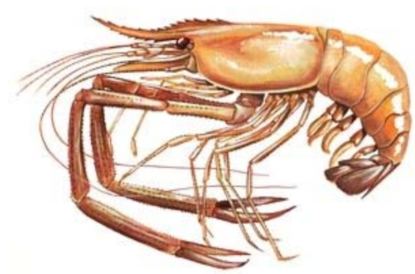
Seafood Watch
Seafood Report

U.S. Farmed Freshwater Prawn

Freshwater prawn
Macrobrachium rosenbergii



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FishWise

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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SFA and Seafood Watch strive to have all seafood reports reviewed for accuracy by external scientists with expertise in ecology, fishery science and aquaculture. Scientific review, however, does not constitute an endorsement on the part of the reviewing scientists of SFA or the FishWise® program, or the Seafood Watch program or their recommendations. SFA and Seafood Watch are solely responsible for the conclusions reached in this report.

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Executive Summary

Freshwater prawns, *Macrobrachium rosenbergii*, are farmed in the U.S. on a small-scale; the national industry produces less than 200,000 lbs annually. This species is also known as the giant river prawn, the giant freshwater prawn or the Malaysian prawn.

The following aspects of the farming practices used to raise freshwater prawns in the U.S. suggest that the industry is largely sustainable.

Seedstock are procured from domestic hatcheries. Prawns are omnivorous and require little to no fishmeal in their diets. Additionally, prawns show a preference for feeding on naturally occurring food sources in their ponds such as insect larvae, worms and plant detritus so that supplemental feed is generally only used in small quantities as a fertilizer to increase the natural productivity of the ponds.

Catfish feeds are used to supplement prawn diets and to fertilize ponds during the grow-out stage. The average inclusions rates of fishmeal and fish oil in catfish feeds in the U.S. are 4% and 0.5%, respectively. During the nursery stage, prawns are fed a diet with a higher inclusion rate of fishmeal and oil, but this stage only lasts for one month of the six-month life cycle, and the FCR of prawns is more efficient during this time. The resulting wild fish in to farmed fish out conversion ration (WI:FO) when combining data from the nursery and grow-out stages is 0.68, which corresponds to a 'low' use of marine resources.

Freshwater prawns can only grow from late spring to early fall in the contiguous U.S. Escaped prawns do not have the thermal tolerance to survive winters in the U.S. ecosystems in which they are cultured, and successful reproduction would be seriously challenged by the need for brackish water to complete their life cycle. Purposeful introductions of *M. rosenbergii* in Hawaii, where conditions are more suited to its survival, have reportedly failed. There is no evidence of self-sustaining stocks in U.S. waters.

Disease has not caused notable problems for the U.S. freshwater prawn farming industry. There have been no reported outbreaks in the history of the industry, so there is no evidence of amplification, retransmission, introduction or translocation of disease or parasites to wild stocks. The inherent bio-safety risks of U.S. operations are moderate due to infrequent effluent events (only at draining). The stock status of native *Macrobrachium* species is unknown. Overall, this leads to a "low" risk of disease transfer to wild stocks. However, should a disease outbreak occur in the future, the ranking for this criterion could be reassessed.

The pollution and habitat effects of freshwater prawn farming operations are low. Freshwater prawns are territorial and cannibalistic, which restricts stocking densities: low-input culture yields little discharge of soluble and solid wastes, minimizing effluent effects. Most farms either re-use all of their effluent or treat it via settling ponds, reconstructed wetlands or grass filter fields, and all are constructed on agricultural land, which is considered of low ecological sensitivity.

Freshwater prawn farms are generally well managed in the U.S., due at least in part to the fact that the species' physiology and cultivation is compatible with sustainable practices. Although several federal regulations governing aquaculture in the U.S. do not apply to the freshwater prawn industry, it is stated within these regulations that this is due to the industry's small scale and minimal effluents. Farmers all report using best management practices manuals available from a variety of sources and chemical use is regulated by government bodies. Therefore, management of the U.S. freshwater prawn farming industry is considered appropriate and effective.

Domestic aquaculture currently produces less than 1% of the shrimp and prawns consumed in the U.S., and the majority of this small percentage is made up by the Pacific white shrimp, *Litopenaeus vannamei*, not by freshwater prawns.

Analysis of all criteria leads to an overall seafood recommendation of **Best Choice** for U.S. farmed freshwater prawns.

Table of Sustainability Ranks

U.S. Freshwater Prawn (*Macrobrachium rosenbergii)*:

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Use of Marine Resources	√			
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√			
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:

Best Choice	Good Alternative	Avoid

II. Introduction

Basic biology

The giant river prawn, *Macrobrachium rosenbergii* (De Man, 1879) (Figures 1, 2), is indigenous to all of southern and southeastern Asia, northern Oceania and the western Pacific Islands (Figure 3). This species is also known as the giant river prawn, the giant freshwater prawn or the Malaysian prawn. *Macrobrachium rosenbergii* inhabits inland freshwater areas but the larval stage requires brackish water, so uncultivated individuals are often found in estuaries.

Prawns are tropical animals, requiring temperatures warmer than 65°F to grow (Dasgupta 2005). The minimum temperature for optimal production of *M. rosenbergii* in culture is 82.4 °F (New 2002). The lowest temperature *M. rosenbergii* can tolerate, when acclimatized to 77 °F, is 58.82 °F. Prawns remain motionless at temperatures below 64.4 °F (Manush et al. 2004).

Figure 1: Adult *Macrobrachium rosenbergii* (MSU 2009)

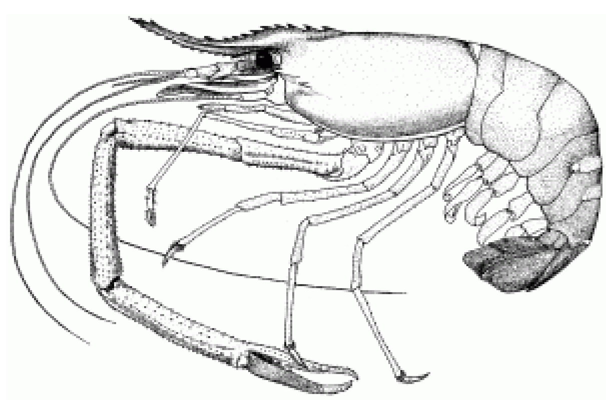

Figure 2: Diagrammatic representation of *Macrobrachium rosenbergii* (FAO 2009c)

Figure 3: Native range of *Macrobrachium rosenbergii* (FAO 2009a).

Freshwater prawn aquaculture

The genus *Macrobrachium* is commonly grown using aquaculture methods and, as a result, has been introduced to almost every continent. The top four producers of this species in 2007 were China, Thailand, India and Bangladesh (FAO 2009a). Compared with the main producers of *M. rosenbergii*, U.S. production volumes are very small (Dasgupta 2005). Of the 213,274 mt (470,188,685 lbs) produced globally in 2007 (Figure 4), U.S. production accounts for only 200 mt (440,925 lbs) (Figure 5), equivalent to 0.1% of global production (FAO 2009a). However, (New and Kutty 2009) state that local correspondents estimated production to have been just 90 mt (198,416 lbs) in 2007. Results of our own interviews estimate current U.S. production at 90.1 mt (198,614 lbs). Hawaii currently produces the most freshwater prawns, making up 25% of the U.S. industry (Appendix II). Prawn aquaculture is different in Hawaii than the continental U.S. due to year-round temperatures within the tolerance range of *M. rosenbergii*. This allows for multiple harvests throughout the year. Farming practices will be discussed in more detail below.

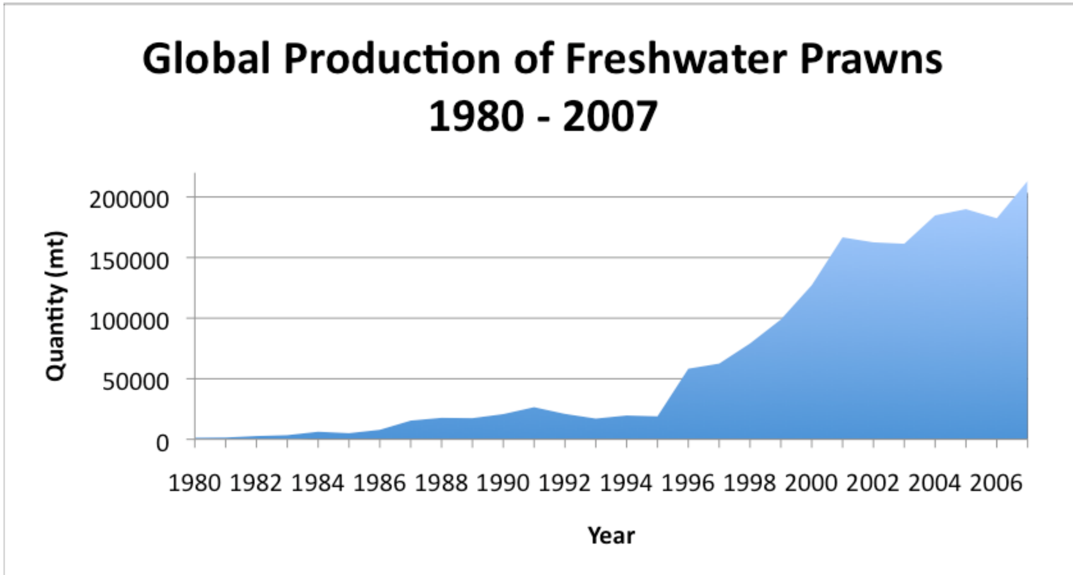

Figure 4: Quantity (metric tons) of *M. rosenbergii* produced by global aquaculture 1980–2007. From V. Galitzine (FAO 2009c).

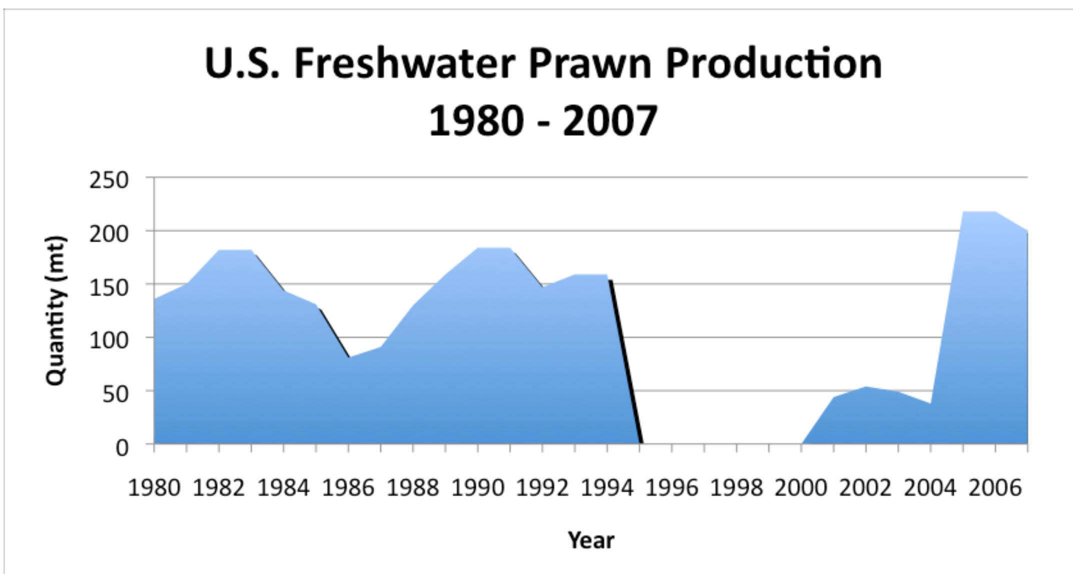

Figure 5: Quantity (metric tons) of *M. rosenbergii* produced by U.S. aquaculture 1980 – 2007. From V. Galitzine (FAO 2009c)[1].

Industry development

The freshwater prawn industry has been developing in the U.S. since the 1960s. Production began in Hawaii and subsequent operations emerged in South Carolina during the 1970s and in Mississippi during the 1980s (Dasgupta 2005). Early in the industry, prawn cultivation suffered from a paucity of seedstock and marketing difficulties that

[1] The apparent absence of U.S. production between 1995–2000 is thought to be a reporting error (New and Kutty 2009)

drove improvements during the 1980s and 1990s including better hatchery and nursery technology, improved pond culture methods, and post-harvest handling protocols for quality control and product preservation (Dasgupta 2005). During this time, shrimp and prawn wholesale values decreased significantly, and U.S. producers were unable to compete with cheaper imported prawns. Retail and direct sales were the only remaining marketing options for U.S. farmers whose main asset was the freshness of their domestic product (Dasgupta 2005).

Constraints currently facing the freshwater prawn industry in the U.S. can be summarized in four major points (Posadas 2003):

1. Lack of local nurseries—there are fewer than six nurseries nationwide, resulting in high prices for nursed juveniles. Transportation stress compromises survival, so there is a general need for on-site or nearby (<100 miles) nursery facilities.
2. Low survival in commercial grow-out operations—relatively low production is common (< 800 lbs per acre) and only a single crop can be produced during the limited grow-out season.
3. Insufficient processing, transport and marketing infrastructure—with the exception of traditional shrimping areas, nurseries face high mortality rates for live *M. rosenbergii*.
4. Competition from imported farm-raised shrimp and prawns—imports have been consistently gaining domestic market share.

The large size of freshwater prawns and the ability to supply live markets remain useful selling points for U.S. producers.

Farming practices

Farmers employ semi-intensive stocking densities for the culture of freshwater prawns. Commercial ponds in the U.S. generally have stocking densities ranging between 8,000 and 30,000 individuals per acre. Some farmers stock at lower densities (8,000 to 10,000 individuals per acre), known as extensive or low-input culture, while others use a semi-intensive stocking density of 15,000 to 18,000 individuals per acre. A few producers practice intensive stocking of more than 18,000 individuals per acre (Dasgupta 2005). Freshwater prawns are highly territorial and cannibalistic and cannot be stocked at the same intensity as marine shrimp (Tidwell et al. 2004). Competition for resources and territorial behavior in males mean that *M. rosenbergii* exhibit differential growth rates and multiple morphologies within ponds (New et al. 2000). Artificial substrates made from plastic mesh have been found to increase production and reduce mortality by allowing the animals to distribute themselves more widely in the pond; having more space allows the prawns to grow larger (Dasgupta 2005) and newly molted prawns can seek refuge in the upper part of the substrate while their new shell hardens (D'Abramo 2009). Additional substrate also allows for biofiltration (Caporelli 2009).

Recent research in the U.S. has focused on the intensification of production without compromising water quality or average harvest size. Research on the contribution of naturally occurring food to prawn diets, and the effects of artificial substrates and grading animals prior to stocking (to reduce heterogeneous individual growth and aggressive interactions) has aided in the development of a 'best management practices' production model. This model has increased production from an average of 893 lbs per acre of 1.1 oz animals to almost 2,680 lbs per acre of 1.4 oz animals over 110 days of culture. However, this level of production has only been achieved in research ponds; commercial ponds have yet to exceed 1,790 lbs per acre (Tidwell et al. 2005).

Differences from marine shrimp farming

Freshwater prawns cannot be reared at the densities achieved by marine shrimp farmers—productivity is generally lower, management is less labor intensive and the potential for waste or abuse of resources is minimal. In the past, the cultivation of *M. rosenbergii* escaped the attention of those concerned with social and environmental issues, not only because of its smaller scale compared to the marine shrimp industry, but mainly due to the fact that its ecological impact was not seen as significant. Additionally, specific negative effects of *M. rosenbergii* culture on the environment have not been documented (New et al. 2000). Recently, research addressing the environmental impact of freshwater prawn aquaculture has provided data showing that *Macrobrachium* culture is more environmentally sound than aquaculture operations growing other shrimp genera (Kutty 2005).

Scope of the analysis and the ensuing recommendation

The present analysis encompasses every aspect of *M. rosenbergii* aquaculture as practiced in the U.S., from the production of broodstock to the harvest of adults. Key aspects of species biology, feed use, disease management, pollution, local ecology and management practices and their regulation are taken into account for this assessment. Freshwater prawn farming in Puerto Rico was not assessed.

Availability of science

Due to the small scale of the U.S. industry, there is little publicly available information from industry: useful information from producers included information on the species' biology, feed use and certain cultivation techniques. Most information that is currently publicly available about the culture of *M. rosenbergii* comes from academic sources that maintain intimate links to industry via collaborative research used to improve the efficiency and quality of farming practices. Information in this report regarding farm numbers, volumes and practices was supplemented by information from telephone interviews with producers and state agency officials.

Information on the export and import of *M. rosenbergii* is scarce. In the case of exports, this is likely because domestically produced freshwater prawns are largely consumed within U.S. markets. While freshwater prawns are certainly imported for U.S. markets, import statistics available from the National Marine Fisheries Service combine the numbers of *M. rosenbergii* with those of the marine shrimp *L. vannamei* such that it is not currently possible to establish exact quantities for imports.

Market availability

Common and market names:

M. rosenbergii is sold as freshwater prawn, Malaysian prawn, giant river prawn, bouquet géant (Fr) and langostino de río (Es).

Seasonal availability:

The growth period of *M. rosenbergii* from juvenile to a market-sized adult is four months (June to September) in the temperate regions of the U.S. where adult prawns are harvested by late September (Dasgupta 2005). Most of this product is sold fresh on the farm, although some may be frozen and sold throughout the year. In Hawaii, prawns are harvested and sold at multiple times throughout the year.

Product forms:

M. rosenbergii are commonly sold live, whole, headed and peeled.

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

Criterion 1: Use of Marine Resources

Nutritional requirements and feed production

Freshwater prawns are omnivorous scavengers that are able to digest various food sources (New et al. 2000). *Macrobrachium* also grow well with little or no fishmeal or fish oil added to their diet (Tidwell 2007), feeding largely from the natural productivity of their ponds. When coupled with the highly territorial behavior that dictates low stocking densities, freshwater prawns end up using very few marine resources relative to marine shrimp.

Recently, there has been a concerted focus on the use of natural fertilizers to enhance the native productivity of ponds and decrease the need for supplementary feed. Feeding through natural productivity is one of the main factors contributing to the sustainability of freshwater prawn farming (New et al. 2000). At stocking densities ranging from 8,000 to 12,000/acre, formulated feeds are not required for the provision of nutrients. Good growth rates can be achieved via combination of a semi-water-soluble pelleted nutrient supplement and the natural productivity of a pond, stimulated by an active autotrophic system (D'Abramo et al. *in press*). Many farms report using an entirely vegetarian 'feed' to fertilize their ponds and stimulate natural productivity[2,3]. Suitable nutritional supplements for enhancing natural productivity include corn gluten pellets and wheat middlings[4] (D'Abramo et al. *in press*).

Freshwater prawns are fed a series of feed types over the course of cultivation, each satisfying nutritional needs at different points in their life history. During the larval stage, freshwater prawns are kept in brackish water (Dasgupta 2005) and fed principally *Artemia* nauplii (small brine shrimp) along with a supplemental diet typically comprised of fish/squid, chicken eggs, beef liver powder and marine fish oil (D'Abramo et al. 2003). This larval stage lasts between 22 and 30 days, at which point post-larvae are stocked in freshwater to be nursed for approximately 30 days (Dasgupta 2005). At the nursery stage, prawns require diets high in protein compared with feeds used at other life stages, and a trout starter feed is commonly used, sometimes supplemented with shredded frozen beef liver (D'Abramo et al. 2003)[5]. When stocked into earthen grow-out ponds, juveniles do not initially need any feeding since they satisfy their nutritional requirements by consuming natural pond biota (D'Abramo et al. 2003). As they grow, these juveniles become increasingly carnivorous, exhibiting stronger preference for snails, worms and insects. At this point, it becomes more important to provide high quality, nutritionally complete diets (Tidwell et al. 2002). During the final grow-out phase, commercially available sinking channel catfish feed is an effective diet used by some farmers (D'Abramo et al. 2003) or, alternatively, farmers can stimulate the natural productivity of the ponds using vegetarian feeds that act as fertilizers, as described above (D'Abramo 2009).

Feeding schedules influence how much protein is needed in the feed. *M. rosenbergii* is a slow, continuous feeder that chews food to a suitable particle size before swallowing. By feeding the prawns multiple times daily, the breakdown of food pellets and subsequent nutrient leaching minimizes feed losses (Tidwell et al. 2002). When prawns are fed twice daily, research shows that that using expensive, high-quality marine shrimp diets is no more advantageous than using cheaper, domestically produced pelleted diets. However, the percentage of larger, higher value animals does increase slightly (~ 5%). If prawns are fed only once daily or the pond is new and has relatively little natural productivity, higher protein diets may be more important (Tidwell et al. 2002).

Stock status of reduction fisheries[6]

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 agriculture and

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[2] Such as the six farms in North Carolina that make up the American Prawn Cooperative, collectively the largest freshwater prawn producer in the country (Weiseman 2009).
[3] One of the farms contacted also reported using a prawn feed manufactured by Purina that contains small amounts of fishmeal (Mattingly 2009).
[4] Commonly used in the farming of terrestrial livestock.
[5] This supplementation practice has become less common (Tidwell pers. comm., 2009).
6 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

aquaculture feeds. The precise sources of fishmeal and fish oil can be difficult to determine due to the proprietary nature of commercial feed formulations. Nevertheless, reduction fisheries target 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, Watson et al. 2006, MATF 2007).

Removing forage species from the marine ecosystem will have impacts on marine mammals, seabirds and ocean foodwebs (Baraff and Loughlin 2000, Tasker et al. 2000, Furness 2003, Becker and Beissinger 2006). Fisheries targeting forage species also have the potential to reduce the productivity of other fisheries that rely on forage fish species as prey (Walters et al. 2005). Forage fish are often high in oil and are also nutritious in their own right, and could thus be used most efficiently by humans for direct consumption (Watson et al. 2006). Furthermore, forage fish populations tend to be highly cyclic and there are multiple sources of uncertainty regarding these species' population sizes. Fisheries scientists recommend that these fisheries be pursued with caution, given the potential impacts of removing essential biomass from marine systems (NRC 2009). Healthy forage fish populations are also thought to be critical for maintaining resilience in the face of global climate and oceanographic changes (IPCC 2009).

It is generally believed that most forage fish populations are stable over multiple years, though they naturally oscillate with ocean conditions (Hardy and Tacon 2002, Huntington et al. 2004). However, concerns have been raised about the potential for increased demand from expanding industries for farmed carnivorous fish (Weber 2003) since most populations are currently classified by the FAO as fully exploited (Tacon 2005).

In commercial catfish feeds, menhaden meal is generally used (Robinson et al. 2001). According to the Atlantic States Marine Fisheries Commission, the 2006 stock assessment showed that Atlantic stocks are not considered to be overfished nor is overfishing occurring (ASMFC 2009). The same is true for Gulf of Mexico stocks according to the Gulf States Marine Fisheries Commission (GSMFC 2009).

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 seedstock

In addition to fish used in feed, marine resources are consumed in aquaculture via the wild juveniles used to populate ponds and the broodstock captured for propagation. Therefore, husbandry that allows the reproductive cycle to be closed in captivity is an important determinant of sustainability in aquaculture.

The life cycle of the freshwater prawn has been successfully closed in captivity in the U.S., eliminating the need to capture specimens from the wild. Ovarian maturation and spawning of freshwater prawns can be achieved in captivity without any special manipulation of environmental conditions, providing regularity in the supply and quality of produced prawns (New et al. 2000), both of which can be challenging when rearing marine shrimp. Broodstock adults are collected from pond-reared freshwater prawn populations during the autumn harvest and are over-wintered indoors in temperature controlled tanks (Tidwell et al. 2005).

In the U.S., nursed juveniles for stocking in grow-out ponds are purchased from domestic hatcheries (D'Abramo et al. 2003) or from regional nurseries that buy from hatcheries (Upstrom 2009). In 2007, there were three hatcheries in the contiguous U.S., all inland and operating recirculating systems (New and Kutty 2009). Some hatcheries also have their own grow-out operations (Fratesi 2009).

WI:FO yield, inclusion and economic feed conversion[7]

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).

Here we calculate, for farmed *M. rosenbergii* in the U.S., 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 (WIFO)

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, season, condition of fish and the efficiency of forage fish reduction plants (Tyedmers 2000).

In the present analysis, we use the fishmeal yield rate of 22% suggested by Tyedmers (2000) as a reasonable year-round average from South American reduction fisheries. A fishmeal yield rate of 22% is 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 one unit of fishmeal.

[7] Portions of this section have been taken directly from (Galitzine et al. 2009).

We also show calculations based on a fish oil conversion rate of 12%, or 8.3 units of wild fish for each 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), which would correspond to 20 units of wild fish for each unit of fish oil. However, to be consistent with previous Seafood Watch Reports, we continue to use the Tyedmers (2000) value until a new definitive estimate is published, while also presenting numbers based on estimates from Tacon and Metian (2008). Since 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 results of a global survey undertaken between December 2006 and October 2007 suggest that the mean percentages of fishmeal and fish oil included in freshwater crustacean feeds globally are 15% (ranging over 5–25%) and 0.75% (ranging over 0–3%), respectively (sample sizes not cited) (Tacon and Metian 2008). However, the U.S. was not included in the samples, and the industry-specific literature reports that channel catfish feed is a suitable diet for freshwater prawn grow-out (D'Abramo et al. 2003). The mean percentages of fishmeal and fish oil included in catfish feeds in the U.S. are 4% (ranging over 3–6%) and 0.5% (ranging over 0–1%) (Tacon and Metian 2008). Here, we use these rates as the best values currently available to summarize inclusion of fishmeal and fish oil in feeds in the U.S. This estimate will be conservative (from a sustainability standpoint) given that at least five of the main U.S. freshwater prawn farms report using an entirely vegetarian feed.

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[8].

This calculation is expressed as:

Feed Weight/(Final Stock Wet Weight – Starting Wet Weight) = eFCR[9]

[8] 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 averaged losses over a farming cycle.
[9] Although this calculation is of critical economic importance when determining which feeds provide optimal growth performance for the price, FCRs alone are a poor tool for measuring environmental impact, something better accomplished using overall WI:FO (also know as FFER or feed fish equivalence ratio). If used to infer the conversion of biomass from one form to another, FCRs are problematic because they compare the dry weight of feed to the 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 what comes out. Second, being a weight-based metric, FCR ratios cannot account for differences among feeds that vary in either the amount of fish in feed (inclusion rate) or differences in the

Globally, freshwater crustaceans are estimated to have an eFCR of 1.5 (ranging over 1.2–3), however, this estimate includes only China, India, Taiwan and Thailand and is an average of various species (Tacon and Metian 2008). *M. Rosenbergii* is reported to have an eFCR of around 2.5:1 (Valenti and Tidwell 2006). Such a high FCR may result from the large size of the prawns: for shrimp and prawns, large animals grow less efficiently than smaller animals (Wyban et al. 1995).

Overall WI:FO Calculations

Fishmeal

Larval stage (1/6 of life cycle)

- WI:FO calculations do not apply since larvae are fed principally a live diet of A*rtemia* nauplii

Nursery stage (1/6 of life cycle)

> WI:FO = (4.5 kg wild fish/1 kg fishmeal[10]) X (0.50 kg fishmeal/1 kg feed[11]) X (1 kg feed/1 kg prawns[12])
> = 2.25 kg wild fish/1 kg prawns

Growout stage (4/6 of life cycle)

> WI:FO = (4.5 kg wild fish/1 kg fishmeal[10]) X (0.04 kg fishmeal/1 kg feed[13]) X (2.5 kg feed/1 kg prawns[14])
> = 0.45 kg wild fish/1 kg

The nursery stage has a high WI:FO value (2.25) for fishmeal, but this stage represents both a short time period and a very small part of the total feed consumed (due to the small size of the nursery prawns) in the complete production cycle. The bulk of the total feed consumption occurs during growout. The WI:FO value of 0.45 for growout would be ranked as a 'low' conservation concern. To check that the nursery stage would not alter this ranking, a simple calculation based on the duration of the nursery and growout stages will give an overall WI:FO value that errs on the side of caution due to the difference in size and total feed consumption between these stages.

Overall WI:FO (all life stages) = (2.25 x (1/6)) + (0.45 x (4/6)) = 0.68

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proportions of fish oil to fish meal within individual feeds, where fish oil tends to require more fish to produce per unit weight than fishmeal.

[10] (Tyedmers 2000, Tacon and Metian 2008)
[11] (FAO 2009b)
[12] (Upstrom 2009)
[13] (Tacon and Metian 2008)
[14] (Valenti and Tidwell 2006)

This precautionary overall WI:FO value (0.68) is still ranked as a 'low' concern.

Fish oil
Using the fish oil yield rate of 8.3

WI:FO = (8.3 kg wild fish/1 kg fish oil[15]) X (0.005 kg fish oil/1 kg feed[16]) X (2.5 kg feed/1 kg shrimp[17])
= 0.1 kg wild fish/1 kg prawns

For the sake of completeness, we have also shown the WI:FO calculation with a second estimate of fish oil yield rates of 5% (for the grow-out stage only) from Tacon & Metian (2008).

WI:FO = (20 kg wild fish/1 kg fish oil[18]) X (0.005 kg fish oil/1 kg feed[19]) X (2.5 kg feed/1 kg prawns[20])
= 0.25 kg wild fish/1 kg shrimp

Synthesis
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 aquaculture of a particular species (in terms of the highest WI:FO value). For freshwater prawns, fishmeal rather than fish oil is the limiting portion of the feed. Of the two calculations for fishmeal WI:FO, a value of 0.45 is considered to represent the great majority of the total feed consumed during the complete production cycle. With the knowledge that including the nursery phase will not affect the ranking, the value of 0.45 will be used to represent WI:FO for US freshwater prawns This means that for every pound of wild fish used, 2.2 pounds of prawns are produced, resulting in a net gain of protein into the food chain.

Therefore, overall, due to the omnivorous nature of prawns and the consequent low levels of fish meal and oil in feeds used by freshwater prawn farming operations, combined with the lack of wild-harvesting for juveniles or broodstock and the 'moderate' or 'unknown' stock status of reduction fisheries used to produce fishmeal and oil in feeds, a **Low** conservation concern for use of marine resources give U.S. freshwater farmed prawns a **green** ranking for this criterion.

Use of Marine Resources Rank:

Low	Moderate	High

[15] (Tyedmers 2000)
[16] (Tacon and Metian 2008)
[17] (Valenti and Tidwell 2006)
[18] (Tacon and Metian 2008)
[19] (Tacon and Metian 2008)
[20] (Valenti and Tidwell 2006)

Criterion 2: Risk of Escaped Fish to Wild Stocks

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

Endemism and escape

Macrobrachium rosenbergii is not native to the U.S., but is indigenous to all of southern and southeastern Asia, northern Oceania and the western Pacific Islands (Figure 3).

Escape of *M. rosenbergii* is rare, with only two reported incidences in continental U.S. and Hawaiian waters since 1967[21] (United States Geological Survey's (USGS) Non-indigenous Aquatic Species (NAS)). Five related reports are the result of a set of deliberate but unsuccessful stocking attempts off Maui, Kauai and Oahu during 1968–1969. In Mississippi, another incident describes animals that 'escaped aquaculture' in 2001 (Schofield 2009).

Macrobrachium rosenbergii were deliberately releases into streams in Hawaii from 1968–1969, but it is unlikely that any population became established. The NAS database has listed the species' status in Hawaii as 'failed' (Schofield 2009). The only information available regarding establishment is from a study documenting invasive species in Hawaiian freshwater systems, which states that *M. rosenbergii* had been found in the vicinity of Hawaiian aquaculture facilities. It gives no specific locations or supporting data and concludes that that populations of *M. rosenbergii* in Hawaii have failed to establish ((Devick 1991). Furthermore, Hawaii's freshwater prawn farming industry is now said to have 'collapsed' (Fast and Leung 2003), and is currently estimated to consist of only three farmers producing on approximately 65 acres (Tamaru 2009).

In the 'escaped aquaculture' event near Simmons Bayou, Mississippi, 40 individuals were captured from January 2001 to November 2001: 4 females, 25 males and 11 juveniles (Woodley et al. 2002). None of the specimens collected were of reproductive size and there is the possibility that they were misidentified (D'Abramo 2009). No genetic testing was performed to verify identification and the peer-reviewed literature documenting the event does not describe what characteristics were used to resolve the systematics of the specimens. This case (if the animals were correctly identified) is the first and only record of an escape of freshwater prawns from aquaculture operations in the continental U.S. and Hawaii.

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[21] The NAS database was started in 1990. Incidences prior to that date have been researched using a variety of sources, e.g., museum records (USGS 2009).

Status of escaping prawns and colonization potential

Macrobrachium rosenbergii is non-indigenous to the United States, and although unlikely, escape is always theoretically possible. The most likely mechanism for escape would be screen failures on outlets or screen damage during drain harvesting (Tidwell 2008).

Temperatures in the temperate, contiguous U.S. present considerable barriers to the reproduction and survival of freshwater prawns in the wild. Of the states that farm this species, the waters with the warmest winter sea surface temperatures are in Hawaii (76°F) and Texas (58°F) (NODC 2009). Hawaiian temperatures are suitable for the survival of *M. rosenbergii*, but Texan temperatures are at the low end of the species' physiological tolerance. The Ohio Department of Natural Resources (ODNR) reported the fact that death typically occurs below 55°F in order to get *M. rosenbergii* added to the approved species list (USFPGA 2009). In Kentucky, the local water temperature generally drops to a level that is lethal to prawns a week or two after harvest (Tidwell 2008).

Table 1. Winter Sea Surface Temperatures (SSTs) for States with coastlines that culture *M. rosenbergii*. Temperature data from (NODC 2009).

State	Winter SSTs (°F)	Location of sample
Alabama	51	Dauphin Island
Georgia	51	Savannah Beach
Hawaii	76, 71	Honolulu, Hilo
Mississippi	No data available	
North Carolina	46	Cape Hatteras
South Carolina	48, 50	Myrtle Beach, Charleston
Texas	53, 54, 58, 58	Freeport, Galveston Bay Entrance, Port Mansfield, South Padre Island
Virginia	36	Kiptopeke

Freshwater prawns require brackish water to complete their life cycle. Therefore freshwater prawns could only potentially colonize a new habitat if escape occurred from coastal farms. This constraint also acts to minimize the risk of escape given that most farms in the continental U.S. are situated inland (New et al. 2000). Coastal farms do exist in Hawaii, and the failure of *M. rosenbergii* to establish itself is poorly understood, but this area lacks the large brackish-water river systems thought to be required for successful reproduction of *M. rosenbergii* (Devick 1991). It has also been hypothesized that *M. rosenbergii* has trouble establishing itself in areas where *Macrobrachium lar*[22] is present (Atkinson 1973).

Evidence of spawning disruption, competition for limited resources with and stock status of potentially affected wild prawns

Any potential effects on spawning disruption or competition between escaped prawns and native *Macrobrachium* species in the U.S. are unknown. There are six native species of *Macrobrachium* in the contiguous U.S.: *M. acanthurus, M. carcinus, M. faustinum, M. heterochirus, M. ohione,* and *M. olfersii* (Bowles et al. 2000) and two in Hawaii: *M. grandimanus* and *M. acherontium* (BM 2009). The majority of the contiguous U.S. species are distributed among the southern states of the Gulf Coastal Plain, Mexico and the Caribbean Islands; *M. ohione* can also be found in Arkansas, Oklahoma and Ohio. Successful hybridization crosses have produced viable offspring among different *Macrobrachium* species in the past (Malecha et al. *in press*), although *M. rosenbergii* is only known to have been crossed successfully with *M. malcomsonii* (San Koli 1982) (a species native to southern Asia).

No information currently exists to predict how escaped *M. rosenbergii* would interact with native congenerics. Therefore, effects of potential competition for limited resources between escaped freshwater prawns and native *Macrobrachium* species is also unknown.

Native *Macrobrachium* populations in the contiguous U.S. appear to be declining. Catch yields of *M. ohione* were almost 1,000 tons per year in the 1930s, but reduced to less than 2 tons per year by the early 1970s. Representatives of other *Macrobrachium* species have become difficult to find in recent years, despite there having been fisheries for them in the past. The main factors thought responsible for these declines are river impoundment and destruction of riverine habitats. Other factors may include water quality degradation, diminished stream flows, competition and predation from exotic species, and overharvesting (Bowles et al. 2000). No stock assessments could be found for these species, so current estimates of stock status are unknown. One website listed the conservation status of *M. ohione* as 'apparently secure' (NatureServe 2009b) but had no information on the other native *Macrobrachium* species.

No stock assessment information could be found for the native *Macrobrachium* species of Hawaii. Two websites listed *M. grandimanus* as either 'threatened' (ZipcodeZoo 2009) or 'vulnerable' (NatureServe 2009a). No information on the stock status or conservation status of *M. acherontium* could be found.

Synthesis

There is only one documented incidence of *M. rosenbergii* escaping from captivity and the taxonomic identification of these specimens remains debatable. The physiological

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[22] This non-indigenous prawn species is now ubiquitous in Hawaii (Devick 1991).

characteristics of this tropical species would not allow for its survival should an escape occur in the contiguous U.S., partly due to lethally low winter temperatures and also the biological requirement of brackish water for reproduction. Purposeful introductions of *M. rosenbergii* in Hawaii, where conditions are more suited to its survival, have reportedly failed, so there is no evidence of self-sustaining stocks in U.S. waters. Should prawns escape, the effects of spawning disruption and competition with wild species are unknown, as is the stock status of potentially affected species. Overall, this leads to a **Low** risk of escapes to wild stocks.

Risk of Escaped Fish to Wild Stocks Rank:

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, management of bio-safety risks and the susceptibility of wild stocks to infection.

Table 2. Diseases affecting *Macrobrachium rosenbergii* (FAO 2009c). Note: IH refers to improved husbandry.

DISEASE	AGENT	TYPE	SYNDROME	MEASURES
MMV (*Macrobrachium* Muscle Virus)	Parvo-like virus	Virus	Infected tissue becomes opaque, with progressive necrosis; affects juveniles	IH
WSBV (White spot Syndrome BaculoVirus)	Baculovirus	Virus	White spots; affects juveniles	IH
Unnamed viral disease	Nodavirus	Virus	Whitish tail; affects larvae	IH
Black spot; brown spot; shell disease	*Vibrio*; *Pseudomonas*; *Aeromonas*	Bacteria	Melanised lesions; affects all life stages, but more frequently observed in juveniles & adults	IH; oxolinic acid; nifurpurinol
Bacterial necrosis	*Pseudomonas*; *Leucothrix*	Bacteria	Similar to black spot but only affects larvae, especially stages IV & V	IH; nifurpurinol; erythromycin; penicillin-streptomycin; chloramphenicol
Luminescent larval syndrome	*Vibrio harveyi*	Bacterium	Moribund & dead larvae luminescent	IH; chloramphenicol; furazolidone
White postlarval disease	Rickettsia	Bacterium	White larvae, especially stages IV and V	IH; oxytetracycline; furazolidone; lime, prior to stocking
Unnamed fungal infection	*Lagenidium*	Fungus	Extensive mythelial network visible through exoskeleton of larvae	IH; trifluralin; merthiolate
Unnamed fungal infection (often associated with IMN - see below)	*Fusarium solani*	Fungus	Secondary infection; affects adults	IH
Unnamed yeast infections	*Debaryomyces hansenii*; *Metschnikowia bicuspidata*	Fungi	Yellowish, greyish or bluish muscle tissues in juveniles	IH
Protozoan infestations	*Zoothamnium*; *Epistylis*; *Vorticella*; *Opercularia*; *Vaginicola*; *Acineta*; *Podophyra*; etc.	Protozoans	External parasites that inhibit swimming, feeding and moulting; affect all life stages	IH; formalin; merthiolate; copper-based algicides
IMN (Idiopathic Muscle Necrosis)	[environmental disease]	Unknown	Whitish colour in striated tissue of tail and appendages; when advanced, necrotic areas may become reddish; affects all life stages	IH
MCD (Mid-Cycle Disease)	[undetermined aetiology]	Unknown	Lethargy; spiralling swimming; reduced feeding and growth; bluish-grey body colour; affects larvae, especially stages VI and VII	IH; hatchery disinfection
EED (Exuvia Entrapment Disease), sometimes known as MDS (Moult Death Syndrome)	[undetermined aetiology]	Unknown but probably multiple causes, including nutritional deficiency	Localised deformities; failure to complete moulting; affects late larval stages; also seen in postlarvae, juveniles & adults	IH; dietary enrichment

No information is currently available showing evidence that *M. rosenbergii* has acted as a vector for any documented disease outbreak (New et al. 2000). However, there are always many unknowns with respect to disease transfer. For example, even if there are no conspecific populations present in local environments, some diseases affect multiple species or, in the case of viruses, can "jump" to new species via mutation.

International diseases of freshwater prawns

In recent years, the rapid expansion and intensification of culture practices globally have brought several diseases of infectious and noninfectious etiologies to the freshwater prawn farming industry (Saurabh and Sahoo 2008). Table 2 shows a list of all diseases that can affect *M. rosenbergii* during cultivation. In China, the world's largest producer of *M. rosenbergii* (www.fao.org), several diseases are now commonly found, including black gill disease, black spot disease, rotten tail disease, parasitic disease (*Ciliata* species) and milky-white body (muscle) disease (Weimin and Xianping 2002).

Although currently absent from U.S. farms, a newly discovered disease known as white tail disease (WTD) has been causing a devastating production loss in many countries, particularly in Asia (Saurabh and Sahoo 2008). This disease was first observed in 1992 and is caused by the *M. rosenbergii* nodavirus (*Mr*NV) and its associated extra small virus (XSV). The disease affects prawns such that they exhibit white, opaque muscle in the abdominal segments, generally accompanied by progressive reduction in feeding and swimming (Wang et al. 2008). White tail disease has recently been reported in the French West Indies (Arcier et al. 1999), China (Qian et al. 2003), India (Sahul Hameed et al. 2004, Shekhar et al. 2006), Thailand[23] (Yoganandhan et al. 2005) and Taiwan (Wang et al. 2008). Although nodaviruses have been found in insects and the larvae and juveniles of some marine fish (Wang et al. 2008), and several insects have demonstrated the ability to carry this specific nodavirus (Sudhakaran et al. 2008), no information could be found on retransmission of WTD from prawns to other crustaceans.

Freshwater prawns and disease in the U.S.

Despite the disease outbreaks in the freshwater prawn farming industry in foreign countries, there are no reports of any disease outbreak of concern in U.S. freshwater prawn farming (D'Abramo 2009). Some prawns may be afflicted with a shell disease caused by a facultative bacterium (D'Abramo 2009), clinically manifested by black spots on the outer shell (D'Abramo et al. 2003), but this is extremely rare, not lethal and usually associated with physical damage to the shell—eliminated by the shedding of the old shell and the production of a new uninfected shell (D'Abramo et al. 2003). When freshwater prawn ponds are drained, the water often goes out into pasture or into a receiving stream (Tidwell 2008). In theory, it is possible that, if a disease outbreak had occurred, it could be transmitted to animals inhabiting local waters. There is not

[23] Although freshwater prawn farmers in Thailand cite the protozoan-induced black gill disease as the most common affliction (New et al. 2000, Schwantes et al. 2009).

currently any evidence of such occurrences.

Marine shrimp diseases and freshwater prawns

Freshwater prawns do not suffer mortal effects from common marine shrimp diseases, although they may have the capacity to carry the responsible pathogens. The most serious pathogen affecting cultivated shrimp globally is White Spot Disease (WSD), caused by the White Spot Syndrome Virus (WSSV). The second most significant disease is Taura Syndrome Virus (TSV) (Bondad-Reantaso et al. 2005). When artificially infected with WSSV, *M. rosenbergii* repeatedly demonstrates zero mortality and is considered tolerant to the infection generally caused by this virus (Hameed et al. 2000). Similarly, when *M. rosenbergii* was challenged with TSV in an experiment by the University of Arizona, its performance indicated that it could retain or sequester the virus, but that the virus could not manifest an active (replicative) infection (DAFF 2009).

These tolerances to the two major marine shrimp diseases do not mean that freshwater prawns are immune to all diseases found in crustaceans, or that *M. rosenbergii* does not have the ability to transfer WSSV and TSV, however, no information could be found to support the latter.

In the U.S., there have been no studies assessing the susceptibility of native river shrimps (*Machrobrachium* spp.) to diseases of penaeid shrimps (Bowles et al. 2000), therefore it is unlikely that studies exist on their susceptibility to diseases of *M. rosenbergii*, seeing as there is no history of disease outbreaks in the U.S. freshwater prawn farming industry.

Risk of amplification and retransmission

Freshwater prawn farming, like most aquaculture operations, raises 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 condition) host populations. However, due to the relatively low stocking densities compared to marine shrimp culture and the lack of any significant diseases found in U.S. freshwater prawn farming, for the purpose of this report we consider there to be no evidence of amplification or retransmission of disease or parasites to wild stocks. There is also no evidence of species introductions or novel pathogens to wild stocks.

Inherent bio-safety of operations

U.S. freshwater prawn farmers use various methods of dealing with effluent. These are discussed in depth in Criterion 4: Risk of Pollution and Habitat Effects. Due to the infrequent nature of pond effluent discharges (only upon harvest), the inherent bio-safety risks of freshwater prawn farming operations in the U.S. are deemed to be moderate.

Status of potentially affected wild shrimp

As discussed earlier, the stock status of potentially affected native *Macrobrachium* species is considered 'unknown'.

Synthesis

Due to the extremely clean record of freshwater prawn farming in the U.S. and the prawns' apparent hardiness when it comes to contracting disease, there is no evidence of amplification, retransmission, introduction or translocation of disease or parasites to wild stocks. The inherent bio-safety risks of U.S. operations are considered moderate due to the infrequency of pond draining. The stock status of native *Macrobrachium* species is unknown. Overall, this leads to a **Low** risk of disease transfer to wild stocks.

Risk of Disease Transfer to Wild Stocks Rank:

Low	Moderate	High	Critical

Criterion 4: Risk of Pollution and Habitat Effects

Freshwater prawn production has three stages: hatchery, nursery and grow-out (Dasgupta 2005). In this report, we focus primarily on grow-out, which is the lengthiest stage of production.

Freshwater prawn farms in the U.S. generally all use the same infrastructure for production (Malecha 2009a) with variable feed type, effluent management (D'Abramo 2009) and stocking densities (Dasgupta 2005). Prawn grow-out is generally conducted in inland earthen ponds that are more easily integrated into the existing landscape than marine shrimp farms due to the fact that they use only fresh water for rearing (New et al. 2000). Furthermore, the low densities used in freshwater shrimp farming mean that the effluent requires less treatment than many other forms of more intensive aquaculture.

Effluent water treatment

There are various techniques employed by U.S. freshwater prawn farmers to manage pond effluent. In the contiguous U.S., farmers and state aquaculture specialists report draining ponds once a year at harvest along with one of the following effluent management techniques (Table 2):

1) Re-using all effluent via pumping into a reservoir/other pond and/or using it for irrigating crops
2) Draining into settling ponds/grass filtering fields prior to discharge into a receiving stream or reconstructed wetlands
3) Re-using some effluent and discharging the remainder into a receiving stream
4) Draining all effluent into a receiving stream

Interviews conducted with state aquaculture specialists and freshwater prawn farmers suggest that an average of 60.75% of farms either re-use all effluent or treat effluent prior to discharging into a receiving stream via the use of settling ponds, grass filtering fields or reconstructed wetlands. In Hawaii, the largest producer of freshwater prawns by volume (Appendix II), production methods are different due to temperatures that allow farmers to harvest throughout the year. Ponds are drained much less frequently, roughly once every 3–4 years for general maintenance, but usually only if a drop in production is noticed. One farm reportedly went ten years without draining their ponds. There are three grow-out facilities in Hawaii, two of which drain effluent into reconstructed wetlands; the remaining farm re-uses all of their effluent to fill ponds for the agricultural crop taro (*Colocasia esculenta*) (Tamaru 2009).

Table 3. Estimated percentage of farms using different effluent management techniques—based on interviews with state aquaculture specialists and freshwater prawn farmers.

State	% of farms re-using all effluent	% of farms reusing some effluent and discharging remainder into receiving stream	% of farms discharging into settling ponds/grass filtering fields prior to discharging into a receiving stream or draining into reconstructed	% of farms discharging into receiving stream/natural wetland	Reference	Full name, title, affiliation
Arkansas	25	50	-	25	(Selden 2009)	George Selden, Aquaculture Extension Specialist, University of Arkansas
Hawaii	33	-	67	-	(Tamaru 2009)	Clyde Tamaru, Aquaculture Extension Specialist, University of Hawai'i
Illinois	-	-	100	-	(Hitchens 2009)	Paul Hitchens, Aquaculture Specialist, Southern Illinois University
Indiana	-	25	25	50	(Lang 2009)	Randy Lang, State Hatchery Supervisor, Indiana Department of Natural Resources
Kentucky	60	20	10	10	(Caporelli 2009)	Angela Caporelli, Aquaculture Coordinator and Marketing Specialist, Kentucky Department of Agriculture
Mississippi	75	-	-	25	(Fratesi 2009)	Dolores Fratesi, Owner of Lauren Farms, Mississippi
NC	-	40	30	30	(Frinsko 2009)	Mike Frinsko Area Specialized Agent, Agriculture - Aquaculture NC Cooperative Extension, NC State University
Ohio	25	25	25	25	(Tiu 2009)	Laura Tiu, Aquaculture Specialist Ohio Center for Aquaculture

						Research and Development, Ohio State University
South Carolina	No data due to small number of farms (<4)				(Gusman 2009)	Kelcey Gusman
Tennessee	No estimates available	-	-	-	-	-
Texas	87.5	12.5	-	-	(Upstrom 2009)	Craig Upstrom, President, Aquaculture of Texas Inc
Virginia	40	25	5	30	(Nerrie 2009)	Brian Nerrie, Extension Specialist-Aquaculture, Virginia State University
National average	34.55	19.75	26.2	19.5		

Other than draining, there are few other ways in which pond water can be released. One management technique, used by smaller farms experiencing trouble with elevated pond pH, is to 'flush' the top 12 inches of water out of the pond: this technique is not practical in larger ponds (D'Abramo et al. 2003). An alternative and preferable technique for amending elevated pH is to add an EPA approved dye to the water to reduce light penetration. This decreases algal growth, which removes carbon dioxide from the water and increases pond pH (D'Abramo et al. *in press*). Another commonly used method of lowering the pH of ponds is to add sugar, a pure carbohydrate that breaks down rapidly to carbon dioxide and carbonic acid, thus lowering the pH (Tidwell 2009). Chemical use in freshwater prawn farming, including the use of dyes, will be discussed in further detail in Criterion 5.

Effluent water treatment in freshwater prawn farming is considered moderately strong, although there remains room for improvement. The freshwater and low-density nature of freshwater prawn culture means that two of the main concerns normally associated with effluent discharge from aquaculture operations are either eliminated or minimized: land salinization is not a concern, and effluent does not tend to contain concentrated nutrients or large amounts of total suspended solids because of the low stocking densities, and little feeding and/or the use of settling ponds. The fact that an estimated 16% of farms currently discharge pond waters directly into natural receiving streams is a consideration for industry improvement.

Local and regional effluent effects

The U.S. imposes strict regulations on effluent management of the aquaculture industry via the Clean Water Act, enforced by National Pollutant Discharge Elimination System (NPDES), a program of the Environmental Protection Agency (EPA) that regulates Concentrated Aquatic Animal Production (CAAP) facilities. However, these regulations only apply to operations producing more than 100,000 lbs per year and/or discharging for more than 30 days of the year. The rationale behind this ruling is a) that facilities below this threshold would be expected to experience significant adverse economic impacts if required to comply with proposed limitations, and b) because facilities below this threshold generate minimal pollutant discharges and/or available pollutant control technologies will reduce pollutant loadings from these operations only minimally. Most pond systems do not require permits because they generally discharge fewer than 30 days per year and are therefore not CAAP facilities, unless specially designated by the NPDES director (EPA 2009b).

All U.S. freshwater prawn farms produce less than 100,000 lbs per year and are therefore not considered CAAP facilities, so do not require discharge permits. The largest known freshwater prawn producer in the contiguous U.S. is the American Prawn Cooperative, made up of six farms, and their average annual production is less than 26,000 lbs per year (Parker 2009). Although federal regulations on effluents do not apply to freshwater prawn farms in the U.S., this is only due to their minimal pollutant discharges and no information could be found (e.g., academic reports, compliance breaches) to suggest that producers are not in compliance with laws governing large-scale aquaculture. Similarly, we could find no evidence tying any regional scale effects (e.g., algal blooms, etc.) to freshwater prawn farms. Further research could be conducted to examine local effluent effects by testing for evidence of shifts in benthic communities, changes in signature species or modified redox potentials in receiving streams. However, the apparently benign aspects of farming of *M. rosenbergii* have led to its inclusion in government policies and programs aimed at promoting sustainable rural development (New et al. 2000).

Although likely benign, due to the lack of research, local and regional effluent effects are considered ‘unknown’.

Sensitivity of habitat and extent of operations

Site selection is probably the most important factor influencing the sustainability of aquaculture (New et al. 2000). Freshwater farm effluent discharge, while infrequent and generally well treated, has unknown impacts on receiving streams. However, most other aspects of prawn aquaculture should cause minimal harm. In conversations with various states’ Departments of Agriculture, university extension agents and prawn farmers, farms are known to be sited on land already designated as agricultural and are never situated on wetlands due to federal protection. In Hawaii, prawn farms are considered artificial wetland and are desired by the U.S. Fish and Wildlife Service to attract rare bird species (Malecha 2009b). According to our criteria, agricultural land is considered of ‘low’ ecological sensitivity.

Extent of operations and resulting habitat impacts

As previously mentioned, freshwater prawns cannot be stocked at the high densities found in marine shrimp operations due to their territorial nature (Tidwell et al. 2004). Most farmers stock semi-intensively with 15,000–18,000 individuals per acre, as opposed to intensive stocking of more than 18,000 individuals per acre, and ponds are small, usually no more than two acres (Dasgupta 2005). The low stocking densities combined with the small size of ponds and the small scale of the industry leads us to consider the resulting habitat impacts from the extent of operations to be low.

Synthesis
Inland site locations on agricultural land combined with the minimal effluents associated with current prawn farming practices and the unknown nature of their effects on local and regional habitats results in a pollution and habitat effect ranking of **Low**.

Risk of Pollution and Habitat Effects Rank:

Low	Moderate	High

Criterion 5: Effectiveness of management[24]

Federal, state and local regulations

The U.S. aquaculture industry is regulated by federal, state and local laws. Responsibility for enforcing environmental laws and regulations is divided among headquarters offices of the Environmental Protection Agency (EPA), EPA regional offices, and state and local agencies. 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 discharging pollutants into federal waters; NPDES permit programs are usually administered by authorized states (EPA 2009a). States are also responsible for issuing permits to farmers who intend to grow *M. rosenbergii* (Table 3).

Federal effluent regulations do not apply to freshwater prawn farming (these regulations are discussed in detail in Criterion 4: Risk of Pollution and Habitat Effects). However, other aspects of freshwater prawn culture are more stringently regulated (discussed below). For the purposes of this report, we consider the laws applied to freshwater prawn farming operations in the U.S. to be appropriate and effective.

[24] Parts of this section have been taken directly from (Galitzine et al. 2009)

Table 4. State-level information regarding permits for the commercial cultivation of freshwater prawns in the U.S.

State	Permit information
Arkansas	Permit required, obtained from Arkansas Game and Fish Commission (Selden 2009)
Hawaii	Permit required. All aquaculturists need to contact the State Department of Agriculture Plant Quarantine (PQ) Invertebrate & Aquatic Biota Specialist to arrange an inspection before acquiring postlarvae and commencing production operations. An Intra-state Live Movement Permit from PQ is also required prior to purchasing and transfer of any postlarvae from any approved supplier in Hawaii. This permit must be shown to the supplier before transfer, as both supplier and purchaser can be held responsible for unauthorized live seedstock transfer (Tamaru 2009)
Illinois	Permit required, obtained from Illinois Department of Natural Resources (Hitchens 2009)
Indiana	No permit required (Lang 2009)
Kentucky	Permit required, obtained from Kentucky Department of Fish and Game Resources (Caporelli 2009)
Mississippi	Permit required, obtained from Mississippi Department of Agriculture (Robertson 2009)
North Carolina	Permit required, obtained from the North Carolina Wildlife Resources Commission (Parker 2009)
Ohio	Permit required, obtained from Ohio Department of Natural Resources (Tiu 2009)
South Carolina	No information obtained
Tennessee	Permit required, obtained from Tennessee Wildlife Resources Agency (USFPGA 2009)
Texas	Permits required, obtained from Texas Commission on Environmental Quality, Texas Department of Agriculture, and Texas Department of Fish and Wildlife, Texas Sales and Use Permit (Upstrom 2009)
Virginia	No permit required (Nerrie 2009)

Licensing as a control measure

Siting and number of ponds in an area

Siting regulations that normally govern the construction of aquaculture facilities in the contiguous U.S. do not apply to freshwater prawn farms. These regulations are controlled by the Army Corps of Engineers (ACE) and regulate Section 404 of the Clean Water Act, which governs the discharge of dredged or fill material into the nation's waters and establishes requirements that must be met before the ACE can issue permits to private parties and governmental agencies for construction in wetlands, streams, rivers and other aquatic habitats. Section 404 does not apply to freshwater prawn farms because it does not prohibit or regulate the discharge of dredge or fill material for the construction of farm or stock ponds (EPA 2009c) and the main focus of the rule is to protect tributaries to navigable waters, interstate wetlands, wetlands that could affect interstate or foreign commerce and wetlands adjacent to other waters of the United States (USFW 2009). Freshwater prawn farms are not built on wetlands: all state aquaculture specialists, university extension agents and prawn farmers interviewed stated that ponds are constructed on agricultural land. In Hawaii, different rules apply and construction of prawn farms is subject to stricter regulations (Appendix III).

Size of ponds

The constraints of the industry appear dictate the small size of ponds, making regulations for pond size control unnecessary. Prawn ponds are typically no more than two acres (Dasgupta 2005), most likely due to the economic restrictions facing the industry. Based on our interviews, few states knew of any specific language to regulate the size of ponds: For example, Illinois has no regulations on construction of ponds as long as they are smaller than 5 acres; as a result, all farmers opted to keep their ponds below this threshold (Hitchens 2009).

Stocking densities

Stocking densities of prawn ponds are dictated by the animals themselves. As mentioned earlier, prawn ponds cannot be stocked above a certain density due to their territorial and cannibalistic nature, therefore there is no need to regulate pond stocking densities. Most extensive prawn farms are stocked at densities ranging from 8,000 to 10,000 individuals per acre, while semi-intensive stocking densities range from 15,000 to 18,000 individuals per acre. A few producers practice intensive stocking with more than 18,000 individuals per acre (Dasgupta 2005).

Better Management Practices (BMPs)

Not every state has its own BMP manual, but producers in states without one claimed to use those produced by either 1) the MS State University Aquaculture Extension Service[25], 2) KY University[26], or 3) Louis D'Abramo[27]. There are also manuals on freshwater prawn culture available to farmers written by research institutions such as the Southern Regional Aquaculture Centre and the Food and Agriculture Organization of the UN (FAO). The fact that U.S. prawn farmers have had no notable escape, disease or pollution problems to date suggests that these BMPs are effective.

Disease prevention

[25] Provided on the MS State University Extension Service website but actually a publication of the Southern Regional Aquaculture Center (D'Abramo et al. 2006).
[26] (KSU 2009)
[27] (D'Abramo et al. *in press*)

Due to the absence of disease in the freshwater prawn farming industry in the U.S. (and perhaps also the scale of the industry), state governments have not invested in the development of contingency plans for disease outbreak. However, several states (Hawaii and North Carolina) do have measures in place or are currently developing them.

Hawaii, the largest producer of freshwater prawns on a state-by-state basis, has a detailed health plan for preventing and treating disease outbreaks. Other states are either developing such plans or follow BMPs to prevent the incidence of disease. In Hawaii, prevention and control of diseases in aquaculture falls under the supervision of the state aquatic veterinarian (currently Dr. Allen Riggs). There is a hierarchy of actions that will be initiated upon notification of a disease case, largely dependent on the nature of the disease, e.g., the World Organization for Animal Health (OIE) listing. Education is used as a disease prevention tool in Hawaii: the State Aquaculture Development Program works closely with the University of Hawai'i to hold workshops providing handouts on prevention methods (Tamaru 2009). North Carolina is required to have an aquatic animal health plan that covers emergency protocols should a disease outbreak occur, but they have not yet finalized their plan (Parker 2009). No other states have formalized plans, although an interview with an aquaculture specialist from South Illinois University mentioned the preventative practice of sourcing water from wells to minimize the risk of disease entering the ponds from an outside source (Hitchens 2009).

The absence of disease outbreaks on freshwater prawn farms in an industry that has been active since the 1960s suggests that preventative measures are currently effective and becoming even more so with the development of individual state contingency plans.

Chemical use

As discussed below, chemical use is generally low in the U.S. freshwater prawn farming industry. The chemicals needed typically include agricultural lime, pond fertilizers and rotenone (Dasgupta 2005).

Agricultural lime[28]

The use of agricultural lime is common in freshwater prawn farming. Liming ponds has three important benefits for prawn farming: it enhances fertilization, prevents wide swings in pH and adds calcium and magnesium to the water, both important nutrients for animal physiology (Wurts and Masser 2004). To correct insufficiently alkaline pond water, agricultural limestone is applied to the dry pond bottom or over the surface of the water to increase total alkalinity to 50 parts per million (Durborow 2002). This alkalinity increases the buffering capacity of the pond water and helps prevent elevated pH, which can kill prawns at values above 9.5 (Durborow 2002). No environmental problems have

[28] Lime is a general term used for various forms of a basic chemical produced from calcium carbonate rocks such as limestone ($CaCO_3$) and dolomite ($CaCO_3$*$MgCO_3$). More specifically, "quicklime" is calcium oxide (CaO) or calcium-magnesium oxide (Ca*MgO). Agricultural lime is generally made from pulverized limestone or chalk. The active ingredient is calcium carbonate but it may include calcium oxide, magnesium oxide and magnesium carbonate (http://en.wikipedia.org/wiki/Agricultural_lime).

been reported from the use of liming materials, and there are no food safety concerns regarding liming and inorganic fertilizers (Boyd and Massaut 1999).

Pond fertilizers

Ponds are generally organically fertilized prior to and after initial stocking. Approximately 3.5–4 weeks before pond stocking, it is recommended that ponds be fertilized by adding roughly 200 lbs of materials such as gluten pellets, soybean meal or cottonseed meal per acre. Three to four days after this initial fertilization, organic fertilizer applications should be continued at a rate of 15 lb/acre every other day until stocking. Inorganic fertilizers should be added to the pond to initiate a microalgal bloom, which prevents nuisance weeds from growing on the pond bottom that can interfere with the efficiency of drain harvesting (D'Abramo et al. *in press*).

After stocking, pelleted feeds can be added in relatively small amounts to fertilize ponds and stimulate natural productivity. The prawns directly ingest little of this supplemental feed, preferring to consume natural foods such as insects and worms until they become limited.

Rotenone

Prawn juveniles are generally 1–2 inches long when stocked and are vulnerable to fish predation. To alleviate this problem, the pesticide rotenone is widely used to eradicate wild fish (known as trash fish) before a pond is stocked. Rotenone interferes with respiration and is toxic to fish at concentrations of 1/3 gallon per acre-foot[29] (Durborow 2002). Rotenone is quickly degraded by sunlight and breaks down rapidly in water, with a half-life of 5–6 days in spring sunlight, 2–3 days in summer sunlight and 1–3 days in water (Extoxnet 1996). Although slightly dangerous to human health, rotenone is considered non-synthetic and the United States Department of Agriculture's National Organic Program allows its use (NOP 2009). Many farmers source water to fill ponds from wells to exclude unwanted fish (Hitchens 2009).

Herbicides

Herbicides are effective at reducing the pH of ponds: these compounds inhibit algal growth and thus the associated sequestration of carbon dioxide. However, BMP recommendations do not endorse the use of herbicides. If a farmer is experiencing trouble with rising pH due to excess algal growth, an approved dye can be applied to tint the water and inhibit the growth of filamentous algae and submerged aquatic vegetation (D'Abramo et al. *in press*). Aquashade is an example of a suitable dye (Caporelli 2009), made from erioglaucine (Acid Blue 9 or FD&C Blue No. 1) and tartrazine (Acid Yellow 23 or FD&C Yellow No. 5), both of which are approved for use in aquaculture by the EPA (EPA 2009a). However, dye is not always necessary. Another commonly used method of lowering the pH of ponds is to add sugar to the water, a pure form of carbohydrate that breaks down rapidly to carbon dioxide and carbonic acid, thus lowering

[29] Acre-foot = volume of one acre of surface area to a depth of one foot (43,560 cubic feet)

the pH (Tidwell 2009).

Antibiotics

In freshwater prawn culture, disease is most prevalent during the hatchery phase and usually results from the proliferation of bacteria caused by undesirably high organic loads. Addition of the antibacterial agent oxolinic acid at 1 mg/L (1 ppm) was the recommended therapeutic treatment at this stage (D’Abramo et al. 2003), although this is no longer recommended or used; improved culture techniques such as filtration now support a prophylactic approach (D'Abramo 2009).

Predator control

All state aquaculture specialists, university extension agents and farmers stated that predation is not a major issue with prawn farming. Prawns tend to stay on pond bottoms, making them less visible to predators. By ensuring sufficiently deep ponds, wading birds can be effectively deterred (Tamaru 2009). The use of additional substrates in ponds also provides prawns with the means to avoid predation (Caporelli 2009). Depredation permits do exist, and farmers can obtain them from the Fish and Wildlife Services of the U.S. Department of Agriculture, however, non-lethal measures must always be proven ineffectual before lethal measures are considered (Selden 2009). No experts reported the use of lethal measures in dealing with predators, however some non-lethal measures mentioned include decoys, whistles and crackers, dogs, live-trapping and releasing raccoons, muskrats and turtles, and manual removal of frogspawn (Caporelli 2009, Hitchens 2009, Upstrom 2009). Most of these controls are benign, but relocation of animals may have limited displacement effects.

Expansion of the industry

At present, there is no comprehensive federal policy regulating aquaculture in the U.S. Furthermore, there has been little policy developed to govern freshwater prawn aquaculture in particular, and certainly no constraint on expansion of the industry. However, the aquaculture industry as a whole does have a National Aquaculture Development Plan with a vision for cultivated aquatic foods to be produced in an environmentally responsible manner (AIN 2009). The aquaculture policy of the U.S. Department of Commerce (DOC) states that this will be achieved by the year 2025 via the development of aquaculture technologies that improve production and safeguard the environment with an emphasis, where possible, on those technologies that employ pollution prevention rather than pollution control techniques (USDOC 2009).

Synthesis

Many of the federal regulations governing aquaculture do not apply to the freshwater prawn farming industry, which is small in scale, produces minimal effluents and has demonstrated few disease problems. Best Management Practices manuals are readily available to farmers; all those interviewed claimed to operate according to the recommendations outlined in such manuals. Chemical use is minimal, predator controls have, at worst, limited mortality and displacement effects, and there is federal recognition that environmental responsibility is an important issue in the expansion of the aquaculture industry as a whole.

If the prawn aquaculture industry increases significantly in size and production, the criteria for management may need to be re-addressed, however at this time, the regulations governing the freshwater prawn industry are deemed appropriate and **Highly Effective**.

Effectiveness of Management Rank:

Highly Effective	Moderately Effective	Not Effective

IV. Overall Evaluation and Seafood Recommendation

Many aspects of freshwater prawn aquaculture are consistent with sustainable practices.

Prawns are grown at low densities because of their territorial nature. Prawns require only low-level feeding during the main grow-out phase. U.S. prawn farmers tend to use either trout or catfish feeds for main grow-out, both of which are low in fishmeal with inclusion rates of wild forage fish of approximately 4% and feed conversion ratios of ~2.5:1 corresponds to a favorable overall WI:FO ratio of less than one.

Escapes in the freshwater prawn farming industry are unlikely because animals are grown inland in contained systems. If escape were to occur, *M. rosenbergii* would not be able to establish populations in the wild due to cold winter temperatures in North America and the unlikelihood of finding the brackish/estuarine waters necessary for completion of their life cycle. In Hawaii, where conditions are more favorable for the survival of the prawn, purposeful introductions of this species are reported to have failed; therefore there are no known established populations in U.S. waters.

The inherent disease resistance of *M. rosenbergii* and farming practices that require low stocking densities have both resulted in excellent prevention of pathogen and disease outbreaks. Due to this lack of outbreaks, there is no evidence of amplification, retransmission, introduction or translocation of disease or parasites to wild stocks. However, should an outbreak occur in the future, this criterion will need re-addressing and could potentially be downgraded.

Habitat effects of prawn farms in the U.S. are considered to be small. Low stocking densities and low-input culture minimize the discharge of solid and soluble wastes and thus effluent effects. Most farms either re-use all of their effluent or treat it prior to discharge and all are constructed on agricultural land, which is considered to be of low ecological sensitivity.

Freshwater prawn farms are well managed in the U.S. Although several federal regulations governing aquaculture in the U.S. do not apply to the freshwater prawn industry, farmers all reported using best management practices manuals, which are available from a variety of sources, government bodies regulate chemical use and predator control techniques have limited effects. Overall, the management of the U.S. freshwater prawn farming industry is considered appropriate.

The present analysis leads to a **green** ranking for all five aquaculture sustainability criteria and an overall seafood recommendation of **Best Choice** for U.S. farmed freshwater prawns.

Freshwater Prawn *(Macrobrachium rosenbergii)*:

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Use of Marine Resources	√			
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√			
Management Effectiveness	√			

Overall Seafood Recommendation:

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.

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Appendix 1 - Aquaculture Evaluation

Species: *Freshwater Prawn* **Region:** US

Analyst: *FishWise* **Date:** *July 2009*

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

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

- uses less wild caught fish (in the form of fish meal and fish oil) than it produces in the form of edible marine fish protein, and thus provides net protein gains for society;
- does not pose a substantial risk of deleterious effects on wild fish stocks through the escape of farmed fish[30];
- does not pose a substantial risk of deleterious effects on wild fish stocks through the amplification, retransmission or introduction of disease or parasites;
- employs methods to treat and reduce the discharge of organic waste and other potential contaminants so that the resulting discharge does not adversely affect the surrounding ecosystem; and
- implements and enforces all local, national and international laws and customs and utilizes a precautionary approach (which favors conservation of the environment in the face of irreversible environmental risks) for daily operations and industry expansion.

Seafood Watch has developed a set of five sustainability **criteria**, corresponding to these guiding principles, to evaluate aquaculture operations for the purpose of developing a seafood recommendation for consumers and businesses. These criteria are:

1. Use of marine resources
2. Risk of escapes to wild stocks
3. Risk of disease and parasite transfer to wild stocks
4. Risk of pollution and habitat effects
5. Effectiveness of the management regime

Each criterion includes:

- Primary factors to evaluate and rank
- Secondary factors to evaluate and rank
- Evaluation guidelines[31] to synthesize these factors
- A resulting **rank** for that criterion

[30] "Fish" is used throughout this document to refer to finfish, shellfish and other farmed invertebrates.
[31] Evaluation Guidelines throughout this document reflect common combinations of primary and secondary factors that result in a given level of conservation concern. Not all possible combinations are shown – other combinations should be matched as closely as possible to the existing guidelines.

Once a rank has been assigned to each criterion, an **overall seafood recommendation** for the type of aquaculture in question is developed based on additional evaluation guidelines. The ranks for each criterion, and the resulting overall seafood recommendation, are summarized in a table.

Criteria ranks and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Consumers are strongly encouraged to purchase seafood in this category. The aquaculture source is sustainable as defined by Seafood Watch.

Good Alternatives/Yellow: Consumers are encouraged to purchase seafood in this category, as they are better choices than seafood from the Avoid category. However, there are some concerns with how this species is farmed and thus it does not demonstrate all of the qualities of sustainable aquaculture as defined by Seafood Watch.

Avoid/Red: Consumers are encouraged to avoid seafood from this category, at least for now. Species in this category do not demonstrate enough qualities to be defined as sustainable by Seafood Watch.

CRITERION 1: USE OF MARINE RESOURCES

Guiding Principle: To conserve ocean resources and provide net protein gains for society, aquaculture operations should use less wild-caught fish (in the form of fish meal and fish oil) than they produce in the form of edible marine fish protein.

Feed Use Components to Evaluate

A) Yield Rate: Amount of wild-caught fish (excluding fishery by-products) used to create fish meal and fish oil (ton/ton):

- Wild Fish: Fish Meal; Enter ratio = 4.5 [i.e. value = 4.5:1 from Tyedmers (2000)[32]]
- Wild Fish: Fish Oil; Enter ratio: 8.3 [i.e. value = 8.3:1 from Tyedmers (2000)]

B) Inclusion rate of fish meal, fish oil, and other marine resources in feed (%):

- Fish Meal; Enter % = 4%
- Fish Oil; Enter % = 0.5%

C) Efficiency of Feed Use: Known or estimated average economic Feed Conversion Ratio (FCR = dry feed:wet fish) in grow-out operations:

- Enter FCR here = 2.5

Wild Input:Farmed Output Ratio (WI:FO)

Calculate and enter the larger of two resultant values:

- Meal: $[\text{Yield Rate}]_{meal}$ x $[\text{Inclusion rate}]_{meal}$ x [FCR] = 0.45
- Oil: $[\text{Yield Rate}]_{oil}$ x $[\text{Inclusion rate}]_{oil}$ x [FCR] = 0.1
- WI:FO = 0.45

Primary Factor (WI:FO)

Estimated wild fish used to produce farmed fish (ton/ton, from above):

- Low Use of Marine Resources (WI:FO = 0 - 1.1) OR supplemental feed not used
- Moderate Use of Marine Resources (WI:FO = 1.1 - 2.0)
- Extensive Use of Marine Resources (WI:FO > 2.0)

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32 Tyedmers (2000): Salmon and sustainability: The biophysical cost of producing salmon through the commercial salmon fishery and the intensive salmon culture industry. PhD Thesis. The University of British Columbia. 272 pages.

Secondary Factors

Stock status of the reduction fishery used for feed for the farmed species:

- At or above B_{MSY} (> 100%)
- Moderately below B_{MSY} (50 - 100%) OR Unknown
- Substantially below B_{MSY} (e.g. < 50%) OR Overfished OR Overfishing is occurring OR fishery is unregulated
- Not applicable because supplemental feed not used

Source of stock for the farmed species:

- Stock from closed life cycle hatchery OR wild caught and intensity of collection clearly does not result in depletion of brood stock, wild juveniles or associated non-target organisms
- Wild caught and collection has the potential to impact brood stock, wild juveniles or associated non-target organisms
- Wild caught and intensity of collection clearly results in depletion of brood stock, wild juveniles, or associated non-target organisms

Evaluation Guidelines

Use of marine resources is "**Low**" when WI:FO is between 0.0 and 1.1.

Use of marine resources is "**Moderate**" when WI:FO is between 1.1 and 2.0.

Use of marine resources is "**Extensive**" when:

1. WI:FO is greater than 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 deemed to be a **Critical Conservation Concern** and a species is ranked **Avoid**, regardless of other criteria, if:

1. WI:FO is greater than 2.0 AND the source of seedstock is ranked red.
2. WI:FO is greater than 2.0 AND the stock status of the reduction fishery is ranked red

Conservation Concern: Use of Marine Resources

Low (Low Use of Marine Resources)

Moderate (Moderate Use of Marine Resources)

High (Extensive Use of Marine Resources)

Critical Use of Marine Resources

CRITERION 2: RISK OF ESCAPED FISH TO WILD STOCKS

Guiding Principle: Sustainable aquaculture operations pose no substantial risk of deleterious effects to wild fish stocks through the escape of farmed fish.

Primary Factors to evaluate

Evidence that farmed fish regularly escape to the surrounding environment

- Rarely if system is open OR never because system is closed
- Infrequently if system is open OR Unknown
- Regularly and often in open systems

Status of escaping farmed fish to the surrounding environment

- Native and genetically and ecologically similar to wild stocks OR survival and/or reproductive capability of escaping farmed species is known to be naturally zero or is zero because of sterility, polyploidy or similar technologies
- Non-native but historically widely established OR Unknown
- Non-native (including genetically modified organisms) and not yet fully established OR native and genetically or ecologically distinct from wild stocks

Secondary Factors to evaluate

Where escaping fish is non-native – Evidence of the establishment of self-sustaining feral stocks

- Studies show no evidence of establishment to date
- Establishment is probable on theoretical grounds OR Unknown
- Empirical evidence of establishment

Where escaping fish is native – Evidence of genetic introgression through successful crossbreeding

- Studies show no evidence of introgression to date
- Introgression is likely on theoretical grounds OR Unknown
- Empirical evidence of introgression

Evidence of spawning disruption of wild fish

- Studies show no evidence of spawning disruption to date
- Spawning disruption is likely on theoretical grounds OR Unknown
- Empirical evidence of spawning disruption

Evidence of competition with wild fish for limiting resources or habitats

- Studies show no evidence of competition to date
- Competition is likely on theoretical grounds OR Unknown
- Empirical evidence of competition

Stock status of affected wild fish

- At or above (> 100%) B_{MSY} OR no affected wild fish
- Moderately below (50 – 100%) B_{MSY} OR Unknown
- Substantially below B_{MSY} (< 50%) OR Overfished OR "endangered", "threatened" or "protected" under state, federal or international law

Evaluation Guidelines

A "**Minor Risk**" occurs when a species:

1) Never escapes because system is closed
2) Rarely escapes AND is native and genetically/ecologically similar.
3) Infrequently escapes AND survival is known to be nil.

A "**Moderate Risk**" 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 native and genetically and ecologically similar to wild stocks or survival is known to be nil.
3) Is non-native but historically widely established.

A "**Severe Risk**" occurs when:

1) The two primary factors rank red AND one or more additional factor ranks red.

Risk of escapes is deemed to be a **Critical Conservation Concern** and a species is ranked **Avoid**, regardless of other criteria, when:

1) Escapes rank a "severe risk" AND the status of the affected wild fish also ranks red.

Conservation Concern: Risk of Escaped Fish to Wild Stocks

Low (Minor Risk)

Moderate (Moderate Risk)

High (Severe Risk)

Critical Risk

CRITERION 3: RISK OF DISEASE AND PARASITE TRANSFER TO WILD STOCKS

Guiding Principle: Sustainable aquaculture operations pose little risk of deleterious effects to wild fish stocks through the amplification, retransmission or introduction of disease or parasites.

Primary Factors to evaluate

Risk of amplification and retransmission of disease or parasites to wild stocks

- Studies show no evidence of amplification or retransmission to date
- Likely risk of amplification or transmission on theoretical grounds OR Unknown
- Empirical evidence of amplification or retransmission

Risk of species introductions or translocations of novel disease/parasites to wild stocks

- Studies show no evidence of introductions or translocations to date
- Likely risk of introductions or translocations on theoretical grounds OR Unknown
- Empirical evidence of introductions or translocations

Secondary Factors to evaluate

Bio-safety risks inherent in operations

- Low risk: Closed systems with controls on effluent release
- Moderate risk: Infrequently discharged ponds or raceways OR Unknown
- High risk: Frequent water exchange OR open systems with water exchange to outside environment (e.g. nets, pens or cages)

Stock status of potentially affected wild fish

- At or above (> 100%) B_{MSY} OR no affected wild fish
- Moderately below (50 – 100%) B_{MSY} OR Unknown
- Substantially below B_{MSY} (< 50%) OR Overfished OR “endangered”, “threatened” or “protected” under state, federal or international law

Evaluation Guidelines

Risk of disease transfer is deemed "**Minor**" if:

1) Neither primary factor ranks red AND both secondary factors rank green.
2) Both primary factors rank green AND neither secondary factor ranks red

Risk of disease transfer is deemed to be "**Moderate**" if the ranks of the primary and secondary factors "average" to yellow.

Risk of disease transfer is deemed to be "**Severe**" if:

1) Either primary factor ranks red AND bio-safety risks are low or moderate.
2) Both primary factors rank yellow AND bio-safety risks are high AND stock status of the wild fish does not rank green.

Risk of disease transfer is deemed to be a **Critical Conservation Concern** and a species is ranked **Avoid** regardless of other criteria, if either primary factor ranks red AND stock status of the wild fish also ranks red.

Conservation Concern: Risk of Disease Transfer to Wild Stocks
Low (Minor Risk)
Moderate (Moderate Risk)
High (Severe Risk)
Critical Risk

CRITERION 4: RISK OF POLLUTION AND HABITAT EFFECTS

Guiding Principle: Sustainable aquaculture operations employ methods to treat and reduce the discharge of organic effluent and other potential contaminants so that the resulting discharge and other habitat impacts do not adversely affect the integrity and function of the surrounding ecosystem.

Primary Factors to evaluate

PART A: Effluent Effects

Effluent water treatment

- Effluent water substantially treated before discharge (e.g. recirculating system, settling ponds, or reconstructed wetlands) OR polyculture and integrated aquaculture used to recycle nutrients in open systems OR treatment not necessary because supplemental feed is not used
- Effluent water partially treated before discharge (e.g. infrequently flushed ponds)
- Effluent water not treated before discharge (e.g. open nets, pens or cages)

Evidence of substantial local (within 2 x the diameter of the site) effluent effects (including altered benthic communities, presence of signature species, modified redox potential, etc)

- Studies show no evidence of negative effects to date
- Likely risk of negative effects on theoretical grounds OR Unknown
- Empirical evidence of local effluent effects

Evidence of regional effluent effects (including harmful algal blooms, altered nutrient budgets, etc)

- Studies show no evidence of negative effects to date
- Likely risk of negative effects on theoretical grounds OR Unknown
- Empirical evidence of regional effluent effects

Extent of local or regional effluent effects

- Effects are in compliance with set standards
- Effects infrequently exceed set standards
- Effects regularly exceed set standards

Part B: Habitat Effects

Potential to impact habitats: Location

- Operations in areas of low ecological sensitivity (e.g. land that is less susceptible to degradation, such as formerly used agriculture land or land previously developed)
- Operations in areas of moderate sensitivity (e.g. coastal and near-shore waters, rocky intertidal or subtidal zones, river or stream shorelines, offshore waters)
- Operations in areas of high ecological sensitivity (e.g. coastal wetlands, mangroves)

Potential to impact habitats: Extent of Operations

- Low density of fish/site or sites/area relative to flushing rate and carrying capacity in open systems OR closed systems
- Moderate densities of fish/site or sites/area relative to flushing rate and carrying capacity for open systems
- High density of fish/site or sites/area relative to flushing rate and carrying capacity for open systems

Evaluation Guidelines

Risk of pollution/habitat effects is "**Low**" if three or more factors rank green and none of the other factors are red.

Risk of pollution/habitat effects is "**Moderate**" if factors "average" to yellow.

Risk of pollution/habitat effects is "**High**" if three or more factors rank red.

No combination of ranks can result in a **Critical Conservation Concern** for Pollution and Habitat Effects.

Conservation Concern: Risk of Pollution and Habitat Effects

Low (Low Risk)

Moderate (Moderate Risk)

High (High Risk)

CRITERION 5: EFFECTIVENESS OF THE MANAGEMENT REGIME

Guiding Principle: The management regime of sustainable aquaculture operations respects all local, national and international laws and utilizes a precautionary approach, which favors the conservation of the environment, for daily operations and industry expansion.

Primary Factors to evaluate

Demonstrated application of existing federal, state and local laws to current aquaculture operations

- Yes, federal, state and local laws are applied
- Yes but concerns exist about effectiveness of laws or their application
- Laws not applied OR laws applied but clearly not effective

Use of licensing to control the location (siting), number, size and stocking density of farms

- Yes and deemed effective
- Yes but concerns exist about effectiveness
- No licensing OR licensing used but clearly not effective

Existence and effectiveness of "better management practices" for aquaculture operations, especially to reduce escaped fish

- Exist and deemed effective
- Exist but effectiveness is under debate OR Unknown
- Do not exist OR exist but clearly not effective

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.)

- Exist and deemed effective
- Exist but effectiveness is under debate OR Unknown
- Do not exist OR exist but clearly not effective

Existence of regulations for therapeutants, including their release into the environment, such as antibiotics, biocides, and herbicides

- Exist and deemed effective OR no therapeutants used
- Exist but effectiveness is under debate, or Unknown
- Not regulated OR poorly regulated and/or enforced

Use and effect of predator controls (e.g. for birds and marine mammals) in farming operations

- Predator controls are not used OR predator deterrents are used but are benign
- Predator controls used with limited mortality or displacement effects
- Predator controls used with high mortality or displacement effects

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

- Exist and are deemed effective
- Exist but effectiveness is under debate
- Do not exist OR exist but are clearly ineffective

Evaluation Guidelines

Management is "**Highly Effective**" if four or more factors rank green and none of the other factors rank red.

Management is "**Moderately Effective**" if the factors "average" to yellow.

Management is deemed to be "**Ineffective**" if three or more factors rank red.

No combination of factors can result in a **Critical Conservation Concern** for Effectiveness of Management.

Conservation Concern: Effectiveness of the Management Regime

Low (Highly Effective)

Moderate (Moderately Effective)

High (Ineffective)

Overall Seafood Recommendation

Overall Guiding Principle: Sustainable farm-raised seafood is grown and harvested in ways can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

Evaluation Guidelines

A species receives a recommendation of "**Best Choice**" if:

1) It has three or more green criteria and the remaining criteria are not red.

A species receives a recommendation of "**Good Alternative**" if:

1) Criteria "average" to yellow
2) There are four green criteria and one red criteria

A species receives a recommendation of "**Avoid**" if:

1) It has a total of two or more red criteria
2) It has one or more Critical Conservation Concerns.

Summary of Criteria Ranks

Conservation Concern

Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources				
Risk of Escapes to Wild Stocks				
Risk of Disease/Parasite Transfer to Wild Stocks				
Risk of Pollution and Habitat Effects				
Effectiveness of Management				

Overall Seafood Recommendation

Best Choice

Good Alternative

Avoid

Appendix II – Estimates of U.S production by State

The information presented below is based on phone interviews and email communications with state aquaculture specialists and freshwater prawn farmers. Numbers listed for Tennessee are likely higher than actual numbers because the only data found comes from the United States Department of Agriculture's U.S. Census of Agriculture 2007, which combines data for all crustacean culture. There were no numbers available for South Carolina because the USDA's National Agricultural Statistics Service does not collect data if there are less than four farms.

State	Number of commercial farms	Acres	Annual production (lbs)	Reference	Full name, title, affiliation
Arkansas	12	20	16,000	(Pigue 2009)	Ron Pigue, owner of Delta Crawfish, Arkansas
Hawaii	3	65	49,855	# of farms and acres = (Tamaru 2009)	Dr Clyde Tamaru, Aquaculture Extension Specialist, University of Hawai'i
				production lbs = (Aguinaldo 2009)	Romulo D Aguinaldo, Owner of Romy's Kahuku Prawns and Shrimp Inc, Hawaii
Illinois	12	10	3,609 (in 2008)	(Hitchens 2009)	Paul Hitchens, Aquaculture Specialist, Southern Illinois
Indiana	12	18	9,900	(Pellman 2009)	Jerry Pellman, owner of Navilleton Shrimp and Buffalo Farm, Indiana
Kentucky	25	30	24,000	(Caporelli 2009)	Angela Caporelli, Aquaculture Coordinator and Marketing Specialist, Kentucky Department of Agriculture
Mississippi	5	25	21,250	(Fratesi 2009)	Dolores Fratesi, owner of Lauren Farms, Mississippi
NC	11	36	26,000	(Parker 2009)	Matt Parker, Aquaculture Business Specialist, North Carolina Department of Agriculture
Ohio	20	20	16,000	(Tiu 2009)	Laura Tiu, Aquaculture Specialist, Ohio Center for Aquaculture Research and Development, Ohio State University
South Carolina (mentioned in unpublished New book)	< 4	Statistics are not collected if there are less than 4 farms	Statistics are not collected if there are less than 4 farms	(Gusman 2009)	Kelcey Gusman, Statistical Assistant, South Carolina Department of Agriculture, National Agricultural Statistics Service
Tennessee	9	?	5000	USDA 2009	
Texas	8	15	15,000	(Upstrom 2009)	Craig Upstrom, President, Aquaculture of Texas Inc, Texas
Virginia	16	20	12,000	(Nerrie 2009)	Dr. Brian Nerrie, Extension Specialist-Aquaculture, Virginia State University,
Total	137	259[33]	198,614[34]		

[33] does not include South Carolina or Tennessee)
[34] Tennessee is likely over-estimated, South Carolina not included

Appendix III – Pond construction process in Hawaii according to Dr Clyde Tamaru, Aquaculture Extension Specialist, University of Hawai'i

A) Land tenure (private or leased)

B) Zoning (Dept. of planning and permitting City and County)

C) Special Management Area (SMA) permit process (City and County) http://www.state.hi.us/dbedt/czm/program/sma/participant_guide_to_the_sma.pdf. Agriculture operations are exempt from the permit process but must document that they are to engage in an agricultural process.

D) Conservation District Use Application (CDUA permitting process that will require the approval of either the Chairperson of the Department of Land and Natural Resources or the Board of Land and Natural Resources prior to the start of the project.). This is largely dependant on the zoning of the land. If taking place in a conservation district then an Environmental Assessment (EA) is required and depending on the situation an Environmental Impact Assessment (EIA) is requested.

E) EA or EIS will fall under the State Department of Health (DOH). A project or action that may affect the environment cannot be implemented until an Environmental Assessment (EA) is prepared in accordance with Chapter 343, Hawaii Revised Statutes (HRS). If the lead State or county agency (the proposing agency for agency actions, or the approving agency for applicant actions) anticipates that the project will have no significant environmental impact, then affected agencies, individuals, and organizations must be consulted and a Draft EA (DEA) is written and public notice is published in this periodic bulletin (see, section 343-3, HRS) known as the Environmental Notice. The public has 30 days to comment on the Draft EA from the date of the first notice.

F) It should be pointed out that the main criteria used by DOH to require and EA or EIS is defined by the NPDES Permit (EPA but enforced by DOH). Under the Concentrated Aquatic Animal Production (CAAP) criteria where direct dischargers require an NPDES permit if they annually meet the following general conditions: produce more than 45,454 harvest weight kilograms (about 100,000 pounds) of warm water fish (e.g., catfish, sunfish, minnows). This criteria is used by the DOH for Macrobrachium rosenbergii as well and most farms do not exceed the 100,000 lbs/year criteria so do not need to produce an EA or EIS.

G) Grading and Grubbing (City and County permit)

H) Building Permit (City and County permit)