassigned to any genus.	**Virus**: TSV is an RNA virus that mutates frequently. **Presentation:** Affected cells have bodies occupying large areas within the cytoplasm composed of an amorphous, granular, electron-dense matrix. **Infection**: Cumulative mortalities due to TSV in affected juvenile *L. vannamei* populations have ranged from 40 to 95% (Lightner 1999). It also severely affects *P. setiferus, P. stylirostris* and *P. schmitt.* **Geography**: Until 1998, it was considered to be a Western Hemisphere virus. The first Asian outbreak occurred in Taiwan. It has more recently been identified in Thailand, Myanmar, China, Korea and Indonesia where it has been associated with significant epizootics in farmed *L. vannamei* and *P. monodon* (Wikipedia 2009a). It has been recorded in the U.S. in Hawaii, Florida, Texas and South Carolina.
Yellow-Head Virus	YHV **Taxonomy**: May be a member of the order Nidovirales, the family Coronoviridae and possibly the genus *Torovirus*. More information about the replication strategy is needed to definitively place the virus in the appropriate genus and family within the order Nidovirales.	**Virus**: A pleomorphic enveloped virus with single stranded RNA primarily localized in the cytoplasm of infected cells. There is a long filamentous form of the virus prior to capsid and envelope formation (Gulf States Marine Fisheries Commission 2005). **Presentation**: Occurs in the juvenile to sub-adult stages of shrimp 5 to 15 grams in size. Affected shrimp exhibit light yellow coloration of the cephalothorax area and a generally pale or bleached appearance; they die within a few hours (Gulf States Marine Fisheries Commission 2005). **Infection**: Indications of disease are observed within two days of infection and generally 100% mortality occurs 3–9 days after infection (Lu *et al.* 1995). **Geography**: Yellow-head virus principally infects pond-reared black tiger prawns, *P. monodon*. It was first reported in Thailand (1990) but is known to infect and cause mass mortality in shrimp farming operations throughout southeastern Asia.

Taura Syndrome Virus (TSV)

Taura syndrome virus was first recognized internationally in farms near the mouth of the Taura River, Ecuador in June 1992. The first major outbreaks of TSV in the U.S. occurred in May 1994 on a *L. vannamei* farm on the island of Oahu, Hawaii; by October 1994, it was found at a facility in Florida, and by May 1995 it was present in Texas farms along the southern and central Texas Gulf coast (Overstreet *et al.* 1997). During the 1995 outbreak, dissemination of TSV was attributed to the movement of infected post-larvae and broodstock (APHIS 2004), although this assertion has been debated (Jaenike, June 2007). The United States Department of Agriculture reported another outbreak of TSV in 2004 in Texas. At that time, the Texas Parks and Wildlife Department placed quarantines on the affected facilities prohibiting water discharge and restricting shrimp movement (APHIS 2004). There has been no recurrence of TSV in Texas since (Treece 2008). Most recently, the Hawaii Department of Agriculture announced a TSV outbreak on a shrimp farm in Hawaii in 2007, and a quarantine order was issued. Effluent from this farm does not enter the ocean but is contained on site in basins (HDOA 2007).

Yellow-Head Virus (YHV)

There has been one incident of YHV infection in pond-reared juvenile *L. setiferus* in south Texas, reported in 1995. Nearby shrimp packing plants that imported and re-processed raw, frozen shrimp were the presumed source of the virus (Lightner 1996).

Risk of amplification

Shrimp farms, like most aquaculture operations, rear animals at close to carrying capacity. As such, there is always the potential for pathogenic organisms to amplify in the presence of artificially dense (physically close, potentially compromised conditions) host populations. The outbreaks described above are evidence that disease amplification does occur on U.S. shrimp farms.

Risk of transmission

All three native shrimp species can carry at least TSV without exhibiting the disease, and in theory, have the potential to act as vectors for transmission of diseases onto farms, as may other crustaceans such as crabs (e.g., Kanchanaphum *et al.* 1998). Therefore, pathogens from intake waters could transmit infection to farmed *L. vannamei*. Furthermore, "…no rules have currently been established to protect the farmed shrimp from feral or native shrimp populations, known to be carriers of Baculovirus and a White Spot-like virus" (Treece 2008).

There is limited information currently available with which to assess the risk of transmission of disease from shrimp farms to wild shrimp populations. The risk of transmission is based on a number of factors, few of which have received rigorous research. Issues needing consideration include, at least: a) the susceptibility of wild U.S. shrimp to foreign viruses, and b) the presence of mechanisms for transmission.

Viral susceptibility of wild U.S. shrimp species

In the Gulf of Mexico and the Western Atlantic Ocean, there are three main penaeid shrimp species, which are all commercially fished (Dorf *et al.* 2005): *Litopenaeus setiferus* (Linnaeus, 1767), *Farfantepenaeus aztecus* (Ives, 1891) and *Farfantepenaeus duorarum* (Burkenroad, 1939).

Table 6. Summary of the susceptibility of native U.S. shrimp species to viruses commonly causing outbreaks on international shrimp farms. Information taken from 1) Lightner *et al.* 1998, 2) Overstreet *et al.* 1997.

	Common shrimp farm virus		
Wild U.S. shrimp species	**WSSV[1]**	**TSV[2]**	**YHV[1]**
Litopenaeus setiferus	100% mortality	Can cause mortality	Infects, non-lethal in PLs. Mortality rates not documented.
Farfantepenaeus aztecus	27% mortality	Cannot cause mortality	Infects, non-lethal in PLs. Mortality rates not documented.
Farfantepenaeus duorarum	0% mortality	Cannot cause mortality	Infects, non-lethal in PLs. Mortality rates not documented.

White spot syndrome virus (WSSV)

Transmission of WSSV is mainly through oral ingestion and waterborne routes on farms (horizontal transmission) and vertical transmission (from infected mother shrimp to offspring) in the case of shrimp hatcheries (Wikipedia 2009b).

When postlarval and juvenile stages of the three species of wild U.S. penaeid shrimp (*Fenaeus aztecus, F. duorarum* and *L. setiferus*) were fed tissue infected with WSSV from Asia, specimens exhibited 100% cumulative mortality in *F. setiferus,* 27% cumulative mortality in *F. aztecus*, and no signs of infection and 0% cumulative mortality in *P. duorarum* (Lightner *et al.* 1998).

Taura Syndrome Virus (TSV)

Taura syndrome virus has the potential to infect or be carried by native shrimp species from U.S. waters. It has been experimentally transmitted to wild shrimp species via injection, ingestion and incorporation of the infective material into dietary brine shrimp (Overstreet *et al.* 1997).

Experimental studies have demonstrated that *L. setifuerus* can be killed by TSV, but not *F. aztecus* or *F. duorarum*. Infections in *L. setiferus* take longer to cause mortality than in *L. vannamei* and kill a smaller percentage of *L. setiferus* hosts. Dosage and genetic differences in stocks appear to affect differences in mortality, regardless of which native species acts as a host. For example, a Texas stock of *L. setiferus* was less susceptible to infection and mortality than stocks from Mississippi and South Carolina (Overstreet *et al.* 1997). Therefore, it is theoretically possible that TSV could be introduced to local populations via escapees from aquaculture operations (JSA 1997, Overstreet *et al.* 1997). Other wild crustacean populations, including those fished commercially, may also be at risk from introduced viruses (Dorf *et al.* 2005).

Yellow-Head Virus (YHV)

Yellow-head virus has been shown experimentally to infect and cause serious disease in juvenile stages of the American penaeids *L. setiferus*, *F. aztecus* and *F. duorarum*. Under experimental conditions, postlarval shrimp appear to be resistant to YHV (Lightner *et al.* 1998).

Mechanisms for pathogen transmission

Mechanisms that have been suggested to mediate transfer of shrimp farm viruses in different systems include direct interaction between infected and non-infected shrimp via escapes, inter-pond foraging by avian predators, crab movement, the passive diffusion of water between pond walls and the release of infected water into coastal systems.

Even for the principal viruses that threaten shrimp farms (WSSF, TSV and YHV), research to understand how viruses are transferred between hosts is in its infancy. For example, it is not clear whether most shrimp farm viruses can survive in water outside of host organisms. Recent research has shown zooplankton may be a vector for the transmission of WSSV (Mang *et al.* 2007, Zhang *et al.* 2008). In this case (and if the same were true for other shrimp viruses), uptake by phytoplankton, followed by ingestion by zooplankton is a mechanism that could operate in conjunction with avian predation, crab movement or the passive diffusion of water to foster disease outbreaks within and between farms.

In systems such as those used in the U.S., where disease outbreaks are infrequent, rapidly quarantined and farms occur at low densities, viruses are most likely to be introduced via: 1) imported commodity shrimp from supermarkets, 2) commodity shrimp processing plant wastes (solids and liquid wastewater effluent), and 3) shrimp used as bait (both imported commodity shrimp and domestic) (Treece 2008).

It is standard commodity shrimp farming practice to harvest and sell the crop when viral outbreaks are detected. This is acceptable from a human health perspective because consumption of shrimp viruses poses no threat to people. However, it also means that shrimp viruses enter coastal waters from restaurant waste, home waste, seafood suppliers and processing plants. Commodity shrimp that are not consumed may be used as bait or may end up deposited in landfills/other refuge sites, later to be transmitted to natural water bodies by birds, insects, animals or other means (Overstreet *et al.* 1997).

Risk of retransmission

The issue of disease retransmission from wild shrimp back to farms is largely unstudied. All three native shrimp species can carry at least TSV without exhibiting the disease and, in theory, have the potential to act as vectors for retransmission, as may other crustaceans such as crabs (e.g. Kanchanaphum *et al.* 1998). Therefore, pathogens from intake waters could theoretically retransmit infection to *L. vannamei* on farms, although we could find no reports of such occurrences. Furthermore, "…no rules have currently been established to protect the farmed shrimp from feral or native shrimp populations, known to be carriers of Baculovirus and a White Spot-like virus" (Treece 2008).

Evidence of pathogen introductions and establishment

There is evidence that in 1997 and 1998, wild white and brown shrimp (*Litopenaeus Setiferus* and *Farfantepenaeus aztecus,* respectively) were detected with WSSV off the coast of Texas (but not TSV or other pathogens) (Dorf *et al.* 2005). The WSSV present in wild stocks may have come from farm effluent or escapees. It could also have come from the multitude of non-farm related vectors listed above. Subsequent surveys checking for the presence of farm viruses in wild stocks from 1997–2000 produced no evidence of diseased animals in the wild (Dorf *et al.* 2005). A similar study surveying wild shrimp along the Gulf of Mexico in areas adjacent to shrimp farms (in Mexico) also did not show evidence of diseased animals (Chavez-Sanchez *et al.* 2007).

There was a second report of WSSV in native *L. setiferus* stocks off Mississippi in the Gulf of Mexico in 2004 (Treece 2008). We could find no evidence of systematic disease surveys of wild penaeid shrimp after 2004.

This indicates that in at least one instance of an introduction, there was no evidence that shrimp farm viruses became established in wild U.S. stocks. The effects of a second recorded introduction remain unknown. Further surveys are also needed to know whether WSSV has become established in U.S. stocks of other crustaceans such as crabs and crayfish.

Biosecurity: Pathogen resistant/genetically modified organism strains

Multi-generational selection for desirable culture traits, including disease resistance, has been possible in *L. vannamei* because this species grows and breeds easily in culture. Selective breeding of other species, such as *Penaeus monodon*, has not been as successful due to the difficulties of captive reproduction (Conklin 2003).

The use of disease-free or disease-resistant strains of shrimp in U.S. aquaculture reduces the risk transferring pathogens from culture to the surrounding environment, and the use of domesticated specific pathogen-free (SPF) and specific pathogen resistant (SPR) shrimp stocks[6] has been called the most important aspect of U.S. shrimp aquaculture's biosecurity programs (Lightner 2005).

All shrimp farms on the U.S. mainland reportedly stock TSV-resistant strains exclusively. The only U.S. locations where non-TSV-resistant shrimp are stocked are in Hawaii, where a few farms still use them. There is currently no TSV in Hawaii, and there are no major seafood processing plants in the Hawaiian Islands that could potentially function as junctions for disease transfer.

[6] Developed by the Oceanic Institute, Hawaii under the U.S. Marine Shrimp Farming Program (USMSFP)

The Oceanic Institute is currently attempting to develop genetically modified shrimp with increased disease resistance (Oceanic Institute 2008). Research is focused on the manipulation of antimicrobial genes. To date, the Oceanic Institute has successfully produced transgenic shrimp carrying the cecropin gene, which should confer pathogen resistance. Future efforts will focus on producing an F1 generation of transgenic shrimp that will then be tested for resistance to a suite of viral, bacterial, fungal, and protozoan pathogens. The commercial use of genetically modified livestock remains controversial.

Managing for disease and quarantine procedures

Since disease management on farms is relevant to exchanging farms, and because 99% of production from exchanging farms occurs in Texas, we provide disease management information from this state.

"In 1997 the Texas State Legislature requested Texas Department of Agriculture, Texas Commission on Environmental Quality (TCEQ) and Texas Parks and Wildlife Department (TPWD) to develop a Memorandum of Understanding for the coordination of the agencies on aquaculture regulatory matters, which was implemented in 1999…. Rules adopted by the regulatory agencies have been successful in the response to disease outbreaks in pond-raised shrimp…. Operators must immediately notify TPWD officials regarding any mortalities of farm raised shrimp; hatchery operators are required to have their shrimp certified monthly during operations as disease free by a department-approved disease specialist (Texas Veterinary Medical Diagnostic Lab); and operators are required to show they possess or have applied for the appropriate TCEQ discharge permit. All farms have cooperated with the agencies and progress has been made in controlling diseases and …cleaning up discharges."

Biologists from the TPWD can quarantine diseased shrimp and stop discharges on farms until the threat to native shrimp has passed. State rules require cessation of discharge during the quarantine period, except in accordance with an Emergency Plan approved by the TPWD and following approval of the executive director. The executive director can lift the prohibition on discharge to allow for implementation of the facility's Emergency Plan, in accordance with a permit from the TPWD, following the lifting of the quarantine by the TPWD.

Status of potentially affected wild shrimp

The status of stocks is relevant where there is the potential for pathogens to move via exchanging farms into coastal waters. The risk to wild stocks from disease will usually be less severe than the risk to farm populations because wild animals avoid the amplification risks inherent to the high stocking densities used in culture. Furthermore, shrimp are prolific and short-lived, which may make them somewhat resistant to catastrophic events. Wild populations will be more susceptible when they are already at risk due to depressed numbers or other factors that compromise breeding potential, growth or survival.

In the U.S., brown and white shrimp are the main commercial harvests of warmwater shrimp; neither is overfished, nor is overfishing occurring (Table 7) (Cascorbi 2004). In the Gulf of Mexico, brown shrimp are the principle catch, followed closely by white shrimp. The Gulf of

Mexico fishery captures lesser amounts of pink shrimp along with small volumes of rock shrimp, royal red and seabobs (Council 2008). In South Carolina, white shrimp are the principal catch. In 2006, Amendment 13 capped the number of vessels in the federal fishery and established a ten-year moratorium on the issuance of commercial shrimp vessel permits. Reporting and certification of landings are now required and will continue to be until the end of the ten-year moratorium.

In the U.S., exchanging farms occur principally in Texas, with individual facilities in South Carolina and Hawaii (Appendix IV). To date, there has been no obvious effect of disease transmission from farms on wild stocks in the Gulf of Mexico (Chavez-Sanchez *et al.* 2007). Shrimp are also an annual species with high fecundity, and so may have less propensity to host pathogens because of high population turnover.

Table 7. Official status of commercially harvested U.S. shrimp stocks (NOAA 2009). Numbers shown correspond to the last quarter of 2008. Website last updated Feb 2, 2009.

Latin	Common name/ Fishery	Jurisdiction/ Location	Status
Farfantepenaeus. Aztecus	Brown shrimp	SAFMC	No overfishing; Not overfished
Syconia brevirostris	Brown rock shrimp	SAFMC	No overfishing; Not overfished
Farfantepenaeus duorarum	Pink shrimp	SAFMC	Not subject to overfishing; Overfished
Litopenaeus setiferus	White shrimp	SAFMC	No overfishing; Not overfished
Farfantepenaeus aztecus	Brown shrimp	GMFMC	No overfishing; Not overfished
Syconia brevirostris	Brown rock shrimp	GMFMC	No overfishing; Not overfished
Farfantepenaeus duorarum	Pink shrimp	GMFMC	Subject to overfishing, B/BMSY< 80%; Not overfished
Litopenaeus setiferus	White shrimp	GMFMC	No overfishing; Not overfished
Hymenopenaeus robustus	Royal Red shrimp	GMFMC	No Overfishing; Not overfished
Xiphopenaeus kroyeri	Sea bobs	GMFMC	Neither defined
Heterocarpus laevigatus	Smooth nylon shrimp	Hawaii	No regular commercial fishery

Synthesis

The use of disease-resistant strains coupled with strong management practices that have shown at least moderate capacity to contain pathogenic outbreaks alleviates the risk of disease transfer to wild U.S. shrimp stocks. However, there is a proven capacity for infectious viruses known to have lethal effects on wild native species to be transmitted from *L. vannamei* to all three commercially fished U.S. farmed shrimp populations, although no known examples of such have occurred *in situ*. Disease transfer to wild stocks is also possible and currently most likely from processing facilities, restaurants or other venues that receive commodity shrimp from Asia. Therefore, we have not concluded that there is evidence of disease transfer from farm animals to wild stocks. Surveys of wild shrimp in the Gulf of Mexico have also not shown evidence that viruses associated with shrimp aquaculture have become established in wild, native shrimp or crustacean stocks.

Risks to wild stocks vary directly with production method where there is no risk from zero-exchange and covered farms, low risk from inland, contained ponds (only via avian predation) and moderate risk of pathogen transfer from exchanging coastal farms. Where exchange of water occurs, escaped animals, waterborne vector organisms and/or pathogens would all theoretically have the potential to encounter animals from wild stocks. In the U.S. industry, exchanging farms occur predominantly in Texas, but at least one such facility also occurs in each of South Carolina and Hawaii.

Since 87% of U.S. production comes from exchanging farms, the overall industry ranks "moderate" for risk of disease transfer to wild stocks.

Risk of disease transfer to wild stocks rank:

Zero-exchange and inland ponds:

Low Moderate High Critical

Exchanging:

Low **Moderate** High Critical

Criterion 4: Risk of Pollution and Habitat Effects

Shrimp farms in the U.S. usually operate using either seawater in coastal pond cultures or low-salinity groundwater in inland pond cultures, both farmed semi-intensively (Moss 2002, Stickney June 2007). There are two zero-exchange recirculating farms in the U.S.—Marvesta Shrimp Farms in Maryland ships in tankers of water from the Atlantic, filters it and treats it with ultraviolet light to remove bacteria, viruses and algae (Marvesta Shrimp Farms 2009) and Seafood Systems in Michigan creates its own saltwater via a mix similar to what can be purchased from aquarium stores (Allen April 2009). These farms can be considered super-intensive (Van Wyk *et al.* 2000, Samocha *et al.* 2001). Siting for aquaculture is generally regulated at the local level, with the need to respect statewide guidelines on sensitive habitats and siting.

Inland pond systems

Inland shrimp farming is generally thought to have substantial advantages from an environmental perspective, primarily due to the reliance on best management practices, including having ponds confined by walls and clay soils with low filtration. The key disadvantage of inland shrimp farming is the possibility that salinization of local water sources may result (Boyd 2001). The salinity of the water used in Alabama, Arizona and Texas is low and in Florida farmers typically use hard freshwater (Moss 2002). The perceived advantages of inland farming are considered to outweigh the possible risk of salinizing local waters. These advantages include reduction of disease introduction from waterborne and airborne vectors, more efficient water use, the elimination of damage to coastal ecosystems and economic benefits due to the diversification of land use for food production (Boyd 2001, Alava 2004).

Effluent water treatment

Inland farming systems often use effluent water to irrigate agricultural crops such as olive trees and durum wheat (Moss 2002). In Arizona, the salinity of pond water is low (Whetstone *et al.* 2002) and shrimp aquaculture has been paired with existing agricultural irrigation for crops like wheat, sorghum, olives and cotton (McIntosh and Fitzsimmons 2003). Nutrient-enriched shrimp farm effluent has been found to supply 20–30% of the nitrogen necessary for wheat production with an average salinity of only 0.2 ppt higher than the local well water flowing onto farms (McIntosh and Fitzsimmons 2003).

Ponds that do not use their effluent for irrigation generally discharge into freshwater streams and shallow freshwater aquifers. Any farm directly discharging water is subject to Effluent Limitation Guidelines developed by the Environmental Protection Agency and Best Management Practices have been developed to improve the quality of effluents (USDA-Natural Resources Conservation Service and Auburn University 2003c). These practices aim to maximize the capability of ponds to assimilate wastes and assure that farm operations are conducted in a responsible manner. Examples of such practices include storing water in a reservoir when it is drained for harvest and re-using it for the next crop, discharging into a settling basin to minimize suspended solids and then discharging slowly (USDA-Natural Resources Conservation Service and Auburn University 2003a)[7], and monitoring streams for compliance with EPA in-stream criteria for chlorides (USDA-Natural Resources Conservation Service and Auburn University 2003c).

Local and regional effluent effects

Incidents of salinization adjacent to inland aquaculture farms have occurred in the past with inland shrimp farming. Near one farm in Alabama, elevated salt concentrations were found in a local stream flowing through the farm as well as in the shallow aquifer beneath it when culture ponds were partially drained for harvesting. The elevated salt level exceeded 230 mg/L, the maximum concentration allowed in regulations set by the Alabama Department of Environmental Management. More frequent reuse of water and more gradual release of pond effluents during shrimp harvest has the potential to reduce spikes in stream and aquifer chloride concentrations, keeping levels in compliance with regulations (Boyd *et al.* 2006). This type of effluent effect is only known to have occurred as a single event in a single state, and is therefore not considered a "substantial" risk.

Sensitivity of habitat and extent of operations

Inland shrimp farms are generally situated on previously developed agricultural land and are perceived as economically beneficial by way of land diversification (Boyd 2001).

Zero-exchange recirculating systems

There are currently two "super-intensive" shrimp farming operations located inland using zero-exchange recirculating systems. These operations have eliminated the risks of pollution via effluent by not discharging any wastewater. Seafood Systems Inc. of Michigan has estimated that three pounds of inorganic waste are collected per month from their farm, and reported to use it as fertilizer on their garden (Allen April 2009). Marvesta Shrimp Farms of Maryland report sterilizing and re-incorporating all waste produced (Fritze December 2008).

Exchanging systems

Traditionally, coastal shrimp aquaculture operations pose greater environmental concerns compared with inland farms. Generally, these problems include the destruction of coastal wetlands during pond construction, hyper-nutrification of estuarine ecosystems by culture pond effluent, entrainment of estuarine biota and the impacts of shrimp farm chemicals on estuarine systems (Hopkins *et al.* 1995). During the 1980s and early 1990s, the majority of shrimp farms were operated on flow-through systems, with large percentages of water exchanged daily. Most farms in the U.S. now operate on largely recirculating systems, modifying their farms slightly to allow for the reuse of culture water instead of discharging it

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[7] Water discharged from settling basins is also lower in nitrogen, phosphorus and biochemical oxygen demand than water entering them and the basins allow for pH adjustment (USDA-Natural Resources Conservation Service and Auburn University 2003b).

(Treece 2002), which significantly reduces many of these risk factors. Daily exchange rates have been cited at 1–3% (Gregg March 2009).

Shrimp farm siting and effluent regulation in the U.S. is more rigorous than in other countries. For example, in Texas:

"Commercial shrimp-culture facilities in the coastal zone must obtain a site-specific wastewater discharge permit from Texas Natural Resource Conservation Commission (TNRCC) Texas Agriculture Code § 134.013. Prior to issuance of the permit, an applicant must provide an environmental report on the conditions at the proposed site. The report must assess potential impacts on sensitive aquatic habitats, significant impacts related to the construction or operation of the facility and any mitigation actions proposed by the applicant. The report must be provided to TNRCC and the Texas Department of Agriculture (TDA). TNRCC must consider this report before making a determination on the wastewater discharge permit, and TDA will only require the report if the proposed activity will occur within the coastal zone, which is defined by the TPWD. TNRCC is required to establish guidelines for this report and its requirements. Licenses are valid for two years." (Fletcher and Weston 1999)

Effluent water treatment

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. The EPA states that all concentrated aquatic animal production facilities must regularly maintain production and wastewater treatment systems. These NPDES permits state how much waste an aquaculture operation is allowed to discharge according to levels of ammonia, dissolved oxygen and total suspended solids. Permits are tailored to each farm specifically, depending on the characteristics of the water body into which the farm is discharging effluent (Jaenike, June 2007). In Texas, legal effluent requirements had a notable effect on management practices: farms built retention ponds and some reduced discharged solids and ammonia by over 98% (Hamper 2001). Retention ponds act as settling basins and are considered here to provide partial treatment of effluent water before it is discharged.

Several large exchanging farms (e.g., Harlingen, Bowers) report the use of constructed wetlands to treat effluent before discharge. Constructed wetlands are ecologically beneficial, low-cost treatment alternatives that have been proven capable of reducing suspended solids, biochemical oxygen demand (BOD), nitrogen, phosphorus and heavy metals from wastewater and act as recirculation filters, thus reducing the impact of effluent on local water bodies (Tilley *et al.* 2002).

Local and regional effluent effects

No information could be found showing evidence of effluent effects from coastal shrimp farms, but there is a theoretical risk of negative effects. Permitting should, in theory, assure that coastal pond effluent does not cause environmental damage. However, the ultimate effectiveness of permitting remains unknown.

Sensitivity of habitat and extent of operations

Coastal shrimp farms are sometimes located on coastal marshlands or riparian habitats, which, under the RAMSAR Convention's international definition, are a form of wetland. RAMSAR defines wetlands as:

"...areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." (Article 1.1)

Currently, farms are not sited on many of the habitats encompassed by this definition because, in the United States, conversion of particular types of wetlands to shrimp ponds is nearly impossible due to current federal regulations for wetland protection (Hopkins *et al.* 1995). Section 404 of the Clean Water Act is the primary vehicle for federal regulation of some of the activities that occur in wetlands (Votteler and Muir 2002) and EPA guidelines state that:

> "…degradation or destruction of special aquatic sites, such as filling in wetlands, is considered to be among the most severe environmental impacts covered by the guidelines…."

Nonetheless, it is understood that some farming activities are water-dependent so it is possible to obtain permission to construct water-pumping stations and effluent canals as long as wetland infringement in minimized. Wetland creation can be required to mitigate minor wetland infringements (Hopkins *et al.* 1995). Because wetlands are an area of high sensitivity, we have taken into account even minor infringements on this type of habitat, but further habitat destruction due to creation of new coastal shrimp farms is of little concern, unlike in some foreign countries lacking strict regulations regarding the destruction of coastal environments.

Currently, there is little expansion of the saltwater shrimp farming industry in the U.S. as the general trend is toward diversification and decreasing operations (Jaenike, June 2007). Use of recirculation techniques along the coast of Texas, where the largest aquaculture production of shrimp in the U.S. occurs, has addressed many effluent and pollution problems.

Water reuse technologies have reduced needs in Texas from over 4,500 gallons for each pound of shrimp produced in the early 1990s to 300 gallons per pound produced currently (Treece 2008). Furthermore, newer technologies being researched by the Oceanic Institute and the USMSFP have managed to reduce water use to less than 50 gallons for each pound of shrimp (Oceanic Institute 2008).

The historical siting of farms on habitat falling within broad definitions of wetlands, despite strong BMPs and protective current permitting, gives this factor a "high" risk ranking.

Synthesis

Excellent effluent management associated with zero-exchange recirculating systems and with inland operations that infrequently release partially treated effluent, or recycle it for land-based agricultural applications, collectively result in a rank of “low” risk for pollution and habitat effects. However, exchanging operations that discharge partially treated effluent, and may have been built in areas that were formerly wetlands or marshland, pose a “moderate” risk.

Risk of pollution and habitat effects rank:

Zero-exchange recirculating and inland systems:

Low Moderate High

Exchanging:

Low **Moderate** High

Criterion 5: Effectiveness of the Management Regime

Laws and licensing

The U.S. aquaculture industry is regulated by federal, state and local laws. Responsibility for enforcing environmental laws and regulations is divided among Environmental Protection Agency (EPA) headquarters offices, as well as regional, state and local EPA offices. The EPA is responsible for enforcing federal laws such as the Clean Water Act, which authorizes the National Pollutant Discharge Elimination System (NPDES) permit program that controls water pollution by regulating point sources that discharge pollutants into federal waters. These NPDES permit programs are administered by authorized states (EPA 2009b).

In 2004, the EPA finalized guidelines pertaining to the discharge of wastewater from concentrated aquatic animal production operations in response to a lawsuit filed by the Natural Resources Defense Council:

> "In October 1989, the Natural Resources Defense Council and others sued EPA claiming the Agency had failed to comply with the Section 304(m) planning process required by the Clean Water Act. In January 1992, plaintiffs and EPA agreed to a settlement that established a schedule for EPA to promulgate effluent limitation guidelines for 11 specific industrial categories and for eight other categories to be determined by the Agency. EPA selected the concentrated aquatic animal production industry as one of those 11 categories. The revised consent decree requires the EPA to take final action by June 30, 2004." (EPA 2009a)

To implement EPA guidelines regarding effluent discharge of concentrated aquatic animal production, all applicable facilities must:

- Prevent discharge of drugs and pesticides that have been spilled and minimize discharges of excess feed;
- Regularly maintain production and wastewater treatment systems;
- Keep records on numbers and weights of animals, amounts of feed, and frequency of cleaning, inspections, maintenance and repairs;
- Train staff to prevent and respond to spills and to properly operate and maintain production and wastewater treatment systems;
- Report the use of experimental animal drugs or drugs that are not used in accordance with label requirements;
- Report failure of or damage to a containment system; and
- Develop, maintain and certify a Best Management Practice plan that describes how the facility will meet the requirements.

The rules also require flow-through and recirculating discharge facilities to minimize the discharge of solids such as uneaten feed, settled solids and animal carcasses.

A reduction in the discharge of biochemical oxygen demand and nutrients of approximately 300,000 per year was projected. The estimated cost of full compliance for all facilities was

$1.4 million per year. Benefits of compliance include reduced ecosystem stress and improved recreational access (EPA 2009a).

Permitting and monitoring

There are three main types of permits issued for aquaculture in the U.S.: siting, discharge and biosecurity (exotics/disease). Siting permits do not require regular data collection, while discharge and biosecurity-related permits have metrics that require ongoing monitoring.

Siting licenses

Licensing to control the siting, number and size of shrimp farms prevents the degradation of wetlands, as discussed previously in the 'sensitivity of habitat and extent of operations' section of Criterion 4, and is governed by the Section 404 regulatory program of the Clean Water Act. Section 404 regulates the discharge of dredged or fill material into the nation's waters and establishes requirements that must be met. Permits can be issued to private parties and governmental agencies for construction in wetlands, streams, rivers and other aquatic habitats. The United States Army Corps of Engineers (ACE) administers Section 404 under the overview of the EPA. The ACE is the agency that issues permits related to siting. Figure 13 gives an overview of the review process for a permit request.

The United States Fish and Wildlife Service is responsible for investigating the nature of potential fish and wildlife impacts in the Section 404 permitting process (Holmberg 1998). In many states, administration of the Section 404 program is a cooperative effort between the ACE and an approved state coastal zone management program (Hopkins *et al.* 1995). The state programs were founded by and are funded through the Coastal Zone Management Act (CZMA), although state guidelines may be more restrictive than the CZMA federal statute (Hopkins *et al.* 1995).

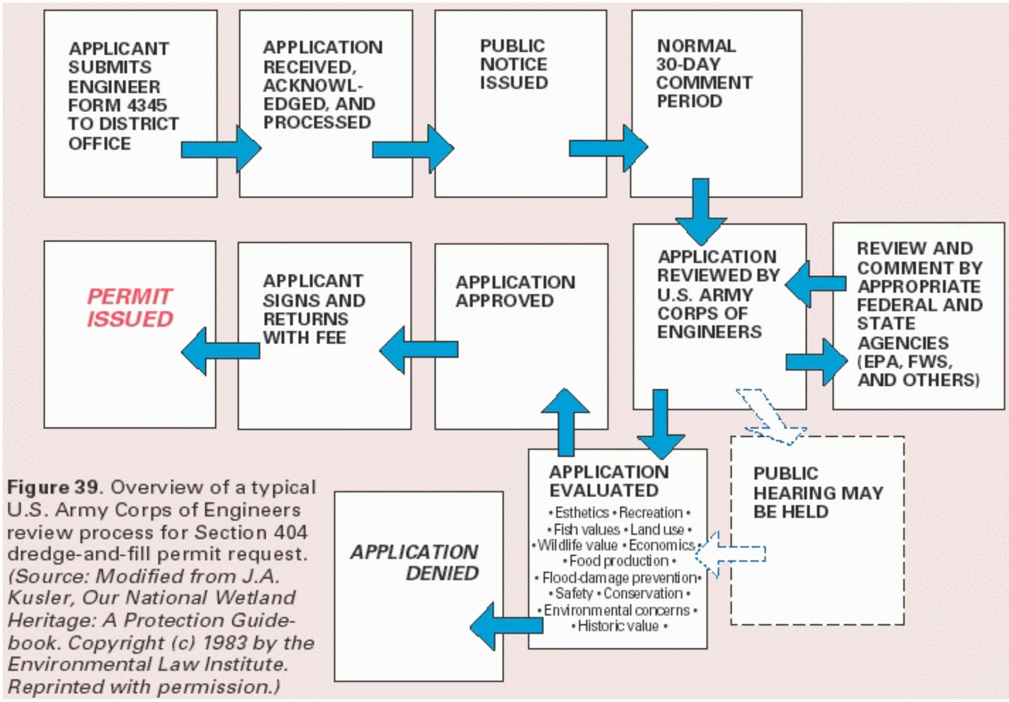

Figure 13: Overview of a typical U.S. Army Corps of Engineers review process for a Section 404 dredge-and-fill permit request (Votteler and Muir 2002).

In Texas, coastal aquaculture is regulated by up to 17 different agencies (Treece 2005). Among these agencies, the Texas Parks and Wildlife Department is tasked with siting:

> "…establishing guidelines for the identification of sensitive aquatic habitat within the coastal zone. These sensitive habitat guidelines provide an outline for the Site Assessment Report, which is required for new and expanding commercial shrimp facilities located within the coastal zone. The Site Assessment Report must assess potential impacts on sensitive aquatic habitats, significant impacts related to the construction or operation of the facility and any mitigation actions proposed by the applicant. TCEQ must consider the Site Assessment Report before making a determination on the wastewater discharge permit."

No information could be found regulating the stocking densities employed by shrimp farmers in the U.S, however, "appropriate" stocking densities are referred to in some Best Management Practices documents (Boyd *et al.* 2008), and for ponds with high stocking densities, additional practices are recommended (Howerton 2001).

Discharge permits

At the state level, discharge regulations are monitored and enforced with regularity during production. In Texas, effluent quality is monitored by the farmers and results are submitted to the Texas Commission for Environmental Quality (TCEQ). Discharge permits are determined by the TCEQ permit writers. Monitoring requirements are unique to each farm and contingent on production volumes (see Table 8 footnotes): more frequent monitoring activities are required on farms that produce more than 100,000 lbs of harvest per year.

The general permit to discharge wastes for Aquatic Animal Production facilities (including Concentrated Aquatic Animal facilities) states that the parameters subject to monitoring are flow, total suspended solids, inorganic suspended solids, total residual chlorine and pH (Table 8). Additional monitoring is required to measure dissolved oxygen, carbonaceous biochemical oxygen demand and ammonia nitrogen if the facility is discharging into perennial streams. (Texas Commission on Environmental Quality 2006). Information obtained from monitoring must be submitted to the TCEQ's Enforcement Division at intervals specified in the farm's individual discharge permit. While farm-specific permits are not publicly available without special request, interviews with Bowers Shrimp Farm, a Texas shrimp farm representative of large U.S. producers, indicated that their facility submits results weekly and that TCEQ inspects their sites at least once per year.

Table 8. Numerical effluent limitations applicable to all shrimp farms in Texas by the Texas Commission for Environmental Quality.

Parameter	Daily average limit	Daily maximum limit	Sample type	Monitoring frequency[1]
Flow (MGD)	Report	Report	Estimate/Meter	1/day
Total suspended solids	N/A	90 mg/l	Grab	1/month
Inorganic suspended solids	N/A	Report (mg/l)	Grab	1/month
Total residual chlorine	N/A	0.1 mg/l	Grab	1/day[2]
pH (standard units)	6.0 minimum	9.0 maximum	Grab	1/week

[1] Aquatic animal production facilities that discharge less than 30 days per year or produce less than 100,000 lbs harvest weight per year only have to monitor these parameters once every six months, except for flows that must be measured daily.
[2] Monitoring for total residual chlorine is required only when the effluent being discharged has been chlorinated.

For other states producing shrimp, the state monitors the water quality of discharges once every month while farms are in operation. Regulations for Parks and Wildlife Departments are monitored by biologists, while wardens from the same agency are responsible for enforcement. Reforms to state-level legislation governing aquaculture occur every two years, but in Texas the TCEQ has jurisdiction to modify the code via public hearings at any time without waiting for a formal session in the legislature (Treece 2009a).

The enforcement and compliance history of U.S. shrimp farms with respect to EPA regulations (e.g., the Clean Water Act) is based on data from the Permit Compliance System (PCS), a system that has been used since 1974, and from the modernized version of the PCS, the ICIS-NPDES (Integrated Compliance Information System—National Pollutant Discharge Elimination System) and can be found at:

http://www.epa-echo.gov/echo/

Biosecurity permitting and disease prevention

Biosecurity measures, including disease prevention, are regulated by state agencies and require regular monitoring. In Texas, farms culturing *L. vannamei* are required to have an Exotic Species Permit, and in order to obtain this permit, the Texas Parks and Wildlife Department (TPWD) must conduct an inspection of the facility to examine the effluent discharge system and ensure that potentially harmful exotic species are unable to escape. These permits must be renewed annually, so this particular inspection occurs at least once a year but may occur more frequently as additional inspections are required if the farm modifies its facilities by, for example, creating additional ponds or modifying the effluent discharge system.

To prevent disease outbreaks, Exotic Species Permit holders must complete a weekly clinical analysis checklist and must submit a synopsis of these checklists to the TPWD every month. If a farmer wants to exchange water or harvest, the TPWD must be notified so that a shrimp inspection can be conducted. The initial inspection is usually conducted within 6–8 weeks of stocking and is either performed by a TPWD-approved examiner or the farmer may submit samples to an approved diagnostic laboratory for disease examination (Juan and Adami Jr 2003). If a farm is discharging water continuously, shrimp inspections will occur once every two weeks (Juan, August 2009). If disease results are negative, a report must be submitted to TPWD before approval for discharge can be granted; if they are positive, a quarantine will be imposed for a specific time period depending on the disease (Juan and Adami Jr 2003).

South Carolina has similar documentation available describing the permitting process of shrimp farms, which includes language detailing disease management. Permits are issued by the director of the Office of Fisheries Management (OFM) and are administered by the Fisheries Permitting Office. Components of the permit include statements describing conditions related to quarantine, reporting, inspections, compliance and emergency orders. The permit requires an operation plan that includes a non-negotiable disease management contingency plan. Any source of shrimp stock must be approved by South Carolina’s Department of Natural Resources (DNR) and in its evaluation, the DNR will consider the facility’s biosecurity characteristics, water sources and treatment, disease history and disease testing protocol, among other things. Biologists and compliance officials of the DNR monitor compliance with specifications outlined in the permit via site visits, facility inspections, log book reviews, receipt of and response to written correspondence with the permittee and assurance of quarantine, when required (South Carolina Department of Natural Resources 2002).

The United States Department of Agriculture is responsible for the National Center for Animal Health Emergency Management, which controls the Emergency Management Response System, but emergency measures are often implemented via local authorities. For example, the Hawaii Department of Agriculture issued a quarantine order on a shrimp farm in 2007 when TSV was detected by the Aquaculture Development Program (HDOA 2007). Biosecurity protocols in the U.S. are considered to have the highest standards worldwide (Ostrowski, June 2007).

Better Management Practices

In addition to the variety of permits required by different government agencies, the EPA requires concentrated aquatic animal producers to develop Best Management Practices (BMPs) to describe how facilities will meet the set requirements of their guidelines. The United States Department of Agriculture Natural Resources Conservation Service (NRCS) has extensive BMPs that are publicly available online for inland aquaculture including "Managing Ponds for Inland Culture of Marine Shrimp" (USDA-Natural Resources Conservation Service and Auburn University 2003c). Since inland and closed systems have not been found to have significantly adverse environmental impacts, their BMPs are assumed to be effective. Hawaii has developed its own set of BMPs that address water quality, site selection, farm operations and effluent management (Howerton 2001). However, no information could be found to attest to the direct effectiveness of BMPs in Hawaii or on exchanging farms in the U.S. Therefore, the effectiveness of BMPs is deemed unknown.

Therapeutics

Approved drugs for use in aquaculture are set by the Food and Drug Administration, and rules are enforced via the Center for Veterinary Medicine.

Drugs approved for penaeid shrimp culture in the U.S. include (by product name and supplier): Parasite-S, Western Chemical Inc; Formalin-F, Natchez Animal Supply Co. and Formacide-B, B.L. Mitchell Inc. All three include the drug formalin and are used to control protozoan parasites (species of the family *Bodo, Epistylis* and *Zoothamnium*). In tanks, 50-100 µL/L is permitted up to four hours daily; in earthen ponds, 25 µL/L is permitted as a single treatment. These treatments cannot be used if the water is warmer than 80 °F, if there is a heavy phytoplankton bloom or if dissolved oxygen is less than 5 mg/L. Ponds may be retreated in 5–10 days if needed (FDA 2008). Guidelines for chemical use also exist in BMPs (Boyd *et al.* 2008).

A list of FDA-approved drugs for aquaculture can be found at: http://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/ucm132954.htm

State regulations may be more specific than federal regulations in the management of therapeutics. In Texas, regulations state that if any drugs, medications or chemicals approved by the EPA or the FDA have been used, water must be diluted, held for a specific time or neutralized prior to discharge as directed on the product label or as necessary to comply with state regulations relating to Texas Surface Water Quality Standards (cite general permit doc).

Predator control

Little information could be found on the use of predator control techniques. One document was found mentioning the use of screens to prevent the introduction of predators via inflow (AquaNIC 1993). Harlingen Shrimp Farms reported that their predator controls are "limited mainly to scare-away methodologies." Better Management Practices advise aquaculturists against killing birds (Boyd *et al.* 2008).

Expansion of industry

The conversion of wetlands to shrimp ponds in the U.S. is now nearly impossible due mainly to federal regulations for wetland protection (Hopkins *et al.* 1995). It is most likely that any expansion of shrimp aquaculture in the U.S. will take place within the inland/zero-exchange recirculating sector. The aquaculture policy of the U.S. Department of Commerce (DOC) states that aquatic foods shall be produced in an environmentally responsible manner with a specific objective (by the year 2025) to develop aquaculture technologies to improve production and safeguard the environment, emphasizing where possible those technologies that employ pollution prevention rather than pollution control techniques (U.S. Department of Commerce 1999). The creation of a single comprehensive federal policy that could provide holistic regulation for aquaculture and its expansion would be of great utility.

Synthesis

Regulations regarding site development, effluent release, biological security, drug and chemical use along with all other major aspects of operations are in place and enforced at federal, state and local levels. Extensive BMPs have been adopted by most operations, while permitting processes enforce monitoring of farm effluent and biosecurity risks such as exotic species escape and disease outbreak. Processes managed by the EPA and ACE have shown marked improvement since new legislation in 2004, and resources are available to help farmers when management issues arise with the potential to threaten the industry as a whole. Therefore, U.S. shrimp aquaculture management is ranked "highly effective."

Effectiveness of Management Rank:

Highly Effective   Moderately Effective   Not Effective

IV. Overall Evaluation and Seafood Recommendation

As a whole, U.S. farmed shrimp offers consumers a "**Good Alternative**" source of one of America's most-consumed forms of seafood. However, we distinguish between inland/zero-exchange recirculating systems, which are a "**Best Choice**", and exchanging production systems, which are good alternatives but still have some concerns. Since exchanging production systems produce ~85% of U.S. shrimp by volume, we use their ranking for the overall U.S. recommendation.

The use of marine resources is deemed "moderate" across the board due to the average fishmeal and oil inclusion rates in formulated shrimp feeds of 15% and 4%, respectively, and a Feed Conversion Ratio of 2.0. This means that for every pound of shrimp produced, 1.35 pounds of wild fish are used in feed. Unusually progressive farmers are using fishmeal inclusion rates as low as 5%. If U.S. shrimp producers could broadly embrace such reduced inclusion rates, the industry could obtain a "low" ranking for the use of marine resources.

The risk of shrimp escaping into the wild is only a concern for coastal farms using exchanging systems. The Pacific white shrimp being farmed in the U.S. has been occasionally detected in state waters around the Gulf of Mexico, Hawaii and the mid-Atlantic, although no populations are known to have become established in these areas. Since Pacific white shrimp is a non-native species in all the areas it has been detected, the effects of its interactions with native shrimp are unknown, and wild shrimp stocks remain healthy, exchanging coastal farms receive a ranking of "moderate" risk. Inland and zero-exchanging recirculating systems pose little to no threat to adjacent environments via escapes, and thus pose a "low" risk.

Diseases have been problematic for shrimp farmers worldwide, and the U.S. is no different. However, the U.S. benefits from the ready availability of specific pathogen free broodstock, which all U.S. operations reportedly use. This has been a significant development in disease prevention and represents a strong biosecurity measure. Combined with stringent management and quarantine protocols, this greatly alleviates the risk of disease transmission to the wild. However, it is known that diseases found in farmed shrimp have the capacity to transfer to three commercially fished shrimp species in U.S. waters, so the theoretical risk of transmission remains, although there is no evidence of disease organisms having become established in wild populations. The more serious risk to wild shrimp may currently be viruses imported in diseased commodity shrimp. In terms of disease, exchanging farms have a "moderate" risk of disease transfer to wild stocks while inland and zero-exchange recirculating systems have a "low" risk due to the low likelihood of escapes and interactions with wild stocks.

The U.S. has strict regulations on the release of wastewater and all shrimp farms must obtain permits in order to discharge effluents. Zero-exchange recirculating systems recycle all of their wastewater and inland farms often recycle theirs to irrigate agricultural crops, so the risks of pollution and habitat effects are "low". Exchanging farms have to treat effluent if they do not comply with set standards, and no information could be found on whether their effluent has had negative impacts on the environment. Combined with the strict regulations on wetland protection, exchanging farms receive a ranking of “moderate” for risk of pollution and habitat effects.

Management is deemed “highly effective” for U.S. shrimp aquaculture due to the strict federal, state and local laws that are applied to concentrated aquatic animal production. The industry has extensive Best Management Practices and the monitoring and enforcement of regulations applied to U.S. operations regarding site development, effluent release, biological security and chemical use is generally strong and tailored to individual farms.

Table of sustainability ranks:

	Conservation concern			
Sustainability criteria	**Low**	**Moderate**	**High**	**Critical**
Use of marine resources		√		
Risk of escaped fish to wild stocks	√ Zero-exchange recirculating and inland systems	√ Exchanging		
Risk of disease and parasite transfer to wild stocks	√ Zero-exchange recirculating and inland systems	√ Exchanging		
Risk of pollution and habitat effects	√ Zero-exchange recirculating and inland systems	√ Exchanging		
Management effectiveness	√			

COUNTRYWIDE RECOMMENDATION

U.S. farmed shrimp:

Best Choice | **Good Alternative** | Avoid

OR

Zero-exchange recirculating and inland systems:

Best Choice | Good Alternative | Avoid

Exchanging:

Best Choice **Good Alternative** Avoid

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Scientific review does not constitute an endorsement of the Seafood Watch or FishWise® programs, or their seafood recommendations, on the part of the reviewing scientists. Seafood Watch and FishWise® are solely responsible for the conclusions reached in this report.

Appendix I – Estimates of Daily Water Exchange

Harlingen Shrimp Farm provided **estimates** of water exchange, thought to be greater than, or equal to, most exchanging coastal farms in Texas (Gregg March 2009).

Months of Operation: April - November = 216 days
Maximum daily exchange: 3%.
2006 Total discharge: 1.384 billion gallons (daily operational exchange plus harvest)
Total pond area: 346 acres
Total pond volume: 1 million gallons/acre X 346 acres = 346,000,000 gallons
Daily discharge: 6,407,407.41 gallons/day.

Average daily discharge %: 6,407,407 (daily discharge)/346,000,000 (total pond volume) X100 = 1.85% of their total.

Appendix II – Seafood Watch Rankings of Individual Aquaculture Criteria

Criterion 1: Use of Marine Resources	**Ranking**
Feed use components to evaluate	
A) Yield ratio: amount of wild-caught fish (excluding fishery by-products) used to create fishmeal and oil (ton/ton): Wild Fish: Fish Meal; ratio = 4.5 [i.e. value = 4.5:1 from Tyedmers (2000)] Wild Fish: Fish Oil; ratio = 8.3 [i.e. value = 8.3:1 from Tyedmers (2000)] *Farms using ABN or other feeds that do not contain fishery products (aka 'fish free feeds') = 0	
B) Inclusion ratio of fishmeal, fish oil, and other marine resources in feed (%): Fish Meal; enter % = 15% Fish Oil; enter % = 4%	
C) Efficiency of feed use: known or estimated average economic feed conversion ratio (FCR = dry feed: wet fish) in grow-out operations: Enter FCR = 2.0	
Wild input: farmed output ratio (WI:FO)	
Calculate and enter the largest of the resulting values: $Meal_{max}$: $[\text{Yield ratio}]_{meal}$ X $[\text{Inclusion ratio}]_{meal}$ x [FCR] = 4.5 X 0.15 X 2.0 = 1.35 Oil_{max}: $[\text{Yield ratio}]_{oil}$ X $[\text{Inclusion ratio}]_{oil}$ x [FCR] = 8.3 X 0.04 X 2.0 = 0.664 WI:FO = (maximum high value = 1.35) **Feed use for *L. vannamei*:** Fishmeal inclusion ratio: 0.15 (15%) Average FCR = 2.0 $Meal_{max}$: $[\text{Yield ratio}]_{meal}$ X $[\text{Inclusion ratio}]_{meal}$ X [FCR] = 4.5 X 0.15 X 2.0 = 1.35 **WI:FO = 1.35**	
Primary Factor (WI:FO)	
Estimated amount of wild fish used to produce farmed fish (ton/ton; WI:FO value from above): <u>Green</u>: Low use of marine resources (WI:FO = 0-1.1) OR supplemental feed not used. <u>Yellow</u>: Moderate use of marine resources (WI:FO = 1.1-2.0). <u>Red</u>: Extensive use of marine resources (WI:FO > 2).	
Secondary Factors	

Stock status of the reduction fishery used in feed for the farmed species: Green: At or above B_{MSY} ($\geq$ 100%). Yellow: Moderately below B_{MSY} (50-100%) OR unknown. Red: Substantially below B_{MSY} (e.g. < 50%) OR overfished OR overfishing is occurring OR fishery is unregulated. No Color: Not applicable because no reduction fishery products are used to supplement feed.	
Source of stock for the farmed species: Green: Stock from closed life-cycle hatchery OR wild caught and intensity of collection clearly does not result in depletion of broodstock, wild juveniles or associated non-target organisms. Yellow: Wild caught and collection has the potential to impact broodstock, wild juveniles or associated non-target organisms. Red: Wild caught and intensity of collection clearly results in depletion of broodstock, wild juveniles, or associated non-target organisms.	
Evaluation Guidelines	
Use of marine resources is "Low" (Green) when WI:FO is between 0.0 and 1.1 Use of marine resources is "Moderate" (Yellow) when WI:FO is between 1.1 and 2.0 Use of marine resources is "High" (Red) when: 1. WI:FO > 2.0 2. Source of stock for the farmed species is ranked Red 3. Stock status of the reduction fishery is ranked Red Use of marine resources is "Critical" (Black) and rank is Red, regardless of other criteria, if: 1. WI:FO > 2.0 AND Source of stock for the farmed species is ranked Red 2. WI:FO > 2.0 AND the stock status of the reduction fishery is ranked Red	
Conservation Concern: Use of Marine Resources	

Criterion 2: Risk of Escaped Fish to Wild Stocks	**Ranking**
Primary Factors	
Evidence that farmed fish regularly escape to the surrounding environment: Green: Rarely if system is open OR never because system is closed. Yellow: Infrequently if system is open or unknown. Red: Regularly and often in open systems.	Zero-exchange/ inland: Green Exchanging: Yellow
Status of escaping farmed fish to the surrounding environment: Green: Native; genetically and ecologically similar to wild stocks OR survival and/or reproduction are known not to occur for the escaped species in local, natural environments. Yellow: Non-native but historically widely established or status unknown. Red: Non-native (including genetically modified organisms) and not yet fully established OR native and genetically or ecologically distinct from wild stocks.	Zero-exchange/ inland: Green Exchanging: Yellow
Secondary Factors	
Where escaping fish is non-native – Evidence of the establishment of self-sustaining feral stocks: Green: Studies show no evidence of establishment to date. Yellow: Establishment is probable on theoretical grounds OR unknown. Red: Empirical evidence of establishment.	Green
Where escaping fish is native – Evidence of genetic introgression through successful crossbreeding: Green: Studies show no evidence of introgression to date. Yellow: Introgression is likely on theoretical grounds OR unknown. Red: Empirical evidence of introgression.	N/A
Evidence of spawning disruption of wild fish: Green: Studies show no evidence of spawning disruption to date. Yellow: Spawning disruption is likely on theoretical grounds OR unknown. Red: Empirical evidence of spawning disruption.	Green
Evidence of competition with wild fish for limiting resources or habitats: Green: Studies show no evidence of competition to date. Yellow: Competition is likely on theoretical grounds OR unknown. Red: Empirical evidence of competition.	Zero-exchange/ inland: Green Exchanging: Yellow

Stock status of affected wild fish: Green: At or above (> 100%) B_{MSY} OR no affected wild fish. Yellow: Moderately below (50-100%) B_{MSY} OR unknown. Red: Substantially below B_{MSY} (< 50%) OR overfished, "endangered", "threatened" or "protected" under state, federal or international law.	
Evaluation Guidelines	
A "Low Risk" (Green) occurs when a species: 1. Never escapes because system is closed. 2. Rarely escapes AND is native and genetically/ecologically similar to local stocks. 3. Infrequently escapes AND is native and survival/reproduction is known not to occur. A "Moderate Risk" (Yellow) occurs when the species: 1. Infrequently escapes AND is non-native and not yet fully established AND there is no evidence to date of negative interactions. 2. Regularly escapes AND is native; genetically and ecologically similar to wild stocks OR survival is known not to occur. 3. Is non-native but is historically widely established. A "High Risk" (Red) occurs when the two primary factors rank Red AND one or more additional factors rank Red. Escapes are a "Critical Risk" (Black) and rank is Red, regardless of other criteria, if risk of escapes AND the status of the affected wild fish stocks also ranks Red.	
Conservation Concern: Risk of Escaped Fish to Wild Stocks	
Zero-exchange recirculating and inland systems	
Exchanging systems	

Criterion 3: Risk of Disease and Parasite Transfer to Wild Stocks	**Ranking**
Primary Factors	
Risk of amplification and retransmission of disease or parasites to wild stocks: Green: Studies show no evidence of amplification or retransmission to date. Yellow: Likely risk of amplification or transmission theoretical OR unknown. Red: Empirical evidence of amplification or retransmission.	Zero-exchange/ inland Exchanging
Risk of species introductions or translocations or novel pathogens to wild stocks: Green: Studies show no evidence of introductions or translocations to date. Yellow: Theoretical risk of introductions or translocations likely OR unknown. Red: Empirical evidence of introductions or translocations.	Zero-exchange/ inland Exchanging
Secondary Factors	

Bio-safety risks inherent in operations: Green: Low risk; closed systems with controls on effluent release. Yellow: Moderate risk; infrequent discharged ponds or raceways OR unknown. Red: High risk; frequent water exchange OR open systems with water exchange to outside environment (e.g. nets, pens or cages).	Zero-exchange/ inland Exchanging
Stock status of potentially affected wild fish: Green: At or above (> 100%) B_{MSY} OR no affected wild fish. Yellow: Moderately; below (50-100%) B_{MSY} OR unknown. Red: Substantially below B_{MSY} (< 50%) OR overfished, "endangered", "threatened" or "protected" under state, federal or international law.	
Evaluation Guidelines	
Disease transfer is "Low Risk" (Green) when: 1. Neither primary factor ranks Red AND both secondary factors rank Green. 2. Both primary factors rank Green AND neither secondary factor ranks Red. Disease transfer is a "Moderate Risk" (Yellow) if the ranks of the primary and secondary factors "average" to Yellow. Disease transfer is "High Risk" (Red) if: 1. Either primary factor ranks Red AND bio-safety risks are low (Green) or moderate (Yellow). 2. Both primary factors rank Yellow AND bio-safety risks are high (Red) AND stock status of the wild fish affected does not rank Green. Disease transfer is a "Critical Risk" (Black) and rank is Red, regardless of other criteria, if either primary factor ranks Red AND stock status or the wild fish affected also ranks Red.	
Conservation Concern: Risk of Disease Transfer to Wild Stocks	
Zero-exchange recirculating and inland systems	
Exchanging systems	

Criterion 4: Risk of Pollution and Habitat Effects	
Primary Factors	
Effluent Effects	
Effluent water treatment: Green: Effluent water is substantially treated before discharge (e.g. recirculating system, settling ponds or reconstructed wetlands) OR polyculture and integrated aquaculture are used to recycle nutrients in open systems OR treatment not necessary because supplemental feed is not used. Yellow: Effluent water partially treated before discharge (e.g. infrequently flushed ponds). Red: Effluent water not treated before discharge (e.g. open nets, pens or cages).	Zero-exchange/ inland Exchanging

Evidence of substantial local (within two times the diameter of the site) effluent effects (including alteration of benthic communities, presence of signature species, modified redox potential, etc): Green: Studies show no evidence of negative effects to date. Yellow: Risk of negative effects on theoretical grounds likely OR unknown. Red: Empirical evidence of local effluent effects.	Zero-exchange/ inland Exchanging
Evidence of regional effluent effects (including harmful algal blooms, altered nutrient budgets, etc): Green: Studies show no evidence of negative effects to date. Yellow: Risk of negative effects on theoretical grounds likely OR unknown. Red: Empirical evidence of regional effluent effects.	Zero-exchange/ inland Exchanging
Extent of local or regional effluent effects: Green: Effects are in compliance with set standards. Yellow: Effects infrequently exceed standards. Red: Effects regularly exceed set standards.	Zero-exchange Inland/ Exchanging
Habitat Effects	
Sensitivity of location to habitat impacts: Green: Operations in areas of low ecological sensitivity (e.g. land that is less susceptible to degradation, such as land formerly used for agriculture or otherwise previously developed). Yellow: Operations in areas of moderate sensitivity (e.g. coastal and near-shore waters, rocky intertidal or subtidal zones, rivers or streams (riparian habitats), offshore waters. Red: Operations in areas of high ecological sensitivity (e.g. coastal wetlands, mangroves).	Zero-exchange/ Inland Exchanging coastal
Extent of operations and resulting habitat impacts: Green: Low density of fish/site or sites/area relative to flushing rate and carrying capacity in open systems OR systems are closed. Yellow: Moderate densities of fish/site or sites/area relative to flushing rate and carrying capacity for open systems. Red: High density of fish/site or sites/area relative to flushing rate and carrying capacity for open systems.	Zero-exchange/ Inland Exchanging
Evaluation Guidelines	
Pollution/habitat effects are "Low Risk" (Green) if three or more factors rank Green and none of the other factors rank Red. Pollution/habitat effects are of "Moderate Risk" (Yellow) if factors "average" to Yellow. Pollution/habitat effects are "High Risk" (Red) if three or more factors rank Red. No combination of ranks can result in a "Critical Risk" (Black) for pollution and habitat effects.	
Conservation Concern: Risk of Pollution and Habitat Effects	
Zero-exchange recirculating and inland systems	
Exchanging systems	

Criterion 5: Effectiveness of the Management Regime	**Ranking**
Primary Factors	
Demonstrated application of existing federal, state and local laws to current aquaculture operations: Green: Yes, federal, state and local laws are applied. Yellow: Yes, but concerns exist about effectiveness of laws or their application. Red: Laws are not applied OR laws applied are clearly not effective.	Green
Use of licensing to control the location (siting), number, size and stocking density of farms: Green: Yes, and deemed effective. Yellow: Yes, but concerns exist about effectiveness. Red: No licensing OR licensing used is clearly not effective.	Green
Existence and effectiveness of "better management practices" for aquaculture operations, especially to reduce escaped fish: Green: Exist and deemed effective. Yellow: Exist but effectiveness is up for debate OR unknown. Red: Do not exist OR exist but are clearly not effective.	Zero-exchange/inland: Green Exchanging: Yellow
Existence and effectiveness of measures to prevent disease and to treat those outbreaks that do occur (e.g. vaccine program, pest management practices, fallowing of pens, retaining diseased water, etc.): Green: Exist and deemed effective. Yellow: Exist but effectiveness is up for debate OR unknown. Red: Do not exist OR exist but clearly not effective.	Green
Existence of regulations for therapeutic chemicals, including their release into the environment, such as antibiotics, biocides and herbicides: Green: Exist and deemed effective OR no therapeutics used. Yellow: Exist but effectiveness is up for debate OR unknown. Red: Not regulated OR poor regulation and enforcement.	Green
Use and effect of predator controls (e.g. for birds and marine mammals) in farming operations: Green: Predator controls are not used OR predator deterrents are used but are benign. Yellow: Predator controls are used with limited mortality or displacement effects. Red: Predator controls are used with high mortality or displacement effects.	Green
Existence and effectiveness of policies and incentives, utilizing a precautionary approach (including ecosystem studies of potential cumulative impacts) against irreversible risks, to guide expansion of the aquaculture industry. Green: Exist and are deemed effective. Yellow: Exist but effectiveness is up for debate. Red: Do not exist OR exist but are clearly not effective.	Green
Evaluation Guidelines	
Management is at "Low Risk" (Green) of being considered ineffective if four or more factors rank Green and none of the other factors rank Red. Management is at "Moderate Risk" (Yellow) of being considered ineffective if all factors "average" to Yellow. Management is at "High Risk" (Red) of being considered ineffective if 3 or more factors rank Red. No combination of ranks can result in a "Critical Risk" (Black) for effectiveness of management.	
Conservation Concern: Effectiveness of the Management Regime	Green

Appendix III – U.S. Farmed Shrimp Production by State, 2008

United States production of farmed marine shrimp (*L. vannamei*) by state: states are listed in descending order of production volume. Michigan data was compiled based on a personal communication with Russell Allen of Seafood Systems Inc, all other data were obtained by collegiate correspondence among industry experts, compiled by Granvil Treece Texas A&M. Respondents included: Craig Collins, Desert Shrimp, AZ; Dr. Ya-Sheng Juan, Texas Parks and Wildlife Department (TPWD), Brownsville, TX; Dr. David Teichert Coddington, Greene Prairie Aquafarm, AL; Mark Godwin, Woods Fisheries, FL; Al Stokes, South Carolina; Guy Furman, KY; Dr. James Tidwell, KY; Bob Rosenberry, Shrimp News International, San Diego, CA; Dr. Tony Ostrowski, USMSFP, HI. Lbs gives the total grown-out weight of shrimp by state, % U.S. shows the total volume of shrimp produced by state, as a percentage of the U.S. total, acres gives pond surface areas by state, PL Stocked gives the number of Post-Larval stage young used to populate ponds in a given state. Number of farms is our estimate of the number of farms producing shrimp for consumption (not broodstock), taken from the Table shown in Appendix IV. Farms thought to have ceased operations were not included (italicized, Appendix IV)

Two states, Arkansas and California, are listed in Appendix IV, but do not have production volumes here. The facilities listed for these states do not have working contact information available online. Total production volumes presented here, therefore represent best, but likely still not completely accurate, estimates of total U.S. production.

State	Lbs.	% U.S.	Acre	PL Stocked	Number of operating farms
Texas	3,725,392	87.1	975	146,733,750	8
Alabama	171,000	3.9	54	6,000,000	1
Hawaii/Saipan	110,000	2.6	n/a	n/a	3
Florida	73,593	1.7	25	3,080,000	2
Kentucky	66,224	1.6	1 (covered)	2,580,000	??
Maryland	50,000	1.2	n/a	n/a	1
Arizona	50,000	1.2	18	2,600,000	2
Michigan	18,200	0.4	n/a	n/a	1
South Carolina	14,000	0.3	n/a	n/a	1
Arkansas	n/a	n/a	n/a	n/a	0?
California	n/a	n/a	n/a	n/a	0?
Total	4,278,409	100	1073+	160,993,750	

Appendix IV – Production Methods of U.S. Shrimp Farms, by State

Farms producing marine shrimp (*L. vannamei*), by state: states are listed alphabetically. Data for all states, with the exception of Texas, Kentucky and Maryland, were obtained from the U.S. Marine Shrimp Farming Program's (USMSFP) website (http://www.usmsfp.org/ , copywrited 2005). Data for Texas were obtained from Granvil Treece, Texas A&M University. Kentucky and Maryland operations were known to the authors. Farms operated by individuals (versus registered commercial farms), were not included in this table, nor are research facilities. Question marks represent the inability to establish unequivocal information on water exchange practices and/or whether farm waters are discharged into salt water. Farms rearing broodstock are assumed to be no exchange: where we contacted farms and verbally assured no exchange, this was cited as "no exchange". The inability to obtain definitive information for the production methods of all farms was due to communications – which were attempted by one or more of phone calls, e-mail and contact forms on websites. The most recent status of attempts is given in the final column (updated April 4 2009). Farms thought to have ceased operations/diversified into other aquaculture products, based on an absence of contact information, or phone numbers out of service, are italicized.

We caution that this list may be incomplete. Regular updating will be needed as production volumes, economic constraints of current markets and diversification are all rapidly modifying farm operations.

State	Farm Name	Exchanging water/No exchange	Discharge into salt water?	Discharge comment	Contact status
Alabama	Green Prairie Aquafarm	No exchange	No	Uses effluent for farming	Contacted
Arizona	Arizona Mariculture Associates. LLC	?	No	No coast in AZ	Left phone message
	Wood Brothers Shrimp Farm (Desert Sweet Shrimp)	No exchange	No	No coast in AZ	Contacted
	Ewing Shrimp Farm	*?*	*No*	*No coast in AZ*	*No contact details found*
	Arizona Shrimp Company	*?*	*No*	*No coast in AZ*	*No contact details found*
Arkansas	*Brave New Shrimp Seafood LLC*	*?*	*No*	*No coast in AR*	*No contact details*
California	*Sunset Sea Farms*	*?*	*?*	*?*	*Number not in service*
Florida	Indian River Aquaculture, LLC	?	?	?	Number not in service
	Shrimp Improvement Systems	Broodstock	?	?	Left message
	Woods Fisheries	?	?	?	Left message
Hawaii	Aquatic Farms	?	?	?	Left message
	Chen-Lu Farms, Inc.	Broodstock	?	?	No answer
	High Health Aquaculture In.	Broodstock	?	No comment	Contacted
	Island Aquaculture	Exchanging	Yes	No comment	Contacted
	Kona Bay Marine Resources, Inc.	Broodstock	?	?	Left message
	Molokai Sea Farms International	Broodstock	No	Said that "they don't discharge into the ocean"	Contacted
	Paradise Shrimp Farm, Inc	Broodstock	?	?	No answer
	Rainbow Hawaii	Broodstock	?	?	Couldn't leave

	Farms				message - full mailbox
	Taylor Shellfish	?	?	?	Left message
	Kahuku Shrimp Co., Inc	*?*	*?*	*?*	*Number not in service*
	D& J Ocean Farm	*Broodstock*	*?*	*?*	*Number not in service*
	Hawaii Oahu Suisan Inc.	*Broodstock*	*?*	*?*	*Number not in service*
	Shrimp Production Hawaii, Inc	*?*	*?*	*?*	*Number not in service*
Kentucky	Magnolia Shrimp	No exchange	No	All water recirculated, only water input	Visited website
Maryland	Marvesta Shrimp Farms	No exchange	No	All water recirculated, only water input	Contacted
Michigan	Sea Food Systems	No exchange	No	All water recirculated, waste is 3lbs/mo. Inorganic sludge, used as fertilizer on garden	Left message
South Carolina	Palmetto Aquaculture Corp – one producing pond currently	Exchanging	Yes	No comment	Contacted
	Island Fresh Seafood - one pond in 2007, not economically feasible, will re-start if conditions improve	*Exchanging*	*Yes*	*No comment*	*Contacted*
Texas	Bowers Shrimp Farm	Exchanging	Yes	No comment	Contacted
	Harlingen Shrimp Farm	Exchanging	Yes	No comment	Contacted
	Michael and Lucky Shrimp Farm	Exchanging	Yes	n/a	Not contacted - Info from Granvil Treece
	Natural Shrimp International Inc	N/A – water is discharged, not exchanged	No	n/a	Not contacted - Info from Granvil Treece
	Permian Sea Organics	N/A – water is discharged, not exchanged	No	n/a	Not contacted - Info from Granvil Treece
	St. Martin Seafood Shrimp Farm	Exchanging	Yes	n/a	Not contacted - Info from Granvil Treece
	SS-San Tung	Exchanging	Yes	n/a	Not contacted - Info from Granvil Treece

Appendix V – Texas Farmed Shrimp Production, 2008

Volume of shrimp produced by farm, in Texas, in 2008[8]. Data were obtained from Granvil Treece (Texas A&M University), compiled from information made publicly available by Texas Parks and Wildlife Department (TPWD)[9]. The single known state research facility (Texas A&M University) was excluded from presentation and calculations, with the rationale that it does not produce shrimp for public consumption. Lbs gives the total grown-out weight of shrimp by state, % Texas shows the relative contribution to Texas production, by farm. % U.S. shows the relative contribution of all Texan farms to the overall U.S. total marine farmed shrimp production. Acres gives pond surface areas by farm. PL Stocked gives the number of post-larval stage young used to populate ponds. Information on discharge practices was obtained verbally, in phone conversations with farms owners and operators.

Company Name	Lbs.	% Texas	% U.S.	Acres	PL Stocked	Exchanging water/No exchange	Discharge into coastal waters?
Michael and Lucky Shrimp	32,000	0.9	0.8	8.0	2,000,000	Exchanging	Yes
Harlingen Shrimp Farm	520,000	14.0	12.2	337.0	20,340,000	Exchanging	Yes
SS-San Tung	229,022	6.2	5.4	55.0	10,000,000	Exchanging	Yes
Bowers Shrimp Farm	1,850,900	49.8	43.3	349.0	61,000,000	Exchanging	Yes
St Martin Shrimp Farm	1,055,370	28.4	24.7	220.00	51,411,000	Exchanging	Yes
Permian Sea	7,000	0.2	0.2	4.0	400,000	N/A – water is discharged, not exchanged	No
Natural Shrimp	25,000	0.7	0.6	0.5	1,418,750	N/A – water is discharged, not exchanged	No
Total	**3,719,292**	**100**	**87.2**	**973.5**	**146,569,750**		

[8] Data were obtained via collegiate correspondence among industry experts, compiled by Granvil Treece Texas A&M. Respondents included: Craig Collins, Desert Shrimp, AZ.; Dr. Ya-Sheng Juan, TPWD, Brownsville, TX.; Dr. David Teichert Coddington, Greene Prairie Aquafarm, AL.; Mark Godwin, Woods Fisheries, FL.; Al Stokes, South Carolina; Guy Furman, KY.; Dr. James Tidwell, KY.; Bob Rosenberry, Shrimp News International, San Diego, CA.; Dr. Tony Ostrowski, USMSFP, HI

[9] Texas Parks and Wildlife Department (TPWD) regulate exotic species such that farms are required to report production volumes at the end of each year. Data were compiled by Dr. Ya-Sheng Juan with TPWD in Brownsville, Robert Adami with TPWD in Corpus Christi, and Joedy Gray with TPWD in Austin. Information is made public if requested.

Appendix VI – U.S. Shrimp Farms Exchanging into Coastal Waters

Calculations for the overall percentage of operations that exchange farm waters into coastal systems in 1) Texas and 2) the United States.

1) **Texas**: % Production from farms exchanging into coastal waters

- Assumed 3,725,392 lbs. produced in Texas in 2008 (App. V)
- Less production at research facilities (6100 lbs) (App IV vs. App VI)
- Less production from inland Texas farms (Mengers & Son, Permian Sea Organics = 32 000 lbs) (App. VI)
- Over total state production for 2008
- 3,687,292/3,719,292X100 = **99.1%**

2) **United States**: % Production from farms exchanging into coastal waters

- Assumed 3,719,292 lbs. produced in Texas in 2008 for consumption (App. VI).
- Added production from single exchanging farm in South Carolina (14 000 lbs.) (App. IV). Note that there is one other farm, known to exchange farm waters with coastal systems, and currently operational: Island Aquaculture, in Hawaii.
- Less production from inland Texas farms (Mengers & Son, Permian Sea Organics = 32 000 lbs) = 3,687,292
- Over total U.S. production for 2008 = 4,278,409 lbs (App. IV)
- 3,701,292/4,278,409 X 100 ~**86.5%**

Note that this number would be larger with the inclusion of production from Island Aquaculture, HI and potentially other facilities that we have had trouble contacting. Conversely, this value would decrease if any of the state weights given in Appendix III include the production of broodstock. Without complete, farm-level data for every state, ~87% represent a best estimate of the percentage of shrimp in the U.S., produced on exchanging farms connected to coastal systems.

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