# Seafood Watch

Seafood Report

MONTEREY BAY AQUARIUM®

# Farmed Crayfish

*Procambarus clarkii*

(Photo: James W. Fetzner, Jr.)

## Southeast Region

Final Report
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## About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.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 Choice," "Good Alternative," 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® Fisheries 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 Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling (831) 647-6873 or emailing seafoodwatch@mbayaq.org.

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Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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## Executive Summary

The red swamp crayfish is a popular food in the southeastern United States. Louisiana, where the red swamp crayfish is native, produces most—an estimated 90%—of the farmed crayfish produced in the U.S. Crayfish are marketed as both live and frozen product; all live red swamp crayfish available for sale in the U.S. are produced domestically. Contrarily, a significant portion of frozen crayfish tail meat available on U.S. markets is imported from China. In many aspects, crayfish farming is very environmentally friendly. Crayfish are farmed in either agricultural ponds or in rotation with a crop, typically rice. The crop is grown and harvested, and the land is then flooded in preparation for aquaculture. Submerged vegetation provides the basis for a detrital food web that sustains a population of crayfish. The crayfish are later harvested using baited traps. Because no supplemental feed is required, no marine resources are used in feed. Also, crayfish brood their young, a life history characteristic that allows an aquaculture population to be self-sustaining, obviating the need for nursery operations or extensive collection from wild stocks.

Wild stocks of red swamp crayfish are widespread and stable. Crayfish aquaculture does not typically use therapeutants, such as antibiotics, and effluents have not been noted to be of significant concern. Additionally, operations are usually sited in agricultural areas of low ecological sensitivity. Problems that are associated with crayfish aquaculture stem from the frequency of escapes and the subsequent damage to ecosystems. Crayfish regularly escape from aquaculture facilities, and have established invasive populations across the U.S. and the globe. In their introduced range, crayfish have heavily disrupted aquatic ecosystems and threatened the persistence of native crayfish stocks. In China, for example, crayfish have damaged ecosystems by reducing fish and aquatic plant abundance, and by disrupting the food web. Additionally, red swamp crayfish have vectored "crayfish plague," a deadly fungus, to regions outside of North America, decimating native crayfish populations, especially in Europe. Crayfish plague has not been reported to be a problem in China, possibly because the range of introduced red swamp crayfish and that of native crayfish do not overlap, but information is lacking. Also, North American crayfish species appear to be resistant to crayfish plague, so this is not a concern in the U.S., and moreover, the persistence of crayfish plague has led to increased use of red swamp crayfish in aquaculture operations around the world. Overall, the risk of escapes and subsequent ecosystem damage in North America is only moderate, as the bulk of U.S. production occurs in Louisiana, where the species is native, although some aquaculture of red swamp crayfish does take place in states outside its native range. More effective management is required to control the introduction of red swamp crayfish through aquaculture to states and drainages where it does not naturally occur, and more consideration needs to be given to controlling the spread of red swamp crayfish through aquaculture worldwide. Considering the criteria analyzed in this report, Seafood Watch® gives U.S. crayfish the overall seafood recommendation of "Best Choice," and crayfish from China the overall seafood recommendation of "Avoid."

## Table of Sustainability Ranks

| | **Conservation Concern** | | | |
|---|---|---|---|---|
| **Sustainability Criteria** | Low | Moderate | High | Critical |
| Use of Marine Resources | √ U.S. and China | | | |
| Risk of fish escapes and damage to ecosystems, including wild stocks | | √ U.S. | | √ China |
| Risk of Disease and Parasite Transfer to Wild Stocks | √ U.S. | √ China | | |
| Risk of Pollution and Habitat Effects | √ U.S. and China | | | |
| Management Effectiveness | | √ U.S. and China | | |

**About the Overall Seafood Recommendation:**

- A seafood product is ranked "**Avoid**" if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.
- A seafood product is ranked "**Good Alternative**" if the five criteria "average" to yellow (Moderate Conservation Concern) OR if four criteria are of Low Conservation Concern (green) and one criteria is of High Conservation Concern.
- A seafood product is ranked "**Best Choice**" if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.

## Overall Seafood Recommendation:

**Farmed red swamp crayfish, U.S.:**

**Best Choice** 🟩 Good Alternative 🟨 Avoid 🟥

**Farmed red swamp crayfish, China:**

Best Choice 🟩 Good Alternative 🟨 **Avoid** 🟥

# Introduction

## Basic Biology

Crayfish are large freshwater decapods related to lobster. They belong to a highly diverse group of crustaceans that consists of over 500 species. North America, north of Mexico, harbors the greatest diversity of crayfish species; 348 species, about 70% of the world total (Taylor 2002). Globally, crayfish fauna have a patchy but wide native distribution: Southern Europe, Northern Japan, Lower Manchuria, Northeastern China and Southeastern Russia, Australia, Tasmania, New Zealand, Uruguay and Southern Brazil, Southern Chile, and Madagascar (Taylor 2002).

Certain aspects of crayfish biology have facilitated the establishment of invasive crayfish populations across the globe (Lindqvist & Huner 1999). Some invasive crayfish species such as the red swamp crayfish, *Procambarus clarkii*, and the signal crayfish, *Pacifastacus leniusculus*, tolerate large fluctuations in their physical environment (e.g., temperature and salinity), though the red swamp crayfish is less tolerant of cold. Crayfish are omnivorous, feeding on a combination of vegetative matter, small mollusks such as snails, other small invertebrates, and detritus. Juvenile crayfish may also filter feed on small particles in the water (Nyström 2002). These traits make crayfish attractive candidates for aquaculture, as they can be raised in a variety of climates and can be raised in flooded agricultural fields or vegetated ponds without supplemental feed (Huner 1995).

The crayfish mode of reproduction also contributes both to their utility in aquaculture and ability to invade new geographical areas. After mating, crayfish females retain fertilized eggs and brood developing young by attaching them to specialized legs (pleopods) under the tail. After hatching, young remain attached to the female, living off of their yolk sacs, and eventually disperse after several weeks (Huner 2002; Reynolds 2002). Because of their brooding behavior, crayfish stocks in aquaculture can be self-sustaining once established and require no further dependence on hatcheries or collection from wild stocks. Likewise, this reproductive method also lends itself to the establishment of non-native populations in areas where they have been introduced as escapees from aquaculture facilities, from fishermen using them as live bait, or from the pet trade (Lodge et al. 2000a). Additionally, the red swamp crayfish grows rapidly and is very fecund in comparison with other species, aiding its ability to quickly establish populations (Hobbs et al. 1989; Lindqvist & Huner 1999).

As a result of their large size (relative to other freshwater organisms), broad diet, and physiological tolerance, crayfish have major impacts on freshwater ecosystems as native and invasive species. Due to their omnivory, they can control the abundance of both aquatic vegetation and invertebrates and can act as keystone species, heavily influencing ecosystem structure (Hobbs et al. 1989; Lodge et al. 2000a; Nyström 2002). Introduced populations have been reported to have highly negative effects on local ecosystems and native crayfish species (Hobbs et al. 1989; Holdich 1999; Lodge et al. 2000a; Lodge et al. 2000b; Taylor 2002).

Some, but not all, crayfish species create extensive burrow systems. The burrows of red swamp crayfish provide them with shelter against environmental extremes and protection from predators, especially during molting (Gherardi 2002). The red swamp crayfish in its native range inhabits seasonally-flooded wetlands, sheltering in burrows during dry periods. The species also thrives in other aquatic habitats such as ponds and streams and digs burrows in pond and stream banks. Where the red swamp crayfish is non-native these burrows may cause extensive damage to natural shorelines, the roots of agricultural crops, and human-made structures such as levees (Holdich 1999).

### Species in Aquaculture

Several species of crayfish are currently farmed in the U.S., Europe, Australia, and China. The red swamp crayfish (sometimes called the "Louisiana crayfish") is the most commonly cultivated species in the U.S. and China. While U.S. facilities predominantly raise and target red swamp crayfish, farms also inadvertently raise the eastern white river crayfish, *Procambarus acutus acutus*, or more commonly, the gulf white river crayfish, *Procambarus zonangulus*, which may be included in the marketed product (Huner 1995). Because red swamp crayfish and white river crayfish are trapped together from aquaculture facilities and combined for market, exact estimates of the ratio of red swamp to eastern or gulf white river crayfish are difficult. However, red swamp crayfish remains the target species, and usually dominates marketed catch. The Australian red claw, *Cherax quadricarinatus*, has also been promoted as an aquaculture species in the U.S., but has not as yet developed into a significant industry.

Abroad, a greater variety of crayfish species are farmed. Chinese aquaculturists primarily raise the red swamp crayfish (although it is unclear what proportion of imported crayfish from China are raised in aquaculture); European aquaculturists farm the native noble crayfish, *Astacus astacus*, and a combination of two introduced species, the signal crayfish and the red swamp crayfish; and Australian aquaculturists focus on a trio of native species, the yabby, *Cherax destructor*, marron, *Cherax tenuimanus*, and red claw, *C. quadricarinatus*. Additional species farmed abroad include the narrow clawed crayfish, *Astacus leptodactylus*, and the rusty crayfish, *Orconectes rusticus*, although the latter is primarily raised for use as bait.

### Production for the U.S. Market

The bulk of domestic crayfish are produced in aquaculture rather than captured from wild populations (Figure 1; NMFS 2003). In 2002, domestic aquaculture production reached 27,825 metric tons (mt), nearly four times wild fishery landings of 7,077 mt (Figure 1; NMFS 2003). Louisiana is considered the major producer of farmed crayfish, often cited as producing about 90% of the nation's crayfish (de la Bretonne & Romaire 1990; Lutz et al. 2003). The Louisiana State University (LSU) Agricultural Center estimated Louisiana production in 2002 at 27,452 mt (Louisiana State University Agricultural Center 2002); 99% of domestic production, assuming that National Marine Fisheries Service (NMFS) numbers for domestic aquaculture production and LSU estimates are comparable. Some additional production comes from states such as Texas, Mississippi, North Carolina, and South Carolina. Texas produced 363 mt of farmed crayfish in 2003, and North Carolina produced 9 mt in 2002 (North Carolina Dept. of Ag. and Consumer Services 2001; Treece 2004), production amounts two and three orders of magnitude less than Louisiana, respectively. The majority of U.S. farmed crayfish are produced for the domestic market, and exports have declined significantly over the past decade (Figure 2; NMFS 2005). Sweden has been the largest market for U.S. exports, owing to the decimation of Sweden's native crayfish stocks by the introduction of non-native crayfish and "crayfish plague," the fungus *Aphanomyces astaci* (Edgerton et al. 2002; Edgerton et al. 2004).

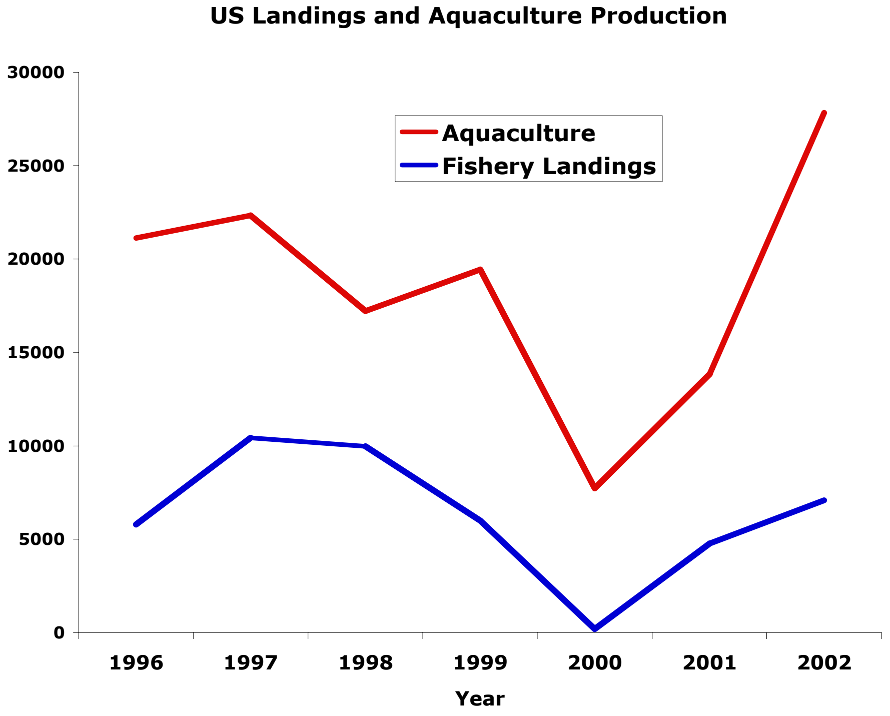

**Figure 1.** U.S. production of crayfish (mt) from aquaculture and capture fisheries, 1996-2002 (NMFS 2002).

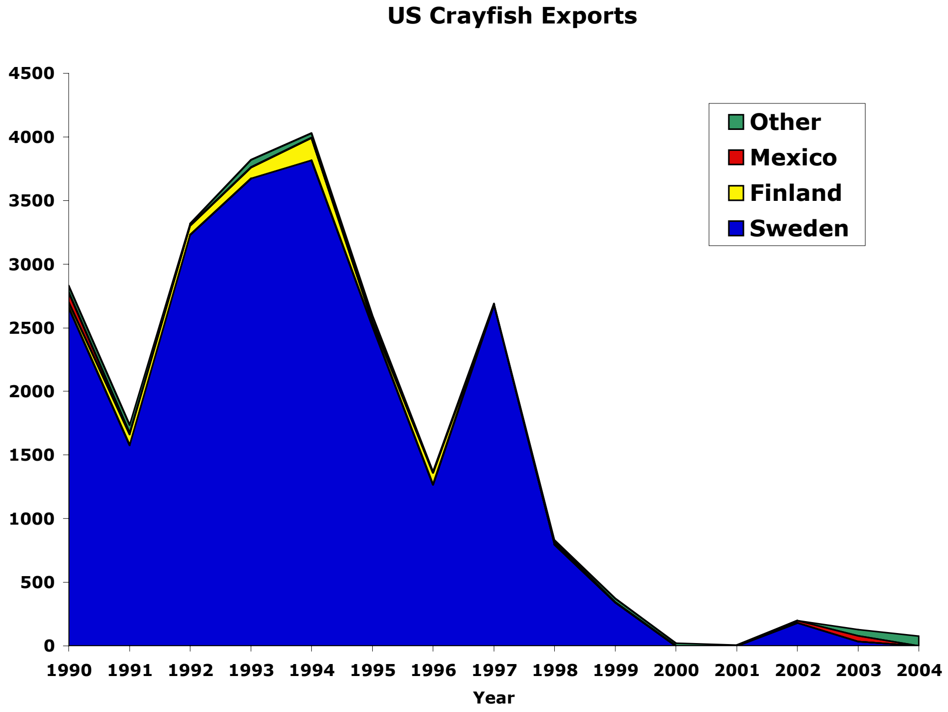

**Figure 2.** Crayfish (mt) exported by the U.S. from 1990-2004 (NMFS 2005).

In contrast to exports, imports of red swamp crayfish have climbed. Imports come almost exclusively from China (Figure 3; NMFS 2005). China had very good weather conditions for crayfish aquaculture in the early to mid 1990s, while weather disrupted Louisiana production, allowing Chinese products to penetrate the frozen-crayfish market. In a complaint to the U.S. International Trade Commission in 1997, industry representatives stated that Chinese imports were taking up to 70% of the U.S. market (Fitzgerald 1998). It should be noted that this market share refers to frozen crayfish, not live. All live crayfish sold in the U.S. are produced domestically. To protect U.S. crayfish producers, stiff tariffs have been placed on Chinese imports. Despite this, Chinese imports are typically priced below U.S. product. Some crayfish suppliers note that their crayfish products may be supplemented with Chinese product when domestic product availability is low. Chinese imports may be a combination of aquaculture and capture of wild (introduced) crayfish, with some aquaculture production coming from aquaculture facilities targeting other species, but also producing crayfish (Huner 1995).

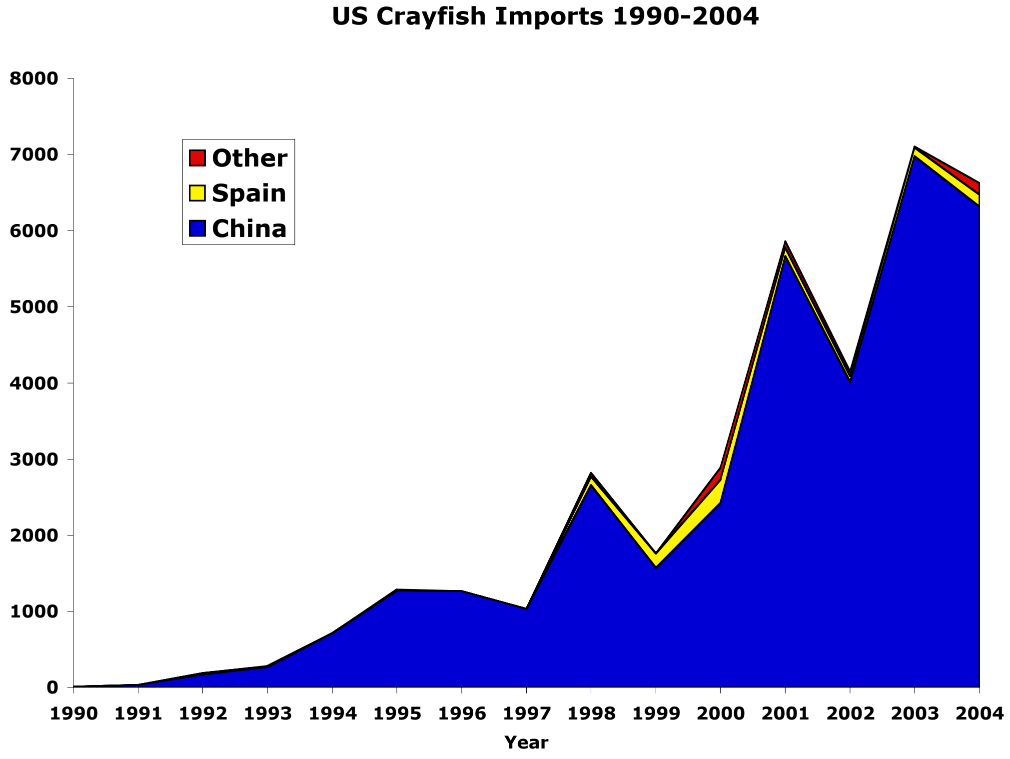

**Figure 3.** Crayfish (mt) imported into the U.S. from 1990-2004 (NMFS 2005)

## Types of Aquaculture Systems

Crayfish can be raised a number of ways, most commonly in extensive systems in conjunction with an agricultural crop. Common methods of farming red swamp crayfish in the U.S. include the following (adapted from Wickins & Lee 2002):

- *Rotation with rice*: Crayfish are raised in rice fields with upraised banks. During spring, rice is cultivated; in fall, fields are re-flooded for crayfish, which may be part of a local self-sustaining population or re-stocked by the farmer. This may also be modified into a rice-crayfish-soybean rotation. In this, as with the following two methods, additional forage need not be supplied, as crayfish feed off detritus and small invertebrates.

- *Open agricultural ponds*: Ponds are placed in marginal growing areas of agricultural land. "Crops" of rice or grass are grown in the area of the pond bed while crayfish are aestivating or spawning in their burrows during spring and summer. When the pond is re-flooded in fall, the crop provides the basis for a detrital food web to support crayfish.
- *Marsh, swamp, and wooded ponds*: Ponds in marsh, swamp, or wooded areas are drained and flooded for crayfish production. Preventing these ponds from anoxic conditions is problematic, and yields are typically lower than with the other two methods.

Less information is available on Chinese methods of crayfish aquaculture. In China, crayfish may be raised in rotation with rice, but reports also state that Chinese crayfish are raised primarily in polyculture systems targeted to raising fish (Huner 1995). Crayfish are harvested with baited traps deployed and collected by boat (Huner 1995; Romaire 1995; Huner 2002).

The flooded fields used for crayfish aquaculture provide additional ecological and societal benefits. In particular, these flooded areas provide extensive habitat and food for a wide variety of waterfowl (Fleury & Sherry 1995; Huner et al. 2002). Aquaculture ponds are also valued for flood control, as reserves for waterways during dry periods, and for providing food to wild fish stocks when water is released from ponds. Farmers also avoid the practice of burning crop stubble by converting it into crayfish forage (J. Huner pers. comm.).

**Status of Wild Populations**

Globally and domestically, crayfish fauna face ecological pressure. Approximately 50% of U.S. and Canadian crayfish species are recognized as vulnerable; 19% are listed as endangered, 13% are listed as threatened, and 15% are listed as species of special concern. Additionally, two species of North American crayfish may already be extinct (Taylor et al. 1996). Native U.S. crayfish are particularly vulnerable to environmental stresses, since species ranges may be very restricted, as small as a single river drainage. In Australia, 33 of 120 native species of crayfish are considered in need of conservation; in Europe, 3 of 5 native crayfish species face similar circumstances (Taylor 2002).

The red swamp crayfish, the major species on the U.S. market, while it may play a role in the decline of other species (see below), is not itself under decline. Wild populations of red swamp crayfish in its native habitat are healthy (Taylor et al. 1996), and the species has expanded its range considerably (Hobbs et al. 1989; Benson & Fuller 1999; Taylor 2002). In North America, the red swamp crayfish is native to the southern U.S., but its current range extends to 16 additional U.S. states, including Hawaii (Figure 4; Benson & Fuller 1999). Other North American crayfish that have extended their range within the U.S., and subsequently been considered problematic as invasive species, include the rusty crayfish, the signal crayfish, and the virile crayfish, *Orconectes virilis* (Hobbs et al. 1989; Lodge et al. 2000a). The use of crayfish as bait, particularly rusty and virile crayfish, has been identified as the chief method of crayfish range extension within the U.S. (Lodge et al. 2000a). Rusty and virile crayfish grow quickly, compete aggressively with many native crayfish species, and have been directly implicated in the decline of several other crayfish species. Because of the attention focused on these "bait-bucket" introductions, less attention has been paid to aquaculture as a vector for crayfish introduction in the U.S., but it is considered of increasing importance (Lodge et al. 2000a). Contributing to the spread of red swamp crayfish has been a historical lack of recognition that a species native to one state may act as an alien pest in another, or even in another river drainage in its native state. National laws aimed at curtailing the introduction of alien species typically focus on international transplantation while ignoring inter-state movement of organisms. However, more states are passing legislation to stop the introduction of exotic species.

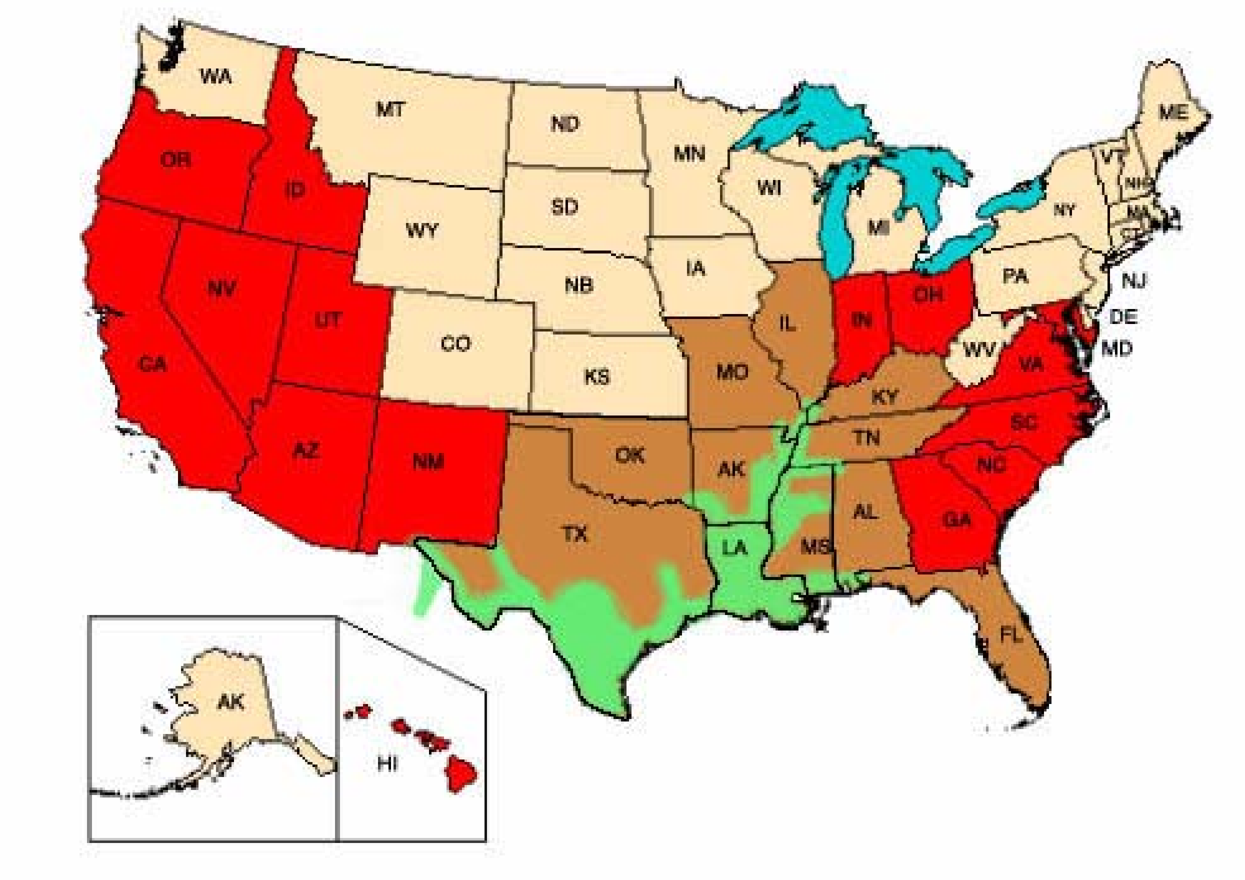

**Figure 4.** Introduced and native range of red swamp crayfish. Green indicates its native range, brown states contain part of its native range, and red states have introduced populations. Modified from Busack (1998) and Benson and Fuller (1999).

Across the world, aquaculture has been recognized as a primary vector for the extension of the red swamp crayfish's range (Lodge et al. 2000a; Wickins & Lee 2002). The red swamp crayfish has extended its range from North America to every continent except for Australia and Antarctica (Huner 1995). Many of the countries in its extended range cultivate red swamp crayfish for food (Ackefors 1999). The only country that exports red swamp crayish in any great amount to the U.S. is China (see above). So, even though red swamp crayfish introductions have caused severe ecological problems globally, little of the crayfish farmed abroad, with the notable exception of China, ever makes it to the U.S. market.

**Scope of the analysis and the ensuing recommendation:**
Because this report is primarily concerned with farmed crayfish available on the U.S. market, it includes an analysis of and recommendations for red swamp crayfish, *P. clarkii*, produced in Louisiana and China. While this report discusses problems with red swamp crayfish as an alien species in U.S. states outside of its natural range, Seafood Watch® bases its recommendations for domestically produced crayfish on conditions in Louisiana, as the state produces approximately 90% of U.S. farmed crayfish. Also, though domestic production includes varying amounts of the eastern white river crayfish, *P. acutus acutus*, and the gulf white river crayfish, *P. zonangulus*, this report does not discuss these species specifically. Wild crayfish and species of farmed crayfish other than red swamp crayfish are not considered in this report.

## Availability of Science

Considerable data are available on red swamp crayfish from peer-reviewed and gray literature. Crayfish aquaculture methodology, crayfish diseases, and crayfish ecology and basic biology have been particularly well studied. The effects of red swamp crayfish as an introduced species in Europe, U.S. states beyond its native range, and many other regions, have also received considerable attention; less direct information is available on the effects of crayfish introductions in China. There has been little research, however, apart from a single study, on the genetic structure of farmed or wild red swamp crayfish (Busack 1988). Extensive data on the nature and effects of effluents from crayfish farming are also lacking. The National Marine Fisheries Service (NMFS) provides data on imports, exports, and total domestic production of red swamp crayfish. Similarly, the Louisiana State University (LSU) Agricultural Center summarizes Louisiana crayfish aquaculture statistics. Data from other states are available in some cases from their respective Departments of Agriculture.

## Market Availability

**Common and market names:**
Red swamp crayfish is also known as Louisiana crayfish, crawfish, crawdad, and mudbug. Other market names include crayfish and crawfish.

**Seasonal availability:**
Availability of live crayfish (U.S. domestic only) varies seasonally. Crayfish are harvested fall through spring in southern Louisiana. Frozen crayfish is available year-round from both domestic and foreign sources.

**Product forms:**
U.S. crayfish are available live and as frozen peeled tail meat. Crayfish imported from China are available frozen whole and as frozen peeled tail meat.

**Production, import, and export sources and statistics:**
Data on domestic production, import, and export of red swamp crayfish are available from NMFS (NMFS 2003; NMFS 2005). The LSU Agricultural Center provides annual summaries of crayfish production, with the last available data being for the year 2004 (LSU Ag. Center 2004). In 2003, the U.S. exported 177 mt of crayfish, a decline of 95% over the previous ten years

(NMFS 2005). In contrast, Chinese imports were 7,101 mt in 2003, an increase of 2,426% over the same ten years (NMFS 2005). Domestic production has been variable with a severe drop in 2000 and an increase in production since (Figure 1). In 2002, domestic production was nearly 34,902 mt, 80% of which was from aquaculture facilities (NMFS 2003).

## Analysis of Seafood Watch® Sustainability Criteria for Farmed Species

### Criterion 1: Use of Marine Resources

**Use of wild fish as feed in crayfish aquaculture**

The use of wild fish stocks as sources for feed in aquaculture operations has become a conservation concern, with aquaculture of some carnivorous species requiring an input of wild fish that is greater that the output of fish produced (Naylor et al. 2000). Farming of crayfish, on the other hand, is a very sustainable form of aquaculture, as cultivation of red swamp crayfish, as it is commonly practiced, requires no use of supplemental feed containing fishmeal or fish-oil. Minor amounts of freshwater and marine fish are used to bait traps during harvesting, but no fish are caught for processing for feed (Caffey et al. 1996).

What differentiates crayfish aquaculture from other types of aquaculture that require supplemental feed is the crayfish's omnivorous feeding behavior. Crayfish feed on many levels of a detrital food web and include in their diet large amounts of plant matter and detritus, as well as worms, snails, insects, and small crustaceans, which provide the animal matter they require to gain sufficient energy and protein (McClain et al. 1998; Wickins & Lee 2002). These invertebrates and crustaceans can be supported by simply flooding agricultural fields or culture ponds, as the decomposition of plants creates all their food necessities, and in turn their inhabiting the flooded areas provides food for the crayfish, and helps support a self-sustaining crayfish population.

Some sources on crayfish farming indicate that supplemental feed may be used, but these supplements tend to be additional vegetable matter such as hay or cattle pellets (Robinson 1989; Wickins & Lee 2002). However, growers have generally found that supplemental feed does not provide sufficient additional production of crayfish to justify the cost (McClain et al. 1998; Wickins & Lee 2002). As a result most modern crayfish aquaculture operations do not use supplemental feed.

Seafood Watch® considers three components when evaluating the use of marine resources in producing farmed fish: the quantity of wild-caught fish used in producing fishmeal and fish oil used in the aquaculture operation; the percent of fishmeal and fish oil in aquaculture feed (the inclusion rate); and the weight of aquaculture feed used per unit weight of farmed fish produced (the feed conversion ratio). Because red swamp crayfish grow in agricultural fields and ponds that require no food supplementation, data on feed conversion ratios for this species are not available. Additionally, since crayfish aquaculture operations do not use feed that contains fishmeal or fish oil, the first two components of this evaluation are zero, and the use of marine resources by extension is also zero. It still remains important to note, however, that some, unquantified amount of freshwater or marine resource is utilized as bait in the harvest of crayfish from aquaculture ponds.

**Source of stock for farmed species**

Wild stocks of red swamp crayfish are considered stable (Taylor et al. 1996). Significant pressure is not put on wild stocks to maintain aquaculture operations, because aquaculture populations are self-sustaining. Even when ponds are completely drained, crayfish survive in burrows until re-flooding and can reenter newly flooded aquaculture ponds from the surrounding area (Huner 1995; Taylor et al. 1996; Huner 1997). The aquaculture facility itself may be the source for the local crayfish population, as crayfish frequently escape aquaculture facilities by burrowing, traveling over land, or escaping during the release of water from the facility.

**Synthesis**

In both the U.S. and China, aquaculture of crayfish uses no marine resources in feed as no supplemental feed is needed for farming red swamp crayfish. Crayfish are raised in extensive ponds or flooded agricultural fields, typically rice fields, which provide all the necessary food for red swamp crayfish in the form of plant matter, detritus, and invertebrates and crustaceans that feed on the decaying plant matter. The only possible use of freshwater or marine resources in farming crayfish is in the bait utilized in their capture during harvest operations; the amount used is unquantified, but is thought to be very low. The omnivorous nature of red swamp crayfish contributes to the self-sustainability of farmed crayfish populations, as does the crayfish's ability to burrow during dry periods (i.e., when fields and ponds are drained for agriculture), and thus restock future farm operations once fields are flooded again. Crayfish can also move into the re-flooded pond or field from the surrounding area, helping to restock aquaculture operations. Due to the self-sustainability of crayfish populations, aquaculture operations rarely have need to re-stock farms with wild crayfish, thus pressure on wild populations is low.

**Use of Marine Resources Rank:**

**U.S. and China:** [✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

**Criterion 2: Risk of Escapes to Wild Stocks and Ecosystems**

Crayfish aquaculture has resulted in the establishment of red swamp crayfish populations around the world, including throughout the U.S. (Penn 1954; Taylor et al. 1996; Lodge et al. 2000b; Lodge et al. 2000a; Taylor 2002). The impacts of red swamp crayfish escapes from aquaculture are entirely dependent on whether the aquaculture facility is located within or outside the species' native range. Therefore, the impacts of escapes from facilities in the U.S., primarily in Louisiana, are currently considered moderate, while the impacts of escapes from Chinese facilities are considered severe.

**U.S. and China: Frequency of escapes**

Red swamp crayfish regularly escape from aquaculture facilities through a combination of their life history characteristics and methods of crayfish aquaculture. Red swamp crayfish burrow in the banks of streams and ponds, which allows them to travel beyond aquaculture fields and ponds. Additionally, crayfish can survive exposure to the air and thus may be able to travel short distances over land from aquaculture facilities to the surrounding area. Hobbs et al. (1989) stated the problem directly: "As it is impossible to prevent the species from escaping from the earthen pond systems employed to raise the crayfish, one can anticipate that a successful culture project will be tantamount to a successful transplantation."

### U.S.: Impacts of escaped crayfish on the surrounding environment

Louisiana produces most of the domestically-farmed red swamp crayfish on the U.S. market, in areas within its native range. Escapes from aquaculture in Louisiana, therefore, probably have little impact on native red swamp crayfish populations or local ecosystems. Moreover, because crayfish move between wild and farmed populations, and because there has been no selective breeding of farmed crayfish, there is no theoretical reason for wild and aquacultural populations to be genetically distinct. Only one study has been done on genetic variation in red swamp crayfish, both wild and farmed, and it found no significant variation between or within sampled populations (Busack 1988).

Crayfish do cause considerable harm to U.S. ecosystems outside their native range, although research on impacts has concentrated on *Orconectes* species (Lodge et al. 2000a). Red swamp crayfish readily establish populations in areas where they have been introduced due to their ability to survive fluctuating environments, their capacity to brood young, and their relatively high growth and reproduction rates (Hobbs et al. 1989). Once established, introduced crayfish can displace native crayfish species and alter ecosystem structure. Crayfish species function as keystone species, exerting control over community structure; they can reduce aquatic vegetation, alter habitat through burrowing, reduce insect populations and by extension the food available to fish, and reduce amphibian populations (Taylor et al. 1996; Lodge et al. 2000a).

Escape of crayfish from aquaculture in areas where they are non-native has contributed to the severe decline of crayfish biodiversity in the U.S. and is considered an ongoing threat (Lodge et al. 2000a; Taylor 2002). Therefore, while crayfish aquaculture is a low conservation concern in areas where red swamp crayfish are native, such as Louisiana, care must be taken to prevent red swamp crayfish aquaculture operations in areas where they are non-native. This includes not only whole states where red swamp crayfish are non-native, such as North Carolina and South Carolina, but also river drainages where they have not occurred historically, even if red swamp crayfish may be native to other parts of that particular state. North American crayfish are highly diverse, and many species are highly geographically restricted, some to a single river drainage (Taylor et al. 1996: Taylor 2002). Therefore, transplantation between drainages can result in conflict between aquaculture crayfish and native populations.

### China: Impacts of escaped crayfish to the surrounding environment

Few scientific studies are available on the impacts of crayfish in China, although escaped crayfish have been reported to damage fish and aquatic plant populations, disrupt local food webs, and damage crops (Li & Xie 2002). Mechanisms for these disruptions have been heavily documented in other areas where crayfish have been introduced, including North America, Europe, Japan, and Africa (Hobbs et al. 1989; Gherardi & Holdich 1999; Lodge et al. 2000a; Taylor 2002; Howard & Matindi 2003; Maezono & Miyashita 2004; Geiger et al. 2005; Rodriguez et al. 2005). Because these mechanisms have been documented across the globe, it is likely they drive the negative effects reported in China. As mentioned above, crayfish function as keystone species in almost every area where they have established an invasive population, reducing macrophyte cover, competing with native fish for prey, and disrupting native detrital food chains (Holdich 1999; Taylor 2002; Howard & Matindi 2003; Maezono & Miyashita 2004; Geiger et al. 2005). Additionally, the burrowing behavior of crayfish can modify heavily the banks of rivers and lakes, destroying habitat for native species (Holdich 1999; Taylor 2002; Geiger et al. 2005). Once established, red swamp crayfish are nearly impossible to eradicate (Holdich 1999; Taylor 2002; Howard & Matindi 2003; Maezono & Miyashita 2004; Geiger et al. 2005).

**Synthesis**

Red swamp crayfish will almost certainly escape from any aquaculture operation as crayfish aquaculture is currently practiced. In the U.S., most crayfish on the market come from Louisiana, where red swamp crayfish is native and not genetically distinct from wild populations. The risk of escaped crayfish to wild stocks in Louisiana, therefore, is currently considered moderate. However, expansion of crayfish aquaculture to other states or to drainages where red swamp crayfish are not native should be strongly avoided. Red swamp crayfish are not native to China, and their escape from Chinese aquaculture operations has caused considerable ecological damage in China through alteration of the food web and habitat modification. The risk of escaped crayfish to ecosystems in China, therefore, is considered a critical conservation concern.

**Risk of Escaped Fish to Wild Stocks Rank:**

| | | | | |
|---|---|---|---|---|
| **U.S.:** | Low 🟩 | [✓ **Moderate** 🟨] | High 🟥 | Critical ⬛ |
| **China:** | Low 🟩 | Moderate 🟨 | High 🟥 | [✓ **Critical** ⬛] |

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

Red swamp crayfish in aquaculture experience few problems with disease, and therapeutants, such as antibiotics, are not typically applied to farmed populations (Huner 2002). Disease problems may be rare because extensive operations keep population densities low, and because traps used in collection are biased toward healthy individuals (Huner 1995; Wickins & Lee 2002).

Although farmed red swamp crayfish populations suffer little from disease, they frequently harbor diseases lethal to crayfish species outside of North America. In Europe, North American crayfish brought over in the late 19th century brought with them “crayfish plague,” caused by the fungus *Aphanomyces astaci*, which has devastated native European crayfish stocks (Edgerton et al. 2002; Edgerton et al. 2004). This has resulted in a positive feedback for the increased use of red swamp crayfish in European aquaculture; the more native populations are reduced or extirpated by crayfish plague, the more the plague-resistant red swamp crayfish are cultivated for food and to replenish “wild” crayfish stocks (Ackefors 1999). The IUCN (The World Conservation Union) lists crayfish plague (but no crayfish) on its “100 of world’s worst invasive alien species” list (Lowe et al. 2000).

Despite the clear effect of disease on European stocks, disease is not a major conservation concern for U.S.-produced crayfish. The fungus that causes crayfish plague is native to the U.S., and U.S. species in general appear resistant to it. There is no evidence to date that diseases are passing between aquaculture crayfish and wild crayfish populations in the U.S.

In China the situation is uncertain. Crayfish have been introduced to the regions of Anhui, Shanghai, Jiangsu, and Hong Kong, all in central to southern coastal regions. The only native crayfish in China reside in the northeast, near the Korean Peninsula. There are no reports of introduced red swamp crayfish populations in areas of native crayfish, but data are lacking. It is also possible that red swamp crayfish would not survive in the colder regions where native Asian crayfish occur. However, red swamp crayfish have established populations at similar latitudes in Japan, Europe, and the U.S. Given the effect of red swamp crayfish and crayfish plague on other indigenous crayfish populations around the world, introduction of the red swamp crayfish into areas of native crayfish in China would almost certainly be disastrous.

**Synthesis**
In the U.S., there have been almost no problems with disease in crayfish aquaculture and no reports of transfer of disease between aquaculture operations and wild stocks. The risk of parasite and disease transfer is thus considered low in the U.S. Outside of North America, especially in Europe, however, aquaculture of red swamp crayfish has had devastating effects on native crayfish populations due to the spread of "crayfish plague," a fungus native to North America but considered highly invasive outside of North America. In China, little information is available on the transfer of disease from crayfish aquaculture to wild populations, but currently it is unlikely that Chinese aquaculture operations and the range of native crayfish overlap, and there are no reports of disease passing to native crayfish. However, given the devastation of crayfish fauna outside of North America by crayfish plague, the likelihood of escapes from aquaculture operations, and the ability of crayfish to establish and expand invasive populations, the risk of disease transfer to native crayfish in China is considered moderate.

**Risk of Disease and Parasite Transfer to Wild Stocks Rank:**

**U.S.:** [✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

**China:** Low 🟩 [✓ **Moderate** 🟨] High 🟥 Critical ⬛

## Criterion 4: Risk of Pollution and Habitat Effects

### U.S. and China

Aquaculture operations typically impact the surrounding environment in many ways, most notably through the clearing of mangroves for aquaculture ponds and the release of biological and chemical waste. Crayfish farms, however, are typically sited in agricultural lands of low ecological sensitivity, rather than in sensitive coastal zones. Additionally, since antibiotics and other therapeutants are not regularly used in crayfish aquaculture, and as crayfish are highly sensitive to pesticides, chemical runoff from crayfish farming operations is probably low. In aquaculture operations, high stocking densities, high feed inputs, and lack of water treatment exacerbate high nutrient levels in effluent. In theory, nutrient runoff from crayfish ponds is mitigated by not using supplemental feed, by maintaining low crayfish densities, and through the presence of vegetation, which uses nutrients in crayfish ponds and acts as a biological "filter."

Surprisingly little information is available, however, on the exact nature and effect of effluents from crayfish facilities. Water can be discharged from crayfish ponds when they are drained after harvesting the crayfish, when rain causes ponds to overflow, or when farmers exchange water to improve water quality in ponds. A study by the Southern Regional Aquaculture Center (SRAC 1998; SRAC 1999) examined effluents from a number of aquaculture operations, including crayfish farms. Scientists found that the type of vegetation within crayfish ponds influenced the effluent; ponds with native vegetation had lower concentrations of nutrients and solids (SRAC 1998; SRAC 1999). Effluent quality was poorest in the summer, when ponds are likely to be drained.

There is no evidence that effluents from crayfish aquaculture have any regional or local effects such as algal blooms or alteration of benthic communities (LSU Ag. Center 2003); however, no scientific studies were found for this report on the effects of effluents on local ecosystems. Any such study would be complicated by the location of the operations in agricultural areas and in rotation with plant crops.

### Synthesis

In both the U.S. and China, crayfish aquaculture operations are carried out in agricultural areas of low ecological sensitivity, and crayfish stocking densities are typically low. Chemicals are not used in crayfish aquaculture operations, due to the sensitivity of crayfish to such chemicals, so the risk of chemical runoff is also low. Information on the effects of nutrient effluents from aquaculture operations is sparse, but reports of facilities in the U.S. being out of compliance with Environmental Protection Agency (EPA) standards have not been found. To date, there has been no published examination of effluent effects at the local or regional level, but such effects are expected to be low based on the methods used for crayfish aquaculture.

**Risk of Pollution and Habitat Effects Rank:**

**U.S. and China:** [✓ **Low** 🟩] Moderate 🟨 High 🟥

## Criterion 5: Effectiveness of the Management Regime

Effective management must be practiced for aquaculture to be sustainable. Sound management includes application of relevant laws to aquaculture and the use of licensing to control location, size, and stocking densities on farms. Regulation of farming practices that can alter the adjacent environment such as effluent release, use of therapeutants, escape of farmed fish, or predator controls that harm or displace taxa such as birds or mammals should also be implemented where appropriate. The formulation of "better management practices" (BMPs) also aids aquaculture practitioners in complying with regulations and meeting sustainability goals. Lastly, effective management must utilize a precautionary approach to avoid risk and guide industry development.

**U.S.**

Management of aquaculture encompasses several issues, thus U.S. regulation is dispersed across many agencies, and split between state and federal control. In most states, aquaculture operations are licensed by the Department of Agriculture in conjunction with state and federal regulations. Licenses require compliance with Environmental Protection Agency (EPA) rules on water quality. The EPA sets national guidelines on effluents through the National Pollutant Discharge Elimination System (NPDES). In addition to regulating pollutants, NPDES requires aquaculture operations have “minimal adverse effects on the biota indigenous to the area” (EPA 2005). Because crayfish aquaculture most commonly uses extensive, vegetated ponds with no addition of high protein feeds, effluent discharge in the form of nitrogenous waste should be minimal.

The Food and Drug Administration (FDA) regulates the levels of pathogens and chemicals, including therapeutants, which may be contained in seafood. Testing and regulation generally take place at the level of the processing plant, which must follow Hazard Analysis Critical Control Point (HACCP) plans (FDA 2001). This testing would detect potential problems from aquaculture practices such as parasites and chemical use.

Louisiana, where most U.S. aquaculture of crayfish is practiced, has published guidelines on best management practices for aquaculture including crayfish (Louisiana State University Agricultural Center 2003). These guidelines mostly address issues of water quality and discharge. They do not address escapement, which will inevitably occur in crayfish aquaculture (Hobbs et al. 1989), but as previously noted, red swamp crayfish are native to the area.

The most pressing regulatory issue outside of Louisiana and other areas where red swamp crayfish are native is the prevention of escape and subsequent establishment of introduced crayfish populations. Regulations regarding the introduction of crayfish species vary from state to state, from a “blacklist” approach, where any species other than those on the banned list may be brought into the state, to a “white-list” approach, where only explicitly permitted species may be brought in without approval. White-lists are considered a more precautionary approach (Lodge et al. 2000b). Additionally, some states have become sensitive to “bait-bucket” introductions and have either enacted laws or started educational programs to deter people from releasing non-native species or moving animals between water bodies within the state. While not specifically aimed at aquaculture, some of these laws might be applied to aquacultural release. Some examples of state regulations include:

- **Alabama:** Red swamp crayfish are native to southern Alabama. While not specifically addressing aquaculture, the Division of Wildlife and Fisheries prohibits releasing any aquatic wildlife into a water body except “those waters from which it came” (Alabama Dept. of Cons. and Nat. Resources 2003).
- **North Carolina:** Red swamp crayfish are not native to North Carolina, but have been introduced. Aquaculture licenses are issued by the Department of Aquaculture and the states uses a white-list approach to introduced species. Red swamp crayfish are on the

white list. In 2002, there were seven red swamp crayfish farms in North Carolina (North Carolina Dept. of Ag. and Consumer Services 2001).

- **Delaware:** Delaware Sea Grant not only promotes aquaculture, but also lists red swamp crayfish as "naturally" occurring in the Mid-Atlantic region, ignoring its exotic status in all east coast states except Florida, where it is native only in the westernmost tip (Delaware Sea Grant 2005).
- **Florida:** Red swamp crayfish are native only in the westernmost tip of the state. Florida uses a white-list approach. Red swamp crayfish are considered non-native by the Department of Agriculture, but may be cultured with a special permit. However, pond aquaculture of red swamp crayfish is expressly prohibited (Florida Dept. of Ag. and Consumer Services 2002).
- **Ohio:** Red swamp crayfish are not native to Ohio, but have been introduced. Ohio uses a modified white-list approach with "A" and "B" lists. "A" species are explicitly permitted, while "B" species are exceptions with special permitting. Red swamp crayfish is considered a "B" species, and may be cultured with two levels of escapement protection (Ohio Division of Wildlife 2005).
- **Georgia:** Red swamp crayfish are not native to Georgia, but have been introduced. Georgia uses a black-list approach but focuses on the pet trade and certain aquatic nuisance species such as grass carp (Georgia Dept. of Nat. Resources2003). In aquaculture, only "domestic" fish may be farmed, but this includes any introduced species that have established populations in the state prior to 1992 (Georgia Dept. of Nat. Resources 2003).

While many states have laws on the books to control introduced species and reduce movement of "aquatic nuisance species" between drainages, their effectiveness in preventing aquaculture of red swamp crayfish in river drainages where they are not native is unclear. Certainly, red swamp crayfish are legally farmed in states where they are not native (e.g., North Carolina and Georgia). The lack of cohesive state policies on aquaculture and introduced species and the presence of initiatives in many states to promote aquaculture of non-native crayfish species demonstrate that a precautionary approach is not being used nationally to guide the crayfish aquaculture industry (Lodge et al. 2000b).

### China

Since a move towards privatization in the late 1970s, private ownership of aquaculture facilities has become the norm in China (Hishamunda & Subasinghe 2003). The Chinese government issues licenses for aquaculture operations controlling site and size. For the past several decades, it has aggressively promoted aquaculture development, particularly in "underutilized" areas such as flooded fields and tidal flats, to promote economic development and provide a protein source in rural areas (Hishamunda & Subasinghe 2003). As a result, full consideration of environmental impacts such as escapement of exotic species and density of operations may be lacking.

China has also enacted laws to regulate aquaculture's impact on the environment through pollution and the use of therapeutants (Hishamunda & Subasinghe 2003). In 2002 the European Union (EU) temporarily banned the importation of crayfish and several other food products from China after chloramphenicol, a powerful antibiotic banned from agricultural use in Europe, was found in imported shrimp and honey from China (Koonse & Salsbury 2003; Anonymous 2002).

This chemical is prohibited from use as a feed additive in the U.S. as well, and the FDA prevents importation of any food containing the chemical (Anonymous 2002). It is unclear how extensive the problem is in crayfish, as they are often lumped with shrimp in reporting on the issue. Antibiotics are not generally used in extensive red swamp crayfish aquaculture, but are heavily used in intensive shrimp aquaculture (Primavera et al. 1993). Crayfish may be raised in polyculture with fish in China (Huner 1995), a possible source of therapeutant exposure. Louisiana reported finding trace amounts of chloramphenicol in crayfish, below the FDA and EU thresholds (Lazaroff 2002). It is unlikely that antibiotics or other therapeutants are regularly used in crayfish aquaculture, but the episode does indicate problems in regulation of the issue by the Chinese government.

China has acknowledged that invasive alien species have caused extensive environmental and economic damage to the country (Xie et al. 2001; Li & Xie 2002), and has passed several laws to mitigate the problem including quarantines on plants and methods to prevent accidental introductions of pathogens (Eco-security Task Force 2002). However, implementation of these laws may be hampered by infrastructural problems and a lack of expertise at the inspection level (Arthur 1996). Furthermore, red swamp crayfish have already established populations in some areas of the country, obviating the need for their importation. Information was unavailable regarding whether policies exist to control the spread of red swamp crayfish aquaculture to new areas within China.

**Synthesis**

Both the U.S. and China have moved to enact laws that mitigate the effects of aquaculture operations such as pollution. In the U.S., licensing by state agricultural departments typically requires compliance with EPA guideline on water quality, and the FDA tests food products for chemicals and pathogens. While the bulk of U.S. crayfish are raised in areas to which it is native, better state, federal, and industry guidelines are required to ensure that expansion of the industry as it is currently practiced (i.e., with a high chance of escapement) will only be in areas within the red swamp crayfish's native range. U.S. management is considered moderately effective. China has faced questions on its ability to regulate the importation of exotic species and the use of therapeutants, but does have regulations on the books. China has aggressively pursued expansion of aquaculture, and it is unknown whether or not it has enacted any controls on the introduction of red swamp crayfish to areas of China where it has not yet established populations. Management in China is also considered moderately effective.

**Effectiveness of the Management Regime Rank:**

**U.S. and China:** Low 🟩 [✓ **Moderate** 🟨] High 🟥

## Overall Evaluation and Seafood Recommendation

Red swamp crayfish farming in both the U.S. and China uses no marine resources for supplemental feed or stocking; use of marine resource is thus considered to be a low conservation concern for the industry in both countries. Crayfish regularly escape aquaculture operations, readily establish populations in areas where they are non-native, and have been demonstrated to have severe effects on surrounding ecosystems. Because most domestic crayfish are farmed in Louisiana, within the native range of the red swamp crayfish, the risk of escaped fish to wild stocks in the U.S. is considered moderate. Red swamp crayfish, however, are not native to China, and have been reported to cause extensive habitat and ecosystem damage. The risk of crayfish escapes and subsequent damage to ecosystems in China, therefore, is considered a critical conservation concern. Diseases do not typically harm red swamp crayfish in aquaculture because the species is resistant to most major crayfish diseases, including crayfish plague, and because farming of red swamp crayfish typically occurs at low population densities. No problems with disease in crayfish aquaculture have been reported domestically. Abroad, however, red swamp crayfish and other North American crayfish species have provided a vector for crayfish plague, which has decimated populations of native crayfish species, especially in Europe. In China, though red swamp crayfish have caused extensive habitat and ecosystem damage, crayfish introductions are reported in central coastal areas, while the only crayfish species native to China are in the far north, thus no disease transfer to wild crayfish populations has been reported. Following a precautionary approach, however, due to the spread of crayfish plague to other areas of the world, the risk of transfer of disease from crayfish aquaculture to wild crayfish populations in China merits moderate conservation concern.

The risk of pollution and habitat effects are inherently low in crayfish farming. Crayfish aquaculture takes place in agricultural areas, crayfish ponds have low stocking densities, and no additional feed, which may decrease effluent quality, is added to crayfish ponds. Vegetation in ponds provides the detrital food web needed for the self-sustaining populations of red swamp crayfish and helps to improve water quality. For both U.S. and China the risk of pollution effects is low. Lastly, management in both the U.S. and China is considered moderately effective. While the U.S. manages the licensing of farms and has effective laws on the books regarding effluents and therapeutants, it lacks a cohesive management policy to prevent the spread of red swamp crayfish to areas where it is non-native. In China, concerns remain on the effectiveness of laws to control the import of exotic species and the use of therapeutants. Additionally, no information is available on regulations to prevent the spread of exotic aquaculture species within China. Considering the above criteria, U.S. crayfish is given the overall seafood recommendation of "Best Choice," while crayfish from China is given the overall seafood recommendation of "Avoid."

## Table of Sustainability Ranks

| | Conservation Concern | | | |
|---|---|---|---|---|
| **Sustainability Criteria** | Low | Moderate | High | Critical |
| Use of Marine Resources | √ U.S. and China | | | |
| Risk of fish escapes and damage to ecosystems, including wild stocks | | √ U.S. | | √ China |
| Risk of Disease and Parasite Transfer to Wild Stocks | √ U.S. | √ China | | |
| Risk of Pollution and Habitat Effects | √ U.S. and China | | | |
| Management Effectiveness | | √ U.S. and China | | |

## Overall Seafood Recommendation:

**Farmed red swamp crayfish, U.S.:**

**Best Choice** 🟩 Good Alternative 🟨 Avoid 🟥

**Farmed red swamp crayfish, China:**

Best Choice 🟩 Good Alternative 🟨 **Avoid** 🟥

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