USDA

United States
Department of
Agriculture

Animal and
Plant Health
Inspection
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Center for
Emerging
Issues

July 2007

VS

Assessing Infectious Disease Emergence Potential in the U.S. Aquaculture Industry

Phase 2: Infectious Disease Emergence Qualitative Risk Assessment Tool: Development

Phase 3: Infectious Disease Emergence Qualitative Risk Assessment Tool: Application and Results

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Project Approach

Emerging infectious diseases are diseases that have newly appeared in a population or that have existed but are evolving or increasing in incidence or geographic range. Emerging infectious diseases have affected animal and human health in recent decades, demonstrated by bovine spongiform encephalopathy, variant Creutzfeldt-Jakob disease (vCJD), Hendra virus, and Nipah virus, among others. New diseases will continue to emerge and affect animal and public health, along with the economic well-being of countries throughout the world (Brown 2004; King, Marano, and Hughes 2004).

Disease emergence can occur through the evolution of pathogens or the introduction of existing pathogens to a new location, followed by establishment and spread. Pathogen evolution is driven by biological, ecological, environmental, and societal factors, such as those that put adaptive and selective pressure on microbes. Introduction of agents, hosts, or vectors into new settings (including intracountry spread as well as transboundary spread) is promoted through ecological, environmental, and societal changes, economic forces, migration, trade, and travel (Lederberg, Shope, and Oakes 1992; Morse 1995; Smolinski, Hamburg, and Lederberg 2003).

Current methodologies for pathways analysis and risk assessment focus on predicting the likelihood of movement of known diseases to new locations. However, to be able to prevent or decrease the frequency of emerging disease occurrence, a method to predict emergence and movement of novel or evolving diseases is needed. New approaches are needed to accomplish this. Numerous authors have suggested using the biological, ecological, environmental, and societal factors associated with disease emergence to improve prediction; however, interactions among these emergence factors can be complex, making modeling difficult (Linthicum, Anyamba, Tucker, Kelley, Myers, and Peters 1990; Wilson, Levins, and Spielman 1994; Myers, Rogers, Cox, Flahault, and Hay 2000). Attempts to date have focused on predicting the potential movement of known vector-borne diseases, such as Rift Valley fever, by examining climate and ecological factors (Linthicum et al. 1990; Myers et al. 2000).

The goal of this project was to develop a method that could assess disease emergence potential for an animal industry. The method used information on disease emergence risk factors. The focus of the project was to assess an industry's overall likelihood of disease emergence rather than assessing the likelihood of emergence of a particular disease. Such a tool could be used by industry and government officials to identify vulnerable areas and to effectively target mitigation measures. The tool could be used to monitor how changes in the dynamics associated with an industry increase or could decrease the potential for disease emergence over time.

The U.S. food fish aquaculture industry was chosen for this project to provide focus and specificity during the development of the method. Aquaculture is defined as the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, Glossary of Aquaculture, 2006). Food fish includes finfish and shellfish destined for direct human consumption. The food fish industry in the United States and globally has been developing rapidly. The U.S. and global industries have experienced serious disease outbreaks in recent years. For example, white spot disease, a viral disease of shrimp, first emerged in Japan in 1993 and subsequently spread to many other countries in Asia, Central and South America, and the United States (OIE, International Database on Aquatic Animal Disease, 2006).

Overview of Factors Associated with Infectious Disease Emergence in Aquaculture

Many identified drivers or factors are associated with the new appearance and evolution of aquaculture pathogens, and the spread of pathogens to new locations, including between countries (transboundary) and within countries (intracountry). These factors may overlap and interact with each other in complex ways.

New Appearance and Evolution of Pathogens

Some of the factors that can be associated with the new appearance of pathogens and the evolution of existing pathogens include pathogen and host factors, environmental factors, and the population dynamics of the pathogen and host (Antia, R., Regoes, R.R., Koella, J.C., and Bergstrom, C.T. 2003). An example of a pathogen characteristic related to the evolution of existing pathogens is the mutation of benign wild-type pathogens into more virulent strains, either before or after transmission to a farmed host. Infectious salmon anemia (ISA) is thought to emerge in farmed Atlantic salmon when mutated isolates are transmitted from wild salmonids or, following mutation of benign isolates in farmed salmon, after transmission of the benign isolates from wild salmonids (Nylund, Devold, Plarre, Isdal, and Aarseth 2003). Because pathogen evolution can lower the species barrier, pathogens that mutate more easily, such as RNA viruses, are at higher risk for species-crossing (Kuiken, Holmes, McCauley, Rimmelzwaan, Williams, and Grenfell 2006). Existing pathogens that are known to infect (either clinically apparent or inapparent infection) one host species may be new pathogens for another similar species. Infectious pancreatic necrosis (IPN) was first identified as a pathogen of trout, but subsequently it was found to be pathogenic for a wide range of other fish species (Murray and Peeler 2005). Host characteristics that can play a role in the appearance of new pathogens and the evolution of existing pathogens include age, physiological state, genetic strain, and immunity (Murray and Peeler 2005). Another situation in which a disease can emerge in a new species occurs when a species of fish is introduced into a new geographic area. The newly introduced species may lack the immune defense mechanisms of endemic fish species and, therefore, be more susceptible to existing pathogens (Mauel and Miller 2002).

Environmental factors that reduce immunity in the host or reduce the geographical or behavioral barriers that limit contact and potential pathogen transmission may increase risk for new pathogens or increase the evolution of existing pathogens (Kuiken et al. 2006). High densities of fish, poor management, new rearing conditions, and exposure to infectious agents in aquaculture settings can cause stress on the fish, resulting in decreased resistance to opportunistic infections and favorable conditions for the adaptation and amplification of pathogens (Mauel and Miller 2002; Mjaaland, Hungness, Teig, Dannevig, Thorud, and Rimstad 2002; Murray and Peeler 2005). Exposure to infectious agents on the farm can occur through the introduction of infected stock or contaminated water, feed, and equipment. When barriers between farmed fish and wild fish are broken, farmed fish will be exposed to pathogens infecting wild fish and vice versa. Climate change may affect the geographic range of fish species and of pathogens. For example, fish in Northern European countries are now at increased risk from two diseases, *Lactococcus garviae* and proliferative kidney disease, previously only found in warmer climates (Murray and Peeler 2005).

Species-crossing of a pathogen involves a pathogen donor host species and a pathogen recipient host species. The population dynamics of both the donor host species and the recipient host species, such as the population sizes and the degrees of mixing or interaction, influence the likelihood of a virus persisting in a new species (Kuiken et al. 2006). Three types of interactions influence the likelihood of a virus becoming endemic in a new (recipient) host species: (1) interactions between hosts of the donor and recipient species, (2) host-virus interactions within individual hosts of the recipient species, and (3) host-host interactions within the recipient species (Kuiken et al. 2006). Factors that affect these interactions will affect the likelihood of disease emergence. In addition to host population dynamics, pathogen population dynamics play a role in successful disease emergence. An example of pathogen population dynamics influencing the persistence of a pathogen is the population frequencies of different strains and their varying abilities to evade the host's immune system (Gupta, Ferguson, and Anderson 1998).

Pathways for Transboundary Spread

The factors associated with the transboundary spread of emerging and existing aquaculture diseases from one country to another are primarily related to the introduction of the pathogen through a trade pathway, including trade of live fish, fish eggs, fish products, fish feed, and equipment. Although wild fish do not respect manmade boundaries, aquacultured fish typically have a more controlled environment. This is not true, however, in all situations. For example, international trade of live fish is believed to be one of the main mechanisms contributing to the rapid global spread of koi herpesvirus (KHV) (Gilad, Yun, Adkison, Way, Willits, Bercovier, and Hedrick 2003). Trade in live ornamental fish is thought to be responsible for the spread of emerging iridoviruses. Go, Lancaster, Deece, Dhungyel, and Whittington (2006) found that trade in ornamental fish was linked to an iridovirus epizootic of an economically significant farmed finfish in Australia. Imports of salmonid eggs to Japan since the 1950s are thought to have led to outbreaks of numerous diseases on fish farms in Japan, including IPN, infectious hematopoietic necrosis (IHN), and bacterial kidney disease (BKD) (Yoshimizu 1996). Frozen shrimp imported into the United States were found to contain infectious white spot shrimp virus (WSSV) and thought to be the cause of an outbreak of WSSV in farmed shrimp in Texas (Lightner, Redman, Poulos, Nunan, Mari, and Hasson 1997; Durand, Tank, and Lightner 2000). Imported contaminated fish feed and fishing equipment can lead to outbreaks in the importing country (Murray and Peeler 2005). Wild fish and birds are a pathway for the introduction of aquaculture pathogens across country borders. Ships can move microorganisms and live animals between countries in their ballast water, because they take up ballast water in one country and release it in another (Ruiz, Rawlings, Dobbs, Drake, Mullady, Huq, and Colwell 2000).

Intracountry Spread

Many factors associated with the establishment and intracountry spread of both emerging and existing diseases are similar to factors associated with the appearance of new pathogens and the evolution of existing pathogens. The similarities exist because the mixing of hosts and pathogens, and the stresses on each, play a key role in both processes. The rate and pattern of disease spread on a farm, between farms, and in the wild depend on the spatial distribution, movement, and mixing of the host population (Kuiken et al. 2006). The movement of live fish, including broodstock, fry, fingerlings, and fish eggs, is an important means of intracountry pathogen spread between farms, between wild fish and farmed fish, and between wild fish in different geographic areas. A qualitative risk assessment of the routes of transmission of the fish parasite *Gyrodactylus salaris* identified the anthropogenic movement of live fish as the most important route for the spread of the disease between two river catchments (Peeler, Gardiner, and Thrush 2004). The spread of IHN in Europe was aided by the fact that broodstock may act as carriers and vertically transmit the virus. The disease was introduced to several European trout hatcheries through infected eggs (Ghittino, Latini, Agnetti, Panzieri, Lauro, Ciapelloni, and Petracca 2003). Aquaculture disease control programs rely heavily on the restrictions on the movement of live fish for success (Hastein, Hill, and Winton 1999).

Host, pathogen, and environmental factors play important roles in intracountry pathogen spread. Host factors such as age, physiological state (stressed versus unstressed), and genetic strain influence the susceptibility of fish to infection and disease (Murray and Peeler 2005). Pathogen factors that affect disease spread include virulence, transmissibility, infective dose, and survivability in the environment. Environmental factors, such as the distance between farms, and biosecurity practices, such as treatment of incoming and outgoing water, and disinfection of vehicles, equipment, and personnel, have important effects on the local spread of disease (Murray and Peeler 2005). The release of untreated liquid and solid waste from fish processing plants into waterways or landfills is a mechanism for disease spread (Lightner et al. 1997). Scavenging animals such as wild birds can act as disease vectors (Peeler, Gardiner, and Thrush 2004). Severe weather events can lead to the movement of farmed and wild diseased fish. Water temperature can influence virus replication and onset and severity of mortality (Murray and Peeler 2005). The use of effective disease control and prevention meth-ods on- farms, such as vaccination and rapid removal of sick or dead stock, affect the spread of disease. For example, Norwegian farms that removed dead salmon daily throughout the summer were three times less likely to experience an ISA outbreak compared with farms that removed dead salmon less frequently (Murray and Peeler 2005).

Project Overview

Phase 1: U.S. Aquaculture Industry Profile

As a first step to building an infectious disease emergence risk assessment tool for the U.S. food fish aquaculture industry, it was necessary to develop an understanding of the dynamics associated with the industry and how those dynamics might affect disease emergence. Nine broad areas were examined: (1) agent, host, and vector biology; (2) climate, ecology, and the environment; (3) economics and industry; (4) health management; (5) international trade; (6) the political and regulatory climate; (7) production practices; (8) social and cultural issues; and (9) technology. Detailed information was gathered in each of these areas for the industry in general and for six specific aquacultured species that are important in the United States: catfish, hybrid striped bass, salmon, saltwater shrimp, tilapia, and trout. Once this initial information was gathered, the results were used for phase 2, the development and application of an infectious disease emergence risk assessment tool.

Phase 2: Infectious Disease Emergence Qualitative Risk Assessment Tool Development

Using the information about industry dynamics from phase 1, a tool was developed to help industry managers and government officials understand the "riskiness" of industry practices and the ecologic, economic, political, and social factors for disease emergence, and to identify potential opportunities to mitigate the identified risks. The risk assessment tool had to address three separate elements: disease emergence and evolution, pathways for transboundary spread, and intracountry spread. The tool is structured so that it can be used across the multiple sectors in the aquaculture industry, allowing comparisons to be made across sectors. The tool is applicable over time and capable of capturing changing industry conditions that might signal an increase or decrease in risk. Once the tool was developed, it was applied in phase 3 to four aquaculture sectors in the United States: catfish, salmon, saltwater shrimp, and tilapia.

Phase 3: Infectious Disease Emergence Qualitative Risk Assessment Tool Application and Results

The disease emergence risk assessment tool was applied to four aquaculture sectors in the United States: catfish, salmon, saltwater shrimp, and tilapia. A qualitative risk rank (high, medium, or low) was determined for each sector for each of the disease emergence elements (emergence and evolution, pathways, and spread). The results highlight areas in each sector in which risk mitigation efforts could be targeted to decrease risk.

Phase 2: Infectious Disease Emergence Qualitative Risk Assessment Tool Development

Overview

Within the assessment tool, aquaculture disease emergence and spread is separated into three elements: (1) disease emergence and evolution (henceforth referred to as the evolution element); (2) pathways for transboundary disease spread (henceforth referred to as the pathways element); and (3) intracountry disease spread (henceforth referred to as the spread element). The evolution element examines the potential for new pathogens to appear or for existing pathogens to evolve in the aquaculture setting which are not related to direct transboundary spread of a new pathogen. The pathways element examines the potential for known or new pathogens to move from country to country. The spread element examines the potential for newly emerged, evolved, or introduced pathogens to spread from the point of emergence, evolution, or introduction within a country. Each element has a set of designated risk factors, with some risk factors being included in more than one element. This tool does not assess risk for disease emergence in wild fish and does not address the consequences of disease emergence, such as the economic or environmental impact.

The risk assessment tool was developed in three stages. First, for each disease emergence element, a set of risk factors was identified. Identification of individual risk factors to be included in the risk assessment tool was based on research of the industry and factors for disease emergence. These risk factors were drawn from research of the following broad categories of factors associated with disease emergence: (1) agent, host, and vector biology; (2) ecology, environment, and climate; (3) economics and industry; (4) politics and regulations; (5) health management; and (6) social and cultural issues. Sources used to identify risk factors for disease emergence within the industry included published literature such as journals, industry publications, and government publications, as well as discussions with industry experts and site visits to production facilities. Additionally, risk factors were identified based on standard epidemiologic principles and known risk factors for the transmission and spread of diseases.

Second, definitions for level of risk (high, medium, low, no defined risk) were developed for each factor. These risk rankings allow specific attributes associated with industry sectors to be captured and taken into account within each factor. In general, if a risk factor is used in multiple elements, for example, in both the evolution element and the spread element, the level of risk is assessed using the same definition across elements.

Third, the individual risk factors were classified according to specific criteria as either primary or secondary factors. The primary or secondary classification indicates the level of contribution of the factor to overall risk, independent of the outcome of the risk ranking determined in stage two. Specific criteria were developed based on research of factors for disease emergence in aquaculture.

The complete risk assessment tool covering all three disease emergence elements, with the rationale for including each factor, is provided in appendix A.

Risk Factors

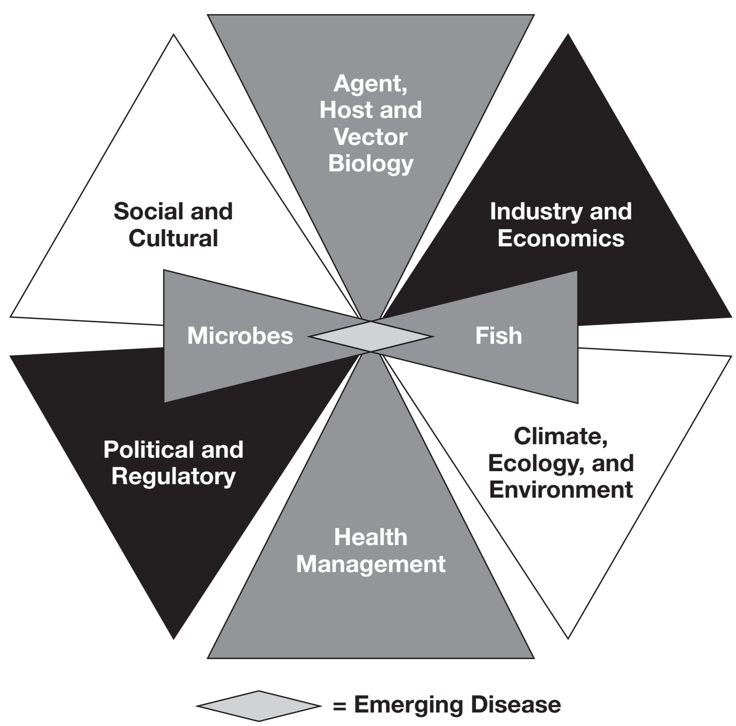
Risk Factor Categories

Selecting individual factors to include in the risk assessment tool for each element was challenging. Previous work on which to draw in the area of infectious disease emergence risk assessment was limited. In addition, few scientific studies outlined the relative contribution of individual factors to infectious disease emergence. Risk factors were drawn from broad categories of forces or drivers associated with infectious disease emergence (Table 1, Figure 1)

Table 1: Risk Factor Categories

Category	Description
Climate, Ecology, and Environment	Includes factors that predominantly are influenced by environmental factors outside of the production "environment," or factors found in nature. Examples include weather, geography, geographic location, and issues dealing with wildlife and wild fish species.
Industry and Economics	Includes factors that are predominantly driven by internal economic influences and decisions within the industry based on economics, production efficiency, technology, and output.
Social and Cultural	Includes factors that are most strongly influenced by cultural norms, social aspects of society, and external economic forces. Examples include current market trends, types of product sold or consumed, increases and decreases in demand, and international movement of fish and fish products.
Political and Regulatory	Includes factors that are mainly influenced by infrastructure of a country, stability, and organized government. The degree and enforcement of laws and regulations about animal movement, animal imports, waste management, water management, and imports that could affect animal health are also included.
Agent, Host, and Vector Biology	Includes factors that are driven by how easy a host is to invade, whether or not the host has a strong-functioning immune system, types and numbers of diseases a host is currently susceptible to, and prevalence of disease agents in an industry.
Health Management	Includes factors that account for the level of health care available and used within an industry. Also includes health-related production practices such as biosecurity and mortalities management.

Figure 1: Convergence of Risk Factors leading to an Emerging Disease



Based on the research conducted, general risk factors were made specific to the aquaculture industry. For example, direct contact between species is a general risk factor for disease emergence because it provides opportunity to transfer and mix pathogens and micro-organisms, in general. This risk factor was tailored to the aquaculture industry by including a risk factor for the amount of polyculture practiced. Polyculture is the production of multiple aquatic species in a single aquaculture environment, including species that may or may not naturally coexist together in the wild, and it provides the opportunity to transfer and mix microor-ganisms between species. Use of waste products from fish or other species for fertilization of aquaculture ponds is another example of a specific risk factor for disease emergence in the aquaculture industry. This use of waste falls under the broader economics and industry category of factors for disease emergence.

Factors ultimately included in the assessment were those that were identifiable and measurable. In some cases, specific information on an important factor was not found and a proxy factor had to be used. An exam-ple of this use of a proxy factor is the use of import value rather than volume for some trade data. This was required because import data do not provide volume data broken out by species. A more complex example of the use of a proxy factor is one addressing the issue of changing consumer demand. Increased consumer demand over a short period of time can result in changes in the supply chain that result in higher disease emergence risk; however, data quantifying consumer demand of various species of aquacultured food fish were not available for this assessment. The proxy risk factor measured recent changes in imports of live food fish. An increasing rate of change in such imports indicates higher demand for the products and may be a signal that aquaculture production, for those species that can be aquacultured, may be increasing in the importing country or that new importers with little experience may be entering the market. These importers may try to increase their import volume quickly without appropriate expansion of infrastructure and without attention to best management practices to ensure healthy and fresh product delivery.

In some cases, important risk factors could not be included in the assessment tool because they were not measurable or because an appropriate proxy could not be determined. These factors are noted in the text. Data may become available in the future allowing some of these risk factors to be included and the definitions of risk levels for some existing factors to be refined. Additionally, efforts were made to avoid including multiple factors that measure the same risk. Application of the tool over time will allow further refinements in factors chosen.

Levels of Risk

For each risk factor, levels of risk ranging from no defined risk to high risk were defined. These risk levels capture and rank the specific attributes associated with industry sectors for each risk factor. For example, for the disease evolution risk factor on broodstock source, the low-risk level is defined as the industry using domesticated breeding to produce broodstock, and the high-risk level is associated with the use of wild-caught fish as broodstock (Table 2). For the broodstock risk factor, the no-defined-risk level is not applicable. Risk levels for the total import value of live ornamental fish are defined in relation to the share of total world imports for the country under assessment (see Table 2). If no fish are imported, the risk factor is assigned as no defined risk. In general, if a risk factor is used in multiple elements, for example, in both disease evolution and spread, the level of risk is assessed in the same way across elements. A com-plete description of risk levels for each factor is found in appendix A.

Primary and Secondary Factors

Factors were categorized as either primary or secondary based on specific criteria related to their likely contribu-tion to disease emergence (Table 3). In general, for the evolution and spread elements, factors related directly to bringing together live fish and pathogens on-farm were considered primary (e.g., movement of live fish, use of untreated water) and factors related to increased stress on the host and pathogen were considered secondary. For the pathways element, primary factors relate to the movement of live fish, which are most likely

Table 2: Example of Levels of Risk for Each Element

Risk Factor	High	Medium	Low	No Defined Risk
Element: Disease Evolution				
Broodstock source	Wild-caught	Mixed source	Domesticated breeding	N/A
Element: Pathways				
Total import value of live ornamental fish (all species)	Import value 20 percent or greater of world imports	Import value 1 percent or more of world imports but less than 20 percent	Import value less than 1 percent of world imports	No imports
Element: Spread				
Disease management practices at the industry level	Lack of disease management; lack of BMPs; no biosecurity; no certification for production system	BMPs, biosecurity, health programs with no adherence or compliance measures	Existence of BMPs, biosecurity, health certification with compliance measures	N/A

Note: BMPs = best management practices; N/A = not applicable

to carry viable pathogens from one country to another, whereas secondary factors relate to the movement of items other than live fish. Secondary factors play an important role in the potential for disease emergence; however, without contact between a live host and a live pathogen on-farm, an infection cannot occur.

Evolution Element

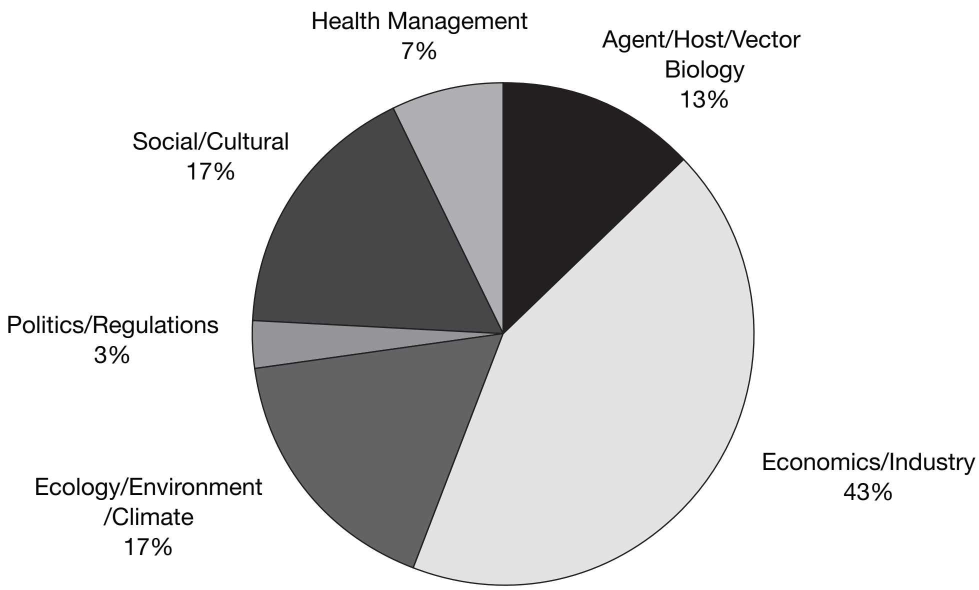
The evolution element examines the potential for new pathogens, which are not related to direct transboundary spread, to appear or for existing pathogens to evolve in the aquaculture setting. Risk factors associated with disease emergence and evolution include those related to altering the environment, stressing the host or pathogen, and bringing the assessed species in contact with microbes or other species. Table 4 summarizes the risk factors included in the assessment tool for the disease evolution element, and figure 2 illustrates the percentage of factors by category. Production practices such as broodstock source, feed practices, polyculture, production systems, and water source are included. Also included are agent, host, and vector biological factors such as existing disease burden (i.e., how much disease is currently present in the industry) and fish life cycles. Climate, ecology, and environment factors addressed include the introduction of nonindigenous species, the latitude at which production takes place, the level of stocking in lakes and streams, and occurrence of major weather disasters. Factors assessing the use of drugs, chemicals, and vaccines in the industry as well as the overall level of health management are also included. For disease evolution, trade-related risk factors are included to capture the opportunity that trade presents to mix non-pathogenic and pathogenic microbes and hosts in new settings. A more detailed rationale explaining how each of the risk factors was chosen and how they contribute to disease evolution is provided in appendix A.

Each factor was determined to be a primary or secondary risk factor. Within the evolution element, at least one of two criteria had to be present for the factor to be classified as primary. These two criteria are as follows: (1) the risk factor provides evidence that pathogens are present in the farmed host, and (2) the factor results in definite interaction or mixing of pathogens or microbes and hosts on-farm. To be classified as a secondary factor, one or more of four criteria had to be met. These four criteria are as follows: (1) the risk factor provides evidence of a change in the environment that could result in increased favorability of conditions for microbial evolution, (2) stressors on the host result in increased susceptibility to pathogens, (3) situations exist on-farm that might result in mixing hosts with pathogens or microbes, and (4) mixing of species and/or microbes in the wild (Table 3).

Table 3: Criteria and Rationale for Primary and Secondary Risk Factors

Category	Criteria	Rationale
Evolution Element		
Category	**Criteria**	**Rationale**
Primary	Provides direct evidence that pathogens are present	The presence of recently documented disease in the assessed species indicates there has been circulation of a pathogen that could be undergoing evolution pressure.
	Results in definite interaction or mixing of pathogens or microbes and hosts on-farm	Microbial evolution selection pressures depend on the types of microbes and hosts present. Mixing of multiple, diverse host species on-farm offers greater opportunity for novel pathogens to evolve. This criterion includes factors that definitely lead to physical proximity of host and microbe on-farm, because proximity is required for contact, interaction, mixing, evolution, and transmission to take place.
Secondary	Change in the environment that could result in increased favorability of conditions for microbial evolution	Environmental change puts selective pressure on microbes to adapt, which can result in a harmless microbe becoming pathogenic. Production practices can have significant impact on the local aquaculture environment.
	Stressors on the host resulting in increased susceptibility to pathogens	Stress negatively affects the immune system, which is one of the primary barriers to infection.
	Situation in which bringing together pathogens or microbes and host on-farm is likely but not definite	Microbial evolution selection pressures depend on the types of microbes and hosts present. This criterion includes factors that might lead to the physical proximity of host and microbe on-farm, because proximity is required for contact, interaction, mixing, evolution, and transmission to take place. Time is also an important factor. A longer production life cycle provides more time for a host to be at risk of exposure to pathogens or microbes that have evolved and results in greater likelihood for disease emergence.
	Mixing of species or microbes in the wild	Mixing of species and microbes in the wild provides opportunities for evolution, transmission, and species-crossing; however, the emerging microbe would then have to come into contact with an aquacultured species on-farm.
Pathways Element		
Category	**Criteria**	**Rationale**
Primary	Direct evidence of presence of pathogens in exporting country	The presence of pathogens in an exporting country makes the presence of pathogens in imported products more likely.
	Movement of live fish from one country to another	Live fish are more likely to harbor live pathogens capable of transmission for longer periods than are dead fish. Live fish are imported in water, which may also be a vehicle for pathogen transmission. Existence of regulations regarding importations of live fish mitigates this risk.
Secondary	Movement of items likely to carry aquaculture pathogens, other than live fish, from one country to another	Unprocessed fish and shellfish products may harbor pathogens capable of transmission, but this is less likely than for live fish. In addition, other products that could be contaminated with pathogens are feed and equipment.
Spread Element		
Category	**Criteria**	**Rationale**
Primary	Movement of live fish	Movement of diseased live fish to another location with susceptible hosts is very likely to spread disease to the new location.
	Results in definite interaction or mixing of pathogens or microbes and hosts	Definite contact between pathogens and hosts occurs on-farm, resulting from the movement of vehicles of transmission such as feed and water.
Secondary	On-farm practices with likely impact on disease transmission within the premises or off the premises	The on-farm environment may promote the spread of disease, such as poor disease management and biosecurity. A production environment focused on rapid increase in production may lead to situations that are more risky for disease spread, such as crowding. The converse, a decreasing production environment, may also lead to risky disease spread situations, such as the releasing of stock or improper destruction of fish.
	Interaction between premises or with wild fish occurs	The numbers and geographic locations of farms may make spread between farms more likely or less likely, depending on the situation. Pathogens present in the wild may make their way onto the farm.

Figure 2: Evolution Element: Percent of 32 Factors by Category



A number of potentially important factors for disease evolution could not be assessed because of data limitations. Factors related to ecology, environment, and climate posed particular challenges, and the impact of ecology, environment, and climate changes is likely not fully captured in the current risk assessment tool. For example, risk factors addressing pollution in waterways and water temperature were not included. In the social and cultural category, a risk factor dealing with smuggling or theft of fish was not included because of lack of data. A risk factor for host genetics, which could affect disease susceptibility and many other factors, was also not included because of lack of a suitable way to measure this risk.

Most of the factors included for the disease evolution element are specific to the species being assessed. A few factors are measured at the all-species level. Measurement at the all-species level denotes the shared risk faced by all aquacultured species associated with these particular risk factors. Additionally, measurement may have taken place at the all-species level because risk to individual sectors could not be determined because of data limitations.

Table 4: 32 Risk Factors in the Disease Evolution Element by Risk Factor Category

P	Denotes Primary Factor
S	Denotes Secondary Factor
Agent, Host, and Vector Biology	
P	Reported aquaculture disease burden (assessed species)
S	Reported total aquaculture disease burden (all species)
S	Length of life cycle (assessed species)
Ecology, Environment, and Climate	
P	Quality of source water (assessed species)
S	Geographic concentration of production (assessed species)
S	Latitude at which production takes place (assessed species)
S	Level of stocking in lakes and streams during most recent year (assessed species)
S	Introduction of nonindigenous species (region or states where assessed species is produced)
S	Occurrence of major weather disasters (production location for assessed species)
Economics and Industry	
P	Polyculture practiced (assessed species)
P	Broodstock source (assessed species)
P	Content and processing of feed fed (assessed species)
P	Waste fertilization (assessed species)
S	Change in production volume over most recent three years (assessed species)
S	Change in production volume of all aquaculture, over most recent three years (all species)
S	Level of stocking density (assessed species)
S	Introduction to new environment during life cycle (assessed species)
S	New technology or management practice used in production (assessed species)
S	Production in new area during last three years (assessed species)
S	Production system used (assessed species)
S	Industry changes to different production system (assessed species)
S	Phased production used (assessed species)
Health Management	
S	Acceptable use of drugs, chemicals, vaccines (assessed species)
S	Level of health management (all species)
Politics and Regulations	
S	Treatment of discharge water
Social and Cultural	
S	Commercial production of a new species (all species)
S	Total imports of live food finfish during most recent year (all species)
S	Total imports of fresh whole food fish, fish livers and roe, and shellfish during most recent year (all species)
S	Change in import value of live food finfish over most recent three years (all species)
S	Change in import volume of fresh whole fish, fish livers and roe, and shellfish over most recent three years (all species)

Pathways Element

Risk factors included for the pathways element address avenues by which a new or existing pathogen can enter the United States (table 5). All of the factors included in the risk assessment tool for the pathways element are measured at the all-species level. Measurement at the all-species level denotes a level of shared risk faced by all aquacultured species associated with these particular risk factors or denotes that the risk to individual sectors could not be determined because of the lack of species-specific data. For example, trade data for live fish are often not available at the level of detail needed to determine sector-specific information because data for many species are lumped together.

International trade factors represent the majority of the risk factors (figure 3). Risk factors for trade address both volume and value items and rate of change. The overall volume and value of trade indicates the size of the "pipeline" of materials, while a rapid rate of change in trade may indicate changes in consumer demand or drops in supply and the potential for new buyers and sellers to enter the marketplace, or that fish may be sourced from new countries to meet demand changes. Also included in the pathways element is a factor for the disease status of countries with which the United States trades, and one factor for the regulatory framework surrounding that trade. Movements of migratory and predatory birds are also included. The rationale associated with the inclusion of each of these factors is provided in appendix A.

Within the pathways element, at least one of two criteria had to be present for the factor to be classified as primary. These two criteria are that (1) the risk factor provides evidence that pathogens are present in the exporting country and (2) live fish move from one country to another. To be classified as a secondary factor, the factor had to involve the movement of items, other than live fish, that might carry aquaculture pathogens from one country to another.

Several challenges arose when using trade data in this element. For important products such as live fish imports, only value, not volume, data were available in the trade statistics. The absence of volume data results from live fish being imported in water, with the fish themselves often being small and difficult to count. From a risk perspective, volume is more important than value, because value increases can be related to price changes rather than true increases in the amount of product. It was not possible to distinguish the reason for importation, such as for human food, fish feed, farming, or household pets. The reason for importation may be relevant to the level of disease risk.

Assessment of the overall country risk for the ballast-water factor presented a challenge because the risk varies by species, based on proximity of production to bodies of water that receive ballast water released from ships. Aquaculture production in marine environments and in other large bodies of water that accommodate oceangoing shipping vessels are most at risk. It was decided to base risk rank on the proportion of a country's total aquaculture production of marine species. The ballast water-related risk for individual aquaculture sectors was not evaluated and may not be the same as the integrated all-species level of risk.

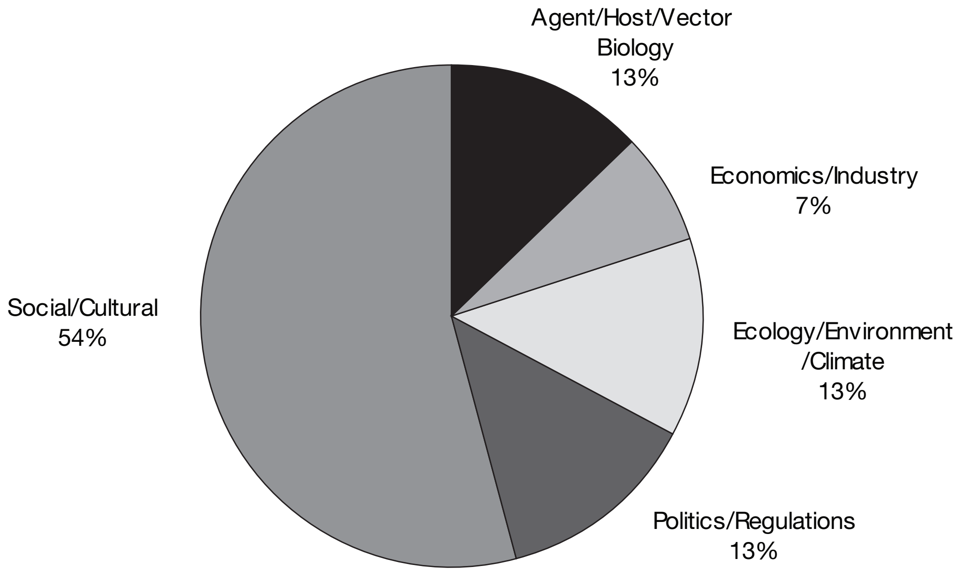
A number of other risk factors that are potentially important to assess pathways risk could not be included because of data limitations. These factors include consumer demand for exotic fish (which might provide an early indicator of new species being imported), imports of fish waste, and smuggling or other illegal movements of fish. Imports of eyed fish eggs (gametes) for aquaculture production are an important pathway for disease spread; however, this factor could not be included because the available data on these imports were incomplete, and because most importation of eyed eggs into the United States is unregulated (personal communication with Peter Merrill, 2006).

Table 5: 17 Risk Factors in the Pathways Element by Category (applies to all species)

P	Denotes Primary Factor
S	Denotes Secondary Factor
Agent, Host, and Vector Biology	
P	Presence of OIE-listed diseases in country from which the largest share of imports (by volume) of live food finfish originate
S	Presence of OIE-listed diseases in country from which the largest share of imports (by volume) of whole food finfish and shellfish originate (fresh or frozen)
Ecology, Environment, and Climate	
P	Ballast-water dumping
S	Migratory and predatory birds
Economics and Industry	
S	Imports of fish feed containing fish products during most recent year
Politics and Regulations	
P	Regulatory infrastructure regarding importations
S	Imports of used aquaculture production equipment
Social and Cultural	
P	Total import value of all live food finfish during most recent year
P	Total import value of all live ornamental fish during most recent year
P	Change in imports of all live food finfish over most recent three years
P	Change in imports of all live ornamental fish over most recent three years
P	Geographic diversity of imports of live food finfish and live ornamental fish
S	Total imports of all fresh whole food finfish, fish livers and roe, and shellfish during most recent year
S	Change in imports of all fresh whole food finfish, fish livers and roe, and shellfish over most recent three years
S	Geographic diversity of all imports of whole food finfish and shellfish (fresh and frozen)

Note: OIE = Office International des Epizooties.

Figure 3: Pathways Element: Percent of 17 Factors by Category



Spread Element

The spread element examines the potential for newly emerged, evolved, or introduced pathogens to spread from the point of emergence, evolution, or introduction between farms within a country. Risk factors associated with spread are those that specifically relate to the movement of fish or microbes on the farm and around the country being assessed (table 6). Most of the risk factors included (figure 4) are related to production practices, including: movement of fish during the production cycle; production system used; content and processing of feed fed; quality of source water; treatment of discharge water; handling of mortalities, slaughter and processing waste; and level and consistency of biosecurity practices. The rationale for inclusion of each of these factors is provided in appendix A.

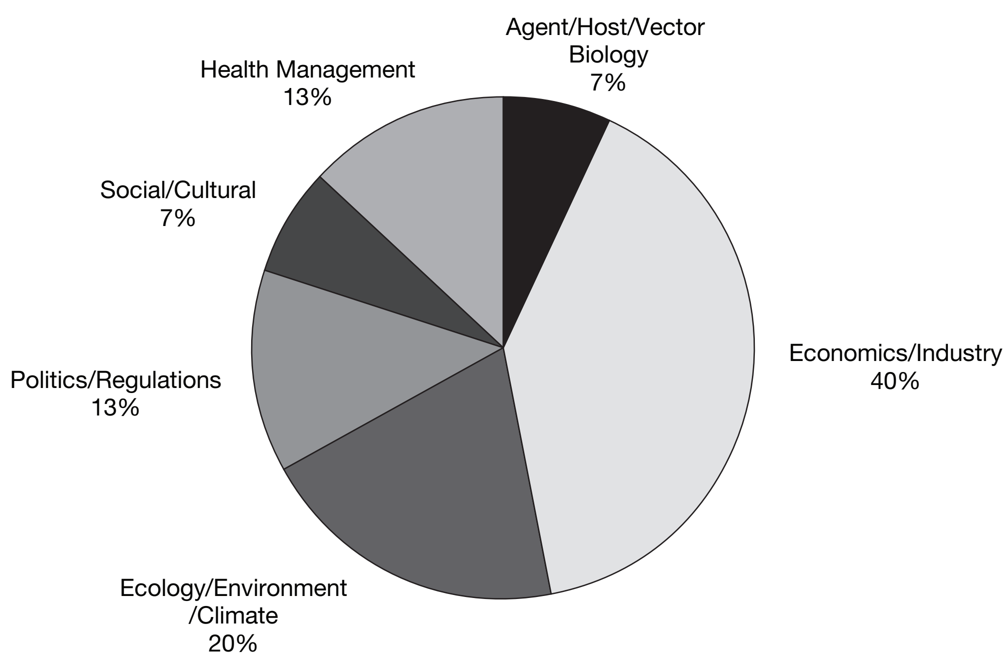
Within the spread element, at least one of two criteria had to be present for the factor to be classified as primary. These two criteria are that (1) the risk factor provides evidence of movement of live fish and (2) definite interaction or mixing of pathogens or microbes and hosts. To be classified as a secondary factor, the factor had to involve on-farm practices that might affect disease transmission within the premises or off the premises or the occurrence of interaction between premises or with wild fish.

Almost all of the factors included in the risk assessment tool to assess spread are specific to the species being assessed. Only one item, rate of change in production volume for all aquacultured species, is measured using all species. This signifies the shared risk faced by all aquacultured species associated with this particular risk factor.

Table 6: 17 Risk Factors in the Spread Element by Category

P	Denotes Primary Factor
S	Denotes Secondary Factor
Ecology, Environment, and Climate	
P	Movement of fish because of predation and major weather events (assessed species)
P	Quality of source water (assessed species)
S	Geographic concentration of production (assessed species)
S	Level of stocking in lakes and streams during most recent year (assessed species)
Economics and Industry	
P	Intentional movement of fish associated with production practices (assessed species)
P	Content and processing of feed fed (assessed species)
S	Total number of farms (assessed species)
S	Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years (assessed species)
S	Change in production volume of all aquacultured species, over most recent three years (all species)
S	Production system used (assessed species)
Health Management	
S	Disease management practices at the industry level (assessed species)
S	Handling of mortalities (assessed species)
Politics and Regulations	
P	State regulations regarding live-hauling (assessed species)
S	Treatment of discharge water (assessed species)
Social and Cultural	
P	Types of sales of products from farms (assessed species)

Figure 4: Spread Element: Percent of 17 Factors by Category



Interpreting the Results

To complete the risk assessment tool, a scheme was established to interpret the results for each aquaculture sector by element, which would consider the results for both primary and secondary factors. A risk factor rank of either high or medium indicates increased risk associated with the risk factor and indicates the factors for which potential opportunities for mitigating risk should be explored. The scheme is based on the percentage of risk factors ranked as high or medium by primary and secondary risk factor categories. To determine the risk rank for a sector by element, percentages of primary factors ranked high or medium greater than 66 percent were considered high risk, those from 34 percent to 66 percent were considered medium risk, and those lower than 34 percent were considered low risk (table 7). This assessment based on the primary factors was then modified by the percentage of secondary factors ranked high or medium. If the percentage of secondary factors ranked high or medium was greater than 66 percent, the assessment based on the primary factors increased one level.

The focus of this risk assessment tool is to assess the current risk of disease emergence and evolution, pathways, and spread within specific aquaculture sectors in a country. For the evolution element, a sector assessment of high risk suggests a high likelihood of disease emergence and evolution, medium risk suggests a significant likelihood, and low risk suggests that it is unlikely that disease evolution will occur. High risk for pathways suggests a high likelihood of disease entering the country, medium risk suggests a significant likelihood, and low risk suggests that entry of disease is unlikely. High risk for spread suggests that disease is likely to spread widely if it emerges or enters the country, medium risk suggests moderate spread, and low risk suggests limited to no spread.

Table 7: Determination of Sector Risk Rank by Element

	High	Medium	Low
Total primary factors ranked high or medium	>66%	34–66%	<34%
Total secondary factors ranked high or medium*	>66%	34–66%	<34%

Note: *If the percentage of secondary factors ranked high or medium is greater than 66 percent, then the assessment based on the primary factors increases by one level.

Phase 3: Infectious Disease Emergence Qualitative Risk Assessment Tool Application and Results

The disease emergence risk assessment tool was applied to four food fish aquaculture sectors in the United States: catfish, salmon, saltwater shrimp (marine species), and tilapia. Risk rankings were determined for each of the three elements: disease evolution, pathways, and spread. Differences in rankings given to each sector on each element suggest differences in risk levels. Results for each element are discussed below. The data used to determine the level of risk for each risk factor for each sector are documented in appendixes B through F.

Disease Evolution Element

Risk factor rankings for each aquaculture sector for the evolution element are presented in Table 8, and a summary of sector risk classification is presented in table 11. In addition to the 24 risk factors in this element, which are ranked by each assessed species, six secondary risk factors are ranked at the all-species level, and four of these factors were ranked as high risk. These four factors are: (1) reported total aquaculture disease burden; (2) change in production volume of all aquaculture over the most recent three years; (3) total imports of fresh whole food fish, fish livers and roe, and shellfish during most recent year; and (4) change in import volume of fresh whole fish, fish livers and roe, and shellfish over the most recent three years.

Expert opinion was relied on to determine the rankings for some factors for which information related to specific industry practices (e.g., content of feed fed, stocking density, level of health management) was not documented in the literature. In some cases, proxy data sources were used because of lack of data availability. For example, the Office International des Epizooties (World Organization for Animal Health, OIE) was used as the source of information for the factor on disease burden; however, OIE does not record the occurrence of all diseases, but only specific OIE-listed diseases. Data detailing the amount of drugs, chemicals, and vaccines used in the aquaculture industry, as well as trends in use, are not available. Therefore, evidence of a trade ban imposed because of findings of drug or chemical residues was used as a proxy to measure this factor. For some factors, data were not available at the level of detail needed. For example, imports of live shellfish are not reported separately from dead shellfish in the trade statistics.

Catfish

The catfish sector had only 2 (33%) primary risk factor that ranked high or medium, but it had 16 (67%) secondary risk factors that ranked high or medium. Although the primary risk factor ranking falls in the low sector risk category (<34%), the secondary risk factor ranking of 67 percent moves the sector risk classification for disease evolution for the catfish sector up one level to medium (see page 17, Interpreting the Results). Medium sector risk suggests a significant likelihood of the new appearance and evolution of pathogens that are not related directly to transboundary movement of pathogens.

Many of the risk factors that ranked high are related to production methods and practices such as the use of an open-pond production system, polyculture, lack of use of phased production, lack of discharge water BMPs, and a low level of use of certified aquaculture health professionals. These factors would be amenable to changes that would lower risk; for example, discharge water BMPs could be developed and implemented and the industry's use of phased production could be increased. Phased production is in use on some large farms, but it is still not a widespread practice. Polyculture in the catfish industry is a method largely used to control the pond ecosystem and it is not a direct source of cash flow. Other methods of weed and algal control could be substituted to reduce risk from this factor. Other factors that ranked high, such as the length of the catfish life cycle and the geographic concentration of farms, may not be feasible to change.

Salmon

The salmon sector had 3 (50%) primary risk factors that ranked high or medium, and it had 14 (59%) secondary factors that ranked high or medium. These rankings place the sector risk classification for disease evolution for the salmon sector in the medium category, suggesting a significant likelihood for the new appearance and evolution of pathogens that are not related directly to transboundary movement of pathogens.

The primary risk factors that ranked high were reported aquaculture disease burden for the salmon sector and quality of source water. Because salmon are farmed in the open ocean, biosecurity measures to prevent disease and control source water are difficult to implement. Some recent progress has been made in understanding the hydrographic distribution of pathogens and parasites and ocean tidal exchange zones to improve source water issues. The assessed species-level secondary risk factors that ranked high also include many production-related factors that are not feasible to change, such as length of life cycle, introduction to new environment during life cycle, open-pond production systems, and treatment of discharge water.

Saltwater Shrimp

The saltwater shrimp sector had only 1 (17%) primary risk factor that ranked high or medium (reported aquaculture disease burden), and it had 13 (54%) secondary risk factors that ranked high or medium. The sector risk classification for disease evolution for the saltwater shrimp sector is low, because the percentage of primary risk factors ranked high or medium falls in the low category (<34%), and the percentage of secondary factors ranked high or medium does not fall in the high category (>66%). The sector classification of low risk suggests that the new appearance and evolution of pathogens not related directly to transboundary movement of pathogens is unlikely.

The primary risk factor that ranked high was reported aquaculture disease burden for the saltwater shrimp sector. The assessed species-level secondary risk factors that ranked high included occurrence of major weather disasters, change in production volume, production occurring in a new geographic area, production system used, and treatment of discharge water. If the current experimentation in the saltwater shrimp sector with a closed recirculating production system is successful, an industry-wide change to this type of closed system would lower the risk from weather disasters and other risks that are associated with an open-pond production system.

Tilapia

The tilapia sector had no primary risk factors that ranked high or medium, and it had 13 (54%) secondary risk factors that ranked high or medium. The sector risk classification for disease evolution for tilapia is low, because the percentage of primary risk factors ranked high or medium falls in the low category (<34%), and the percentage of secondary factors ranked high or medium does not fall in the high category (>66%). The sector classification of low risk suggests that the new appearance and evolution of pathogens not related directly to transboundary movement of pathogens is unlikely.

The assessed species-level secondary risk factors that ranked high were occurrence of major weather disasters, change in production volume over the most recent three years, and introduction of nonindigenous species. The assessed species-level secondary risk factors that ranked medium were length of life cycle, latitude at which production takes place, level of stocking density, production system, and level of health management. Few of these factors are feasible to change; however, increased use in the tilapia industry of fully closed recirculating aquaculture systems (RAS) and adoption of certified aquaculture professionals would help mitigate some of these risks.

Pathways Element

Risk factor rankings for the pathways element are presented in table 9 and a summary of sector risk

Table 8: Disease Evolution Element Results by Sector

Type	**Risk Factor**	**Catfish**	**Salmon**	**Shrimp**	**Tilapia**
Primary Factors					
Agent, host, and vector biology	Reported aquaculture disease burden (assessed species)	Low	High	High	Low
Ecology, environment, and climate	Quality of source water (assessed species)	Low	High	Low	Low
Economics and industry	Polyculture practiced (assessed species)	High	Low	Low	Low
Economics and industry	Broodstock source (assessed species)	Low	Medium	Low	Low
Economics and industry	Content and processing of feed fed (assessed species)	High	Low	Low	Low
Economics and industry	Waste fertilization (assessed species)	No defined risk	No defined risk	No defined risk	No defined risk
Total High Primary		2 (33%)	2 (33%)	1 (17%)	0
Total Medium Primary		0	1 (17%)	0	0
Total Low Primary		3 (50%)	2 (33%)	4 (67%)	5 (83%)
Total No Defined Risk Primary		1 (17%)	1 (17%)	1 (17%)	1 (17%)
Secondary Factors					
Agent, host, and vector biology	Reported total aquaculture disease burden, conditional on species produced (all species)	High	High	High	High
Agent, host, and vector biology	Length of life cycle (assessed species)	High	High	Low	Medium
Agent, host, and vector biology	Geographic concentration of production (assessed species)	High	No defined risk	Medium	Low
Ecology, environment, and climate	Latitude at which production takes place (assessed species)	Medium	Medium	Medium	Medium
Ecology, environment, and climate	Level of stocking in lakes and streams during most recent year (assessed species)	Low	High	No defined risk	Low
Ecology, environment, and climate	Introduction of nonindigenous species (region or states where assessed species is produced)	High	Medium	Low	High
Ecology, environment, and climate	Occurrence of major weather disasters (top-producing states for assessed species)	High	Low	High	High
Economics and industry	Change in production volume, over most recent three years (assessed species)	High	High	High	High
Economics and industry	Change in production volume of all aquaculture, over most recent three years (all species)	High	High	High	High

Note: RAS = recirculating aquaculture systems.

Type	Risk Factor	Catfish	Salmon	Shrimp	Tilapia
Economics and industry	Level of stocking density (assessed species)	Medium	Medium	Medium	Medium
Economics and industry	Introduction to new environment during life cycle, moving to a different type of production system (e.g., RAS to open ponds) (assessed species)	Low	High	Low	Low
Economics and industry	New technology or management practice used in production (assessed species)	Low	No defined risk	No defined risk	Low
Economics and industry	Production in new area during last three years (assessed species)	No defined risk	No defined risk	High	No defined risk
Economics and industry	Production system used (assessed species)	High	High	High	Medium
Economics and industry	Industry changes to different production system (assessed species)	No defined risk	No defined risk	Low	No defined risk
Economics and industry	Phased production used (assessed species)	High	Low	No defined risk	No defined risk
Health management	Acceptable use of drugs, chemicals, and vaccines (assessed species)	Low	Low	Low	Low
Health management	Level of health management (species-specific)	High	Low	Low	Medium
Politics and regulations	Treatment of discharge water (assessed species)	High	High	High	Low
Social and cultural	Commercial production of a new species (all species)	Medium	Medium	Medium	Medium
Social and cultural	Total imports of live food finfish during most recent year (all species)	Low	Low	Low	Low
Social and cultural	Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (all species)	High	High	High	High
Social and cultural	Change in import value of live food finfish over most recent three years (all species)	Low	Low	Low	Low
Social and cultural	Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (all species)	High	High	High	High
Total High Secondary		13 (54%)	10 (42%)	9 (38%)	7 (29%)
Total Medium Secondary		3 (13%)	4 (17%)	4 (17%)	6 (25%)
Total Low Secondary		6 (25%)	6 (25%)	8 (33%)	8 (33%)
Total No Defined Risk Secondary		2 (8%)	4 (17%)	3 (13%)	3 (13%)

Note: RAS = recirculating aquaculture systems.

classification is presented in table 11. All factors in the pathways element were measured at the all-species level; therefore, the results apply across all four aquaculture sectors. The numbers of primary and secondary risk factors that ranked high or medium were five (63%) and six (86%), respectively. The sector risk classification for pathways is high, because although the percentage of primary risk factors ranking high or medium falls in the medium-risk category (34% to 66%), the number of secondary risk factors ranking high or medium falls in the high-risk category (>66%). Therefore, sector risk moves up one level to high. The sector classification for pathways of high risk suggests a high likelihood of disease entering the country through transboundary spread.

The primary risk factor that ranked high was the presence of OIE-listed diseases in the country from which the largest share of imports (by value) of live food finfish originate. U.S. imports accounted for 14.4 percent of world imports of ornamental fish, and U.S. ornamental fish imports increased by 10.4 percent from 2002 to 2004, resulting in a risk rank of medium for these two factors. The United States imported live finfish from 38 percent of the countries in the world leading to a medium-risk rank for this factor. Recently implemented U.S. import restrictions on live fish, fertilized eggs, and gametes of fish species that are susceptible to spring viremia of carp resulted in a medium-risk rank for the regulatory infrastructure factor. The development and implementation of national health requirements for other species, such as testing, health certificates, and quarantines for importation of live fish and fish products, would mitigate the risk of disease entering the country.

Measurement of the overall all-species country risk for the ballast-water factor presented a challenge because the risk varies by species, based on proximity of production to bodies of water that receive ballast water released from ships. Aquaculture production in marine environments and in other large bodies of water that accommodate oceangoing shipping vessels, such as the Great Lakes, are most at risk. U.S. aquaculture production is dominated by the catfish sector, with marine species only constituting 8.6 percent of U.S. production. Therefore, the ballast water risk factor was ranked as low for the United States as a whole. The risk for individual aquaculture sectors was not evaluated and may not be low.

The majority of the secondary risk factors that ranked high are related to the importation of products such as fish feed and fresh whole food finfish (includes both ungutted and gutted), fish livers and roe, and shellfish. The quantity and change in these imports over time are related to economic and social or cultural factors that are not controllable. Risk from migratory and predatory birds is related to the large percentage of aquaculture production in the United States associated with open-pond production systems.

Spread Element

Rankings for each sector for the spread element are presented in table 10 and a summary of sector risk classification is presented in table 11. The spread element includes one secondary risk factor that is ranked at the all-species level. This factor is the change in production volume of all aquacultured species over the most recent three years, and it received a rank of high.

Expert opinion was relied on to determine the rankings for some factors where information related to specific industry practices (e.g., content of feed fed, mortality management) was not documented in the literature. In some cases, proxy data sources were used because of the lack of data availability. For example, there were no data available on the extent of use of predation-avoidance practices for each sector; therefore, type of production system (open versus closed) was used as the proxy measure for this factor.

Catfish

For the catfish sector, the number of primary risk factors that ranked high or medium was four (67%), and it falls in the high sector-risk category (>66%). The number of secondary risk factors ranking high or medium was eight (89%), which also falls in the high sector-risk category (>66%). High sector risk suggests that in the catfish sector disease is likely to spread widely if it emerges or enters the country.

Table 9: Pathways Element Results

Type	Risk Factor	All Species
Primary Factors		
Agent, host, and vector biology	Presence of OIE-listed diseases in country from which the largest share of imports (by value) of live food finfish originate	High
Ecology, environment, and climate	Ballast-water dumping in U.S. waters	Low
Politics and regulations	Regulatory infrastructure regarding importations (all species)	Med
Social and cultural	Total imports of all live food finfish during most recent year	Low
Social and cultural	Total import value of live ornamental fish during most recent year (all ornamental species)	Medium
Social and cultural	Change in imports of all live food finfish over most recent three years	Low
Social and cultural	Change in imports of live ornamental fish over most recent three years (all ornamental species)	Medium
Social and cultural	Geographic diversity of imports of live food finfish and live ornamental fish	Medium
Total High Primary		1 (12%)
Total Medium Primary		4 (50%)
Total Low Primary		3 (38%)
Total No Defined Risk Primary		0
Secondary Factors		
Agent, host, and vector biology	Presence of OIE-listed diseases in country from which the largest share of imports (by volume) of whole food finfish and shellfish originate (fresh or frozen)	High
Ecology, environment, and climate	Migratory and predatory birds	High
Economics and industry	Imports of fish feed containing fish products during most recent year	High
Politics and regulations	Imports of used aquaculture production equipment	Low
Social and cultural	Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (all species)	High
Social and cultural	Change in imports of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (all species)	High
Social and cultural	Geographic diversity of imports of whole food finfish and shellfish (fresh and frozen)	High
Total High Secondary		6 (86%)
Total Medium Secondary		0
Total Low Secondary		1 (14%)
Total No Defined Risk Secondary		0

Note: RAS = recirculating aquaculture systems.

Primary risk factors ranking high were movement of fish because of predation and major weather events, intentional movement of fish associated with production practices, content or processing of feed fed, and State regulations regarding live-hauling. The first three factors are related to production practices, and they would require changes in production practice to mitigate risk, such as covering ponds, producing fingerlings on the same operation where growout occurs, and not using live fish as a food source. States could take action to mitigate risk by creating regulations and compliance measures regarding live-hauling.

Eight (89%) secondary risk factors were ranked high or medium. Of these eight factors, four relate to production practices such as handling of mortalities, disease management practices, and treatment of discharge water. Risk related to these factors could be mitigated by industry-wide changes in production practices. The remaining four factors that ranked high, including geographic concentration, number of farms, and change in production volume, are less controllable; however, these factors can be monitored periodically for changes that may increase or decrease risk.

Salmon

For the salmon sector, the number of primary factors that ranked high or medium was four (67%). This falls in the high sector-risk category (>66%). Six secondary factors ranked high or medium (67%), which also is in the high-risk category, and does not change the sector risk based on the primary factors. The sector risk classification for the salmon sector is high for spread, suggesting that in the salmon sector disease is likely to spread widely if it emerges or enters the country.

Primary risk factors ranking high were movement of fish because of predation and major weather events, quality of source water, and state regulations regarding live-hauling. Because salmon are farmed in the open ocean, it is difficult for the industry to address predation, weather, and source water issues to lower these risks. Some recent progress has been made in understanding the hydrographic distribution of pathogens and parasites and ocean tidal exchange zones to improve source water issues. It would be feasible, however, to take action on regulations regarding hauling of live fish, which would decrease the risk of disease spread.

Five secondary risk factors were ranked high or medium (55%). Most of these high or medium ranking factors would be difficult to change to decrease risk, primarily because of the nature of the open-ocean production system. Increasing the proportion of the industry that practices proper handling and disposal of mortalities would be a feasible change that could lower the risk from this factor.

Saltwater Shrimp

For the saltwater shrimp sector, three primary risk factors ranked high or medium (50%). This falls in the medium sector-risk category (34% to 66%). Because the number of secondary risk factors ranking high or medium was six (67%) and falls in the high sector-risk category (>66%), this moves the sector risk classification based on the primary risk factors up one level to high for spread. High sector risk suggests that in the saltwater shrimp sector disease is likely to spread widely if it emerges or enters the country.

The three primary risk factors ranking high for shrimp were the same as those for catfish: movement of fish because of predation and major weather events, intentional movement of fish associated with production practices, and state regulations regarding live-hauling. If the current experimentation with closed recirculating production systems is successful, an industry-wide change to this type of closed system would address risk involved with predation and weather. Shrimp farms specialize in broodstock production, postlarvae production, or growout, so the need to move shrimp between operations is unlikely to change. It would be feasible, however, for states to take action on regulations regarding hauling of live shrimp.

Six (67%) secondary risk factors were ranked high or medium. Of these six factors, three relate to production practices, such as handling of mortalities, treatment of discharge water, and production system used.

Table 10: Spread Element Results by Sector

Type	Risk Factor	Catfish	Salmon	Shrimp	Tilapia
Primary Factors					
Ecology, environment, and climate	Movement of fish caused by predation and major weather events (assessed species)	High	High	High	Medium
Ecology, environment, and climate	Quality of source water (assessed species)	Low	High	Low	Low
Economics and industry	Intentional movement of fish associated with production practices (assessed species)	High	Medium	High	Low
Economics and industry	Content or processing of feed fed (assessed species)	High	Low	Low	Low
Politics and regulations	State regulations regarding live-hauling (assessed species if possible)	High	High	High	Medium
Social and cultural	Types of sales of products from farms (assessed species)	Low	Low	Low	High
Total High Primary		4 (67%)	3 (50%)	3 (50%)	1 (17%)
Total Medium Primary		0	1 (17%)	0	2 (33%)
Total Low Primary		2 (33%)	2 (33%)	3 (50%)	3 (50%)
Total No Defined Risk Primary		0	0	0	0
Secondary Factors					
Ecology, environment, and climate	Geographic concentration of production (assessed species)	High	No defined risk	Medium	Low
Ecology, environment, and climate	Level of stocking in lakes and streams during most recent year (assessed species)	Low	High	No defined risk	Low
Economics and industry	Total number of farms (assessed species)	High	Low	Low	Medium
Economics and industry	Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years (assessed species)	High	High	High	High
Economics and industry	Change in production volume of all aquacultured species, over most recent three years (all species)	High	High	High	High
Economics and industry	Production system used (assessed species)	High	High	High	Medium
Health management	Disease management practices at the industry level (assessed species)	Medium	Low	Low	Medium
Health management	Handling of mortalities (assessed species)	High	Medium	High	Low
Politics and regulations	Treatment of discharge water (assessed species)	High	High	High	Low
Total High Secondary		7 (78%)	5 (56%)	5 (56%)	2 (22%)
Total Medium Secondary		1 (11%)	1 (11%)	1 (11%)	3 (33%)
Total Low Secondary		1 (11%)	2 (22%)	2 (22%)	4 (44%)
Total No Defined Risk Secondary		0	1 (11%)	1 (11%)	0

Note: RAS = recirculating aquaculture systems.

Risk related to these factors could be mitigated by industry-wide changes in production practices. The remaining three factors that ranked high or medium, including geographic concentration and change in production volume, are less controllable; however, these factors can be monitored periodically for changes that may increase or decrease risk.

Tilapia

For the tilapia sector, three primary factors ranked high or medium (50%). This falls in the medium sector-risk category (33% to 66%). Five secondary risk factors ranked high or medium (55%), which also falls in the medium risk category. Therefore, the sector risk classification is medium. Medium risk suggests moderate spread if an infectious disease were to emerge or enter the country.

The only primary risk factor ranking high was the type of sales of products from farms. Two primary factors ranked medium: (1) movement of fish because of predation and major weather events, and (2) state regulations regarding live-hauling. Tilapia produced in the United States are sold almost exclusively to live-haulers for live markets and restaurants. It is not feasible to change this market; however, better enforcement of live-hauling regulations would help to mitigate the risk associated with the movement of live fish. About 40 percent of tilapia farms in the United States use a modified or open RAS. Movement of these producers to the fully closed production system would decrease risk of disease spread.

Five (55%) secondary risk factors were ranked high or medium. Of these five factors, two relate to production practices such as production system used and disease management practices. Risk related to these factors could be mitigated by industry-wide changes in production practices. The remaining three factors that ranked high or medium, including the number of farms and change in production volume both for tilapia and all species, are less controllable; however, these factors can be monitored periodically for changes that may increase or decrease risk.

Summary of Results

The sector risk classifications for each aquaculture sector for each element are summarized in table 11. The numbers of factors ranked high or medium were added together, because these risk factors (as opposed to the factors ranked low or no defined risk) should be considered significant contributors to each sector's current risk situation.

For the evolution element, the salmon sector had the highest number of primary risk factors that are ranked high or medium. Current salmon production takes place in the open ocean and uses wild-caught broodstock. These practices expose farmed salmon to both wild fish and untreated water, which increase the risk for disease emergence and evolution. In addition, the U.S. salmon sector has experienced significant disease outbreaks in the past five years. The catfish industry had the highest number of factors ranked high or medium among the secondary risk factors for disease evolution. Relative to the other sectors, the catfish sector has a higher geographic concentration of production, is located in states with a high number of nonindigenous species introductions, does not use phased production, and has a low level of use of certified aquaculture health professionals in health management. The sector risk rank was medium for the catfish and salmon industries, meaning that disease evolution is likely to occur in these sectors. The sector risk rank was low for saltwater shrimp and tilapia, meaning that disease evolution is unlikely in these sectors.

The pathways element is not species-specific; therefore, the results apply across all of the assessed species. The pathways element is dominated by trade-related risk factors. Large quantities of live fish and fish product imports, as well as an increasing trend in these imports over time, the large geographic diversity in origin of imports, and lack of health requirements for imports, led to the majority of both primary and secondary factors ranking as high or medium. The risk rank for the pathways element is high, meaning that the likelihood of pathogens entering the country is high.

Table 11: Summary of Results by Sector

Element	Catfish	Salmon	Shrimp	Tilapia
Evolution				
Total primary factors ranked high or medium	2 (33%)	3 (50%)	1 (17%)	0
Total secondary factors ranked high or medium	16 (67%)	14 (59%)	13 (54%)	13 (54%)
Sector Risk Rank	Medium	Medium	Low	Low
Pathways (all species)				
Total primary factors ranked high or medium	5 (63%)			
Total secondary factors ranked high or medium	6 (86%)			
Sector Risk Rank	High			
Spread				
Total primary factors ranked high or medium	4 (67%)	4 (67%)	3 (50%)	3 (50%)
Total secondary factors ranked high or medium	8 (89%)	6 (67%)	6 (67%)	5 (55%)
Sector Risk Rank	High	High	High	Medium

Note: RAS = recirculating aquaculture systems.

For the spread element, there was little difference among the sectors regarding the number of primary risk factors ranking high or medium. For the secondary factors, however, the catfish sector had the most risk factors ranking high or medium. Relative to the other sectors, the catfish industry has a larger number of farms that are more geographically concentrated. In addition, the catfish industry as a whole does not practice proper handling of mortalities. The sector risk rank for the spread element was high for the catfish, salmon, and shrimp sectors, meaning that disease is likely to spread widely in these sectors if it emerges or enters the country. The sector risk rank for tilapia was medium for spread, meaning that spread would be moderate if a disease of tilapia emerged or entered the country.

Utilization of Results

The results gained from application of the disease emergence risk assessment tool can be used in a number of ways. The tool can be used to monitor risk for each emergence element for each industry sector over time through periodically repeating the assessment. In this way, changes in the disease emergence elements can be monitored to determine whether the level of risk is increasing or decreasing. Alternatively, a subset of risk factors could be selected for monitoring. For example, only those risk factors that contribute the greatest to sector risk (i.e., primary risk factors) could be monitored. Monitoring systems could be established for those primary risk factors that currently received a low-risk ranking, thus watching for changes that would result in greater risk of disease emergence. These types of monitoring activities could be part of an emerging disease early warning system that would alert industry and government officials of rising risk for disease emergence. Upon such alerts, actions could be taken to decrease that rising level of risk. For example, an education campaign could be targeted to producers about identified risky behavior, such as improper handling of mortalities, lack of use of veterinary care, or improper movement of animals.

Another use of the results of this qualitative assessment tool could be to determine potential targets for risk mitigation efforts. By examining those risk factors that contribute significantly to risk, industry and government officials can explore potential mitigations that would have the greatest impact. Those risk factors that are primary factors and that received a high-risk ranking could be evaluated for appropriateness to implement mitigation efforts. As an example, lack of regulations regarding live-hauling of fish is a risk factor for which action is feasible and such action would decrease risk. In comparison, length of life cycle is a risk factor for which little can be done to mitigate the risk it brings to the industry. In considering potential mitigations, economics and logistical feasibility need to be considered. By applying the tool in this way, an industry can target mitigation efforts to maximize risk reduction potential in a practical and realistic manner.

A final use of the results gained from applying the disease emergence tool is to identify information and data gaps within an industry. Understanding where these gaps lie, and the impact they have on risk, can be used to direct research funding and data collection efforts. For example, one such information gap identified during this project was lack of data regarding consumer demand for specific species of fish. Such information would be valuable because it indicates demand drivers that affect production behaviors and thus risk of disease emergence. Information and data gaps regarding risk factors that have significant impact on the industry should receive the highest priority.

Application to Other Industries

The food fish portion of the aquaculture industry in the United States was chosen to be used in the development of this risk assessment tool. In applying the tool to several aquaculture species, it became evident that although many of the identified risk factors are non-species- specific and would be relevant when assessing the potential for disease emergence in any animal industry, some of the identified risk factors are specific to the aquaculture industry. Therefore, although this assessment tool provides the basic framework and is a good starting place to develop a similar tool for other animal industries, the individual risk factors would have to be significantly altered to make it applicable. It is believed, however, that the overall process developed, from the beginning research of forces for disease emergence for the species being assessed to the final ranking and classification of risk factors, is a sound one and one that is not specific to aquaculture species.

Conclusion

The disease emergence risk assessment tool developed in this project was able to rank risk across three disease emergence elements for multiple aquaculture sectors. The usefulness of the results to industry and government officials for understanding the level of risk associated with different aquaculture sectors and potential risk mitigations needs to be evaluated. The tool's predictive capabilities need to be assessed over time, as well as the tool's ability to identify changes in risk based on changes in industry dynamics. As this is done, and as the tool is used to a greater extent, it is expected that additions, deletions, and clarifications to the risk factors will be made over time, as is the natural maturation of any new methodology.

In developing this disease emergence assessment tool, several challenges to defining and assessing risk factors were encountered. Data availability was the primary such challenge and expert opinion was relied on heavily, especially for the smaller aquaculture industry sectors for which published statistics were difficult to obtain. Another challenge was in the development of the risk factors themselves, their risk levels, and their categorization into primary and secondary factors. Were all the relevant risk factors identified and included? Were the cut-off points between risk levels appropriate? Further review by industry experts and the application of the tool over time will answer these questions and allow further refinements in the identified risk factors.

Understanding the risks associated with industry sectors can allow mitigation measures to be considered and enacted, reducing risk for disease emergence. Further refinement and evaluation are needed, but this qualitative risk assessment method shows promise of being a helpful tool for government and industry use to monitor potential for disease emergence and to target mitigation efforts in an efficient and effective manner, thus decreasing risk of disease emergence.

Appendix A. Disease Emergence Risk Assessment Tool

Disease Evolution Element					
		Definition of Risk Level			
Factor	Risk Factor Category	High	Medium	Low	No defined risk
Primary Factors					
Reported aquaculture disease burden (assessed species)	Evolution Primary Agent, host, and vector biology	Any OIE-listed disease reported during past five years for species being assessed, OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past five years for species being assessed, but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed) diseases during past five years
	Rationale: The presence of recently documented disease in a species indicates there has been circulation of a pathogen that could be undergoing evolutionary pressure. The presence of disease in an industry can also be a general indicator of other important risk factors such as level of health management or biosecurity. There is no accurate method to quantify the true disease burden within an aquaculture industry. Tracking reports of outbreaks of OIE-listed diseases is one way to quantify this factor in a measurable, consistent method. It will not, however, capture information regarding levels of microbe burdens that could be involved in disease evolution that are not OIE-listed diseases. It also does not capture information in aquaculture sectors that have no OIE-listed diseases. **Data Sources:** OIE, Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Quality of source water (assessed species)	Evolution Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
	Rationale: Uptake water is a potential vehicle for farmers to introduce pathogens and microbes or stressors (change in temperature, chemical, gaseous, or nutrient balance of water) to aquaculture operations. Treatment or filtering of uptake water will reduce the potential for microbial contamination, thus reducing the risk of disease emergence. BMPs regarding uptake water that are followed by an aquaculture industry should also mitigate the risk from this factor. **Data Sources:** Industry literature, expert opinion.				
Polyculture practiced (assessed species)	Evolution Primary Economics and industry	50 percent or more of industry	10 percent or more but less than 50 percent of industry	Less than 10 percent of industry	No polyculture practiced
	Rationale: For the purpose of this document, polyculture is the production of multiple aquatic animal species in a single aquaculture environment. These species may or may not be species that would naturally coexist together in the wild. Raising multiple species together creates an opportunity for cross-species disease emergence. The more producers in an industry practicing polyculture, the greater the risk. **Data Sources:** USDA, National Animal Health Monitoring System, 2003; industry literature and expert opinion.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Broodstock source (assessed species)	Evolution Primary Economics and industry	Wild-caught	Mixed source	Domesticated breeding	N/A
	Rationale: Wild-caught broodstock pose a higher disease emergence risk than domesticated broodstock, because species in the wild have been exposed to an uncontrolled environment and have experienced contact with many other fish species. **Data Sources:** Industry literature.				
Content and processing of feed fed (assessed species)	Evolution Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (dead or live)	N/A	No feeding of uncooked or unprocessed fish waste or fish (dead or live)	N/A
	Rationale: Feeding fish back to fish, particularly when uncooked or unprocessed, provides an opportunity for both cross-species and within-species disease transmission and emergence. **Data Sources:** Feed sales data, industry literature, and expert opinion.				
Waste fertilization practiced (assessed species)	Evolution Primary Economics and industry	Yes	N/A	N/A	No
	Rationale: Incidence of fertilizing ponds with waste, whether from human, livestock, or other animal sources (Martin 2003; Wurts 2004), would be a potential avenue to spread disease or pathogens and microbes. A publication from FAO regarding the development of aquaculture programs in developing countries has discussed the value of using waste, specifically human waste, to fertilize aquaculture ponds (Larsson 1994). Any occurrence of the practice is enough to make the risk high for disease emergence. **Data Sources:** FAO literature, industry literature, and expert opinion.				
Secondary Factors					
Reported total aquaculture disease burden (country level, all species)	Evolution Secondary Agent, host, and vector biology	Any OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years, OR country does not report to OIE	N/A	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported and no credible reports of other (non-OIE-listed) diseases during past three years
	Rationale: The total disease burden in a country is an indication of the overall health of aquaculture species in that country. Factors such as management practices, veterinary care, and others, which affect overall animal health, are reflected by this risk factor. Diseases to use in this risk factor are the “List B” or “Significant” diseases as categorized by the OIE, Collaborating Center for Information on Aquatic Animal Diseases (CCAAD). **Data Sources:** OIE, Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Length of life cycle (assessed species)	Evolution Secondary Agent, host, and vector biology	Life cycle is two years or more	Life cycle is greater than six months and less than two years	Life cycle is six months or less	N/A

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
	Rationale: The longer the life cycle, the greater amount of time provided for a novel pathogen to develop or emerge within that species of fish. Fish that are harvested by the time they are six months old provide less time, and thus are less likely, for a virus or bacteria to mutate or combine with some other virus or bacteria into a pathogenic agent. Length of life cycle should be determined by that which is typical for the species being assessed under aquaculture conditions and production systems. **Data Sources:** Industry literature.				
Geographic concentration of production (assessed species)	Evolution Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area greater than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
	Rationale: An increase in the density of production within a defined geographic region favors emergence of a disease. Increased density can lead to more efficient mechanical or airborne transmission of pathogens and microbes between and within production units. It can also lead to increased efficiency in movement of fish because of predatory birds or weather disasters, which would result in mixing of pathogens and microbes and hosts. **Data Sources:** *Student Atlas of World Geography* 1999; USDA, National Agricultural Statistics Service, 2005.				
Latitude at which production takes place (assessed species)	Evolution Secondary Ecology, environment, and climate	Between 20 degrees north and 20 degrees south latitude	20 degrees north to 50 degrees north OR 20 degrees south to 50 degrees south	Above 50 degrees north or below 50 degrees south	N/A
	Rationale: The latitudinal species diversity gradient is the name for the ecologic phenomenon by which the number of plant and animal species declines as one moves away from the equator. A recent study of the geographic distribution of human parasitic and infectious pathogens and microbes provides evidence that pathogen species richness is highly correlated with latitude and, on average, tropical areas contain higher pathogen species diversity compared with more temperate areas. The researchers found a significant negative relationship between latitude and pathogen species richness (the higher the latitude the less species richness). Latitude is thought to be a proxy variable for bioclimatic factors such as rainfall, which may influence pathogen species survival. Greater numbers of pathogens/microbes and animal species leads to greater biotic interaction and potential for disease emergence (Guernier, Hochberg, and Guegan 2004). **Data Sources:** *Student Atlas of World Geography* 1999.				
Level of stocking in lakes and streams during most recent year (assessed species)	Evolution Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or more, but less than 100 percent, of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is less than 25 percent of the number of assessed species produced for food by aquaculture	No stocking
	Rationale: Breeding of fish in hatcheries and releasing these domestically bred fish into lakes and rivers is a common practice in the United States. The individual States are responsible for determining the species, numbers, and locations of stocking. Although hatcheries seek to raise and release disease-free fish, there is always the potential that disease could be introduced into the wild from the hatcheries (e.g., whirling disease of trout, Colorado Division of Wildlife, 2006). In addition, the sudden addition of large numbers of fish to a body of water may alter the natural balance and cause stress in the ecologic system, leading to increased likelihood of disease occurrence. **Data Sources:** State agencies responsible for stocking fish provided by 50 states for 2002–04.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Introduction of nonindigenous species (region or states where assessed species is produced)	Evolution Secondary Ecology, environment, and climate	Number of nonindigenous species introductions in any of the top species-producing States is five or more during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing States is two, three, or four during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing States is one during the most recent five years	No nonindigenous species introductions in any of the top species-producing States during the most recent five years
	Rationale: Introduction of a nonindigenous species may bring new pathogens and microbes as well as alter the habitat and ecology of the area where it is introduced. States with higher numbers of nonindigenous introductions are at higher risk for disease emergence than states with lower numbers of introductions. According to the U.S. Geological Survey, the number of identified nonindigenous fish introductions during 2001 to 2005 varied from zero in 20 States to one or more in 30 States. Ornamental fish released into the wild that become established are included in these data. Compared with fish introductions, fewer States experienced introductions of nonindigenous crustaceans during 2001–05. Only 12 percent of States had one or more crustacean introduction and 88 percent of States experienced no introductions during 2001–05. **Data Sources:** Personal communication with Pam Fuller, 2006.				
Occurrence of major weather disasters (top-producing states for assessed species)	Evolution Secondary Ecology, environment, and climate	25 percent or more of production takes place in states that experienced hurricanes during the past five years	25 percent or more of production takes place in states that are in the top tertile for flooding, based on the past five years	All else	N/A
	Rationale: Major weather disasters such as hurricanes and floods have the ability to move aquaculture species to new locations. For example, flooding can result in aquaculture ponds overflowing and fish from the ponds ending up in nearby waterways. This movement of animals to new locations results in contacts that would not have otherwise occurred, which in turn increases the risk of disease emergence. These particular types of weather disasters are of great enough size and force to affect all types of aquaculture production, including indoor or RAS, to some extent. **Data Sources:** NOAA, Coastal Services Center, 2005; NOAA, National Climate Data Center, 2005.				
Change in production volume, over most recent three years (assessed species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	Change, up or down, of 3 percent or more, but less than 5 percent, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
	Rationale: An increase in production volume of the assessed species greater than 5 percent over three years indicates that either existing producers are increasing production or that new producers are entering the marketplace. Either case has implications for disease emergence. Increasing production on existing operations results from increased concentration in existing production facilities or the building of new production facilities. New farms imply new production facilities. Lack of familiarity with the species by new producers or the increased potential for stressing by overcrowding by existing producers increases risk of disease emergence. When production is rapidly decreasing, producers may exit the industry by releasing stock, or improperly destroying fish or feed. This can result in increased mixing of fish or feed, leading to increased risk of disease emergence. Rapidly decreasing production volume can cause producers to exit the industry by selling their facility to others, including speculators. Selling to inexperienced speculators could result in poor management behaviors, especially if the industry profit margin is declining. Selling to other producers could result in increased mixing of fish or feed and equipment, leading to increased risk of disease emergence. **Data Sources:** FAO, Fishstat Plus, 2006.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level			
		High	Medium	Low	No defined risk
Change in production volume of all aquaculture, over most recent three years (country level, all species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
	Rationale: An increase in the production volume of all aquacultured species in a country greater than 5 percent over three years indicates that either existing producers are increasing production or that new producers are entering the marketplace at a rapid rate. When production is increasing, either new producers are entering the industry or existing producers are expanding or consolidating and becoming more efficient. In the case of new producers, more potential exists for the use of poor production practice and potential disease transmission through inexperience. When facilities expand or concentrate to produce species more efficiently, the potential for overstocking exists. When production is decreasing, producers may exit the industry by selling their facility to others, including speculators. Selling to inexperienced speculators could result in poor management behaviors, especially if the industry profit margin is declining. Selling to other producers could result in increased mixing of fish or feed and equipment, leading to increased risk of disease emergence. Producers may exit the industry by releasing stock, or improperly destroying fish or feed. This can result in increased mixing of fish or feed, leading to increased risk of disease emergence. **Data Sources:** FAO, Fishstat Plus, 2006.				
Level of stocking density (assessed species)	Evolution Secondary Economics and industry	Industry tends to overstock	High-density stocking but no discernable negative impact on production	All else	N/A
	Rationale: A high level of stocking density leads to higher rates of contact between fish and thus higher rates of disease transmission. When stocking density gets to a point of “overstocking,” fish are being stressed, which leads to increased susceptibility to disease and negative impact on production. Different species tolerate different levels of stocking density before negative health impacts occur, which is an indication of varying levels of hardiness between species. Therefore, the level of stocking density that results in “overstocking” will vary by species. **Data Sources:** Industry literature and expert opinion.				
Introduction to new environment during life cycle (moving to a different type of production system, i.e., RAS to open ponds) (assessed species)	Evolution Secondary Economics and industry	Live in three or more types of environments during life	N/A	Live in two types of environments during life	Live in one type of environment during life
	Rationale: Changing production environment leads to stress on the fish and therefore increased disease susceptibility. It also increases possible exposure to new pathogens and microbes. **Data Sources:** Industry literature.				
New technology or management practice used in production (assessed species)	Evolution Secondary Economics and industry	Greater than 50 percent of producers implemented a new technology or management practice during the past year	10 to 50 percent of producers implemented a new technology or management practice during the past year	Less than 10 percent of producers implemented a new technology or management practice during the past year	Static technology

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
	Rationale: Technological change has been associated with disease emergence. Technology can provide new, unforeseen ecologic niches for microbes. For example, the bacteria responsible for Legionnaires' disease became adapted to air-conditioning cooling towers (Smolinski, Hamburg, and Lederberg 2003). Technological changes in the rendering industry are thought to have contributed to the emergence of BSE. Quick introduction of new technologies by large numbers of producers, without adequate time to evaluate their full range of potential negative impacts, represents a higher-risk potential for disease emergence than a slow gradual introduction, although any introduction of a new technology carries some risk. **Data Sources:** Industry literature.				
Production in new area during last three years (assessed species)	Evolution Secondary Economics and industry	Yes	N/A	N/A	No
	Rationale: Some infectious diseases of fish are not species-specific. The movement of an industry from one geographic area into another, regardless of the species being produced, may lead to the movement and subsequent emergence of a disease in the new area. This geographic proximity of different species in an area increases risk for disease emergence. Not all aquaculture pathogens and microbes are highly fatal to their hosts; asymptomatic carriers are common, and these carriers could facilitate transmission of infectious disease from areas of "old" production to areas of "new" production. This geographic proximity of species creates new potential for contact between species that did not previously have contact. There is a risk whether the species being assessed is moved to a new geographic area where other species are being aquacultured, or whether new production of a species moves to the geographic area where the species being assessed has historically been located. Only the former is taken into account, however, when assessing this risk factor because it is believed that the latter is not measurable. **Data Sources:** USDA, National Agricultural Statistics Service, 2005; industry literature and expert opinion.				
Production system used (assessed species)	Evolution Secondary Economics and industry	Greater than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high- or low-risk level	Greater than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
	Rationale: Aquaculture production systems vary in the degree by which they allow for the producer to control the environment of the farmed species. Producers have the least control of mariculture systems, because the fish are raised in net pens in the open ocean, allowing for interaction with large numbers of wild fish and birds, which can spread disease. Raceways use naturally occurring water systems (streams), again with opportunities for interaction with large numbers of wild fish and birds. Uncovered pond systems may be constructed, but they are still open to the wild environment, particularly to birds, and small numbers of wild fish still find a way into ponds (personal communication with James Steeby 2006). A recirculating aquaculture system (RAS) is an enclosed system that provides much greater control over the water (water is treated and reused), water temperature, and oxygenation, and is protected from weather impacts. An RAS provides increased biosecurity over other types of aquaculture production systems. Lack of environmental control and biosecurity in the more open systems result in increased risk for disease emergence. **Data Sources:** Industry literature.				
Industry changes to different production system (assessed species)	Evolution Secondary Economics and industry	On an annual basis, 10 percent or greater of industry producers changed to a new production system	N/A	On an annual basis, less than 10 percent of industry producers changed to a new production system	No usage of new production systems

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
	Rationale: For the major species currently produced, a single production system seems to dominate. If a shift to a new or different production system were to occur across the entire industry (e.g., raising a maricultured species in ponds), then some period of adjustment to the new production system should be expected. During this period of adjustment, lack of knowledge and lack of proper procedures will result in increased risk for disease emergence. The more recent the industry shift to a new system, the higher the risk of disease emergence. **Data Sources:** Extension specialist, expert opinion, and industry literature.				
Phased production used (assessed species)	Evolution Secondary Economics and industry	Less than 25 percent of industry using all-in, all-out production	25 percent or more, but less than 75 percent, of industry using all-in, all-out production	75 percent or more, but less than 90 percent, of industry using all-in, all-out production	90 percent or more of the industry using all-in, all-out production
	Rationale: Phased production refers to the practice of all-in, all-out production systems in which a pond is dedicated to a single age of fish, of the same size and growth rate. All fish are put into the pond together and all are harvested together. The practice of all-in, all-out production decreases disease emergence risk because potentially disease-carrying fish are not introduced periodically into the pond. After harvest, ponds can be cleaned or left empty for a time to allow any pathogens and microbes that might exist in the environment to die off before the next group of fish is introduced. **Data Sources:** USDA, National Agricultural Statistics Service, 2005; USDA, National Animal Health Monitoring System, 2003; FAO; and industry literature.				
Acceptable use of drugs, chemicals, vaccines (assessed species)	Evolution Secondary Health management	Country had a trade ban imposed for sanitary reasons against the assessed species during the past year	Country had a trade ban imposed for sanitary reasons against the assessed species during the past five years, but not during the past year	Country has had no trade bans imposed for sanitary reasons against the assessed species during the past five years	Country does not export the assessed species
	Rationale: Regulatory oversight of the use of drugs in aquaculture varies among countries. As an example, only six antimicrobial drugs have been approved in the United States for use in any of the more than 800 aquaculture species. “Off-label” use of drugs has the potential for misuse and abuse, and all the related consequences thereof (e.g., antimicrobial resistance, insufficient withdrawal periods). Inappropriate use of drugs, chemicals, and vaccines can be in response to high disease burden or risk factors for disease emergence, such as poor biosecurity practices. This type of inappropriate use of drugs, chemicals, and vaccines is not currently measurable; therefore, export trade bans for sanitary reasons against the species being assessed is used as an indicator of risk because they may indicate that trading partners found traces of drugs, chemicals, or vaccines that were used inappropriately. This risk factor is assessed at the country level and only when the country being assessed is an exporter of the relevant species. **Data Sources:** Regulations, official government Web sites, and news articles.				
Level of health management (assessed species)	Evolution Secondary Health management	Little use or availability of certified aquaculture health professionals of any kind	Some availability and use of certified aquaculture health professionals of any kind	Good availability and use of certified aquaculture health professionals of any kind	N/A
	Rationale: The extent to which certified health professionals (e.g., aquaculture veterinarians, fish biologists) are being used in the various aquaculture industries varies significantly among the industries. Practicing good biosecurity and good health care, including the appropriate use of vaccines, therapeutics, and other chemicals, in disease prevention and control programs, is closely linked to having access to properly trained health professionals. **Data Sources:** Expert opinion.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Treatment of discharge water (assessed species)	Evolution Secondary Politics and regulations	Government regulations or industry BMPs do not exist for discharge water OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water	N/A
	Rationale: Industry practices regarding the treatment of discharge water describe how the industry introduces pathogens and microbes into the water resources of a country. Varying types of production systems have varying levels of risk regarding discharge water. For example, net pens in open bodies of water provide a direct mechanism for mixing of species or transmission of pathogens and microbes between the species inside and outside the nets. Although dilution does occur and mitigating measures can be taken to reduce this risk (such as those that might be defined in a BMP), significant risk still exists. Access to government regulations or adherence may be limited, so information from a BMP program can be used to assess the industry attitude to the treatment of discharge water and therefore the likely risk of transmitting pathogens and microbes by releasing raw water into a watershed. **Data Sources:** Industry literature; Federal and State regulations.				
Commercial production of a new species (country level, all species)	Evolution Secondary Social and cultural	Production of new species has occurred for one to two years	Production of new species has occurred for three to seven years	Production of new species has occurred for more than 7 years but less than 10 years	Production of new species has occurred for 10 years or more
	Rationale: Commercial production of a new species may introduce new microbes into a country's aquaculture industry. In addition, commercial production of a new species of fish, any species, implies that producers are using new production practices with which they likely are not familiar. New fish species may require broodstock that is wild-caught, or only a few generations from wild-caught, potentially increasing the potential for the emergence of a new disease. Polyculture is widely used in aquaculture production and new species may be introduced into polyculture situations without an understanding of the new species' potential to transmit diseases to which other fish in the polyculture system are susceptible. **Data Sources:** USDA, National Agricultural Statistics Service, 2005; industry literature.				
Total imports of live food finfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import value is 10 percent or more of world import value	Import value is 1 percent or greater, but less than 10 percent, of world import value	Import value is less than 1 percent of world import value	No imports
	Rationale: Because species of fish may be susceptible to pathogens and microbes that infect multiple species, total live food finfish imports, regardless of the species being assessed, are important to risk of disease emergence. The larger the volume of imports, the greater the risk. Trade provides an opportunity for the mixing of microbes and hosts in new locations. This mixing might result in simple transmission of a microbe to the host, which is assessed in the pathways element, but it might also result in a more complex and less direct interaction. Examples of outcomes of this more complex interaction include the evolution of a novel pathogen by mixing multiple microbes, evolution resulting in increased virulence of an endemic agent by exposing it to new microbes or environments, or alteration (such as weakening) of the host resulting in disease caused by a pathogen already present. The risk lies not only with the movement of animals and animal products, but also with the contaminated packing materials and waste products associated with transportation and processing. The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. Data for most countries do not record import volume by number of live finfish or weight; therefore, value must be used to evaluate the flow of trade in live food finfish. **Data Sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
	Rationale: Volume of imports indicates the potential for introducing material that may contribute to disease emergence into the U.S. ecosystem and the larger the volume of imports, the greater the risk. Trade provides an opportunity for the mixing of microbes and hosts in new locations. This mixing might result in simple transmission of a microbe to the host, which is assessed in the pathways element. But it might also result in a more complex and less direct interaction. Examples of outcomes of this more complex interaction include the evolution of a novel pathogen by mixing multiple microbes, evolution resulting in increased virulence of an endemic agent by exposing it to new microbes or environments, or alteration (such as weakening) of the host resulting in disease caused by a pathogen already present. The risk lies not only with the movement of animals and animal products, but also with the contaminated packing materials and waste products associated with transportation and processing. **Data Sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Change in import value of live food finfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase over the most recent three-year period in the import value of live food finfish production	3 percent or greater increase, but less than 5 percent, in the import value of live food finfish over the most recent three-year period	Less than 3 percent increase in the import value of live food finfish over the most recent three-year period	No imports
	Rationale: An increasing rate of change in the import of live food finfish indicates higher demand for the products and may be a signal that aquaculture production, for those species that can be aquacultured, may be increasing in the United States. Increased consumer demand over a short period of time can result in changes in the supply chain that result in higher disease emergence risk. For example, new importers with little experience may enter the market. These importers may try to increase their import volume quickly without appropriate expansion of infrastructure and without attention to BMPs to ensure healthy and fresh product delivery The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. Data for most countries do not record import volume by number of live finfish or weight; therefore, value must be used to evaluate the flow of trade in live food finfish. **Data Sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
	Rationale: An increasing rate of change in the import of fresh fish food products and roe indicates higher demand for the products and may be a signal that aquaculture production of those products (i.e., those that can be aquacultured) may be increasing in the United States. Increased consumer demand for a particular species over a short period of time can result in changes in the supply chain that result in higher disease emergence risk. For example, new importers with little experience may enter the market. These importers may try to increase their import volume quickly without appropriate expansion of infrastructure and without attention to BMPs to ensure healthy and fresh product delivery. **Data Sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				

Pathways Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Primary Factors					
Presence of OIE-listed diseases in country from which the largest share of imports (by value) of live food finfish originate	Pathways Primary Agent, host, and vector biology	Any OIE-listed diseases reported during past three years in the country from which the largest share of imports originate OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past three years for species being assessed, but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed) diseases during past three years
	Rationale: Risk of disease transmission is increased if the country of origin for the largest share of live food finfish imports has reported the presence of OIE-listed diseases during the past three years. The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. Data for most countries do not record import volume by number of live finfish or weight; therefore, value must be used to evaluate the flow of trade in live food finfish. The OIE Collaborating Centre for Information on Aquatic Animal Diseases is the clearinghouse for information about aquaculture diseases in OIE member countries. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006; OIE, Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Ballast-water dumping in assessed country	Pathways Primary Ecology, environment, and climate	Marine species production constitutes 50 percent or more of total aquaculture production	Marine species production constitutes 25 percent or more but less than 50 percent of total aquaculture production	Marine species production constitutes less than 25 percent of total aquaculture production	N/A
	Rationale: Ballast water is water carried by ships to ensure stability, trim, and structural integrity. Ships may take up ballast water in one port and release it in another port. Introduction of nonindigenous species (including microbes) has been shown to occur through the release of ballast water (National Research Council 1996). Risk is based on proximity of aquaculture production to bodies of water that receive ballast water released from ships. Aquaculture production in marine environments and in other large bodies of water that accommodate oceangoing shipping vessels are most at risk. Because risk is primarily for marine species, risk is assessed based on proportion of a country's aquaculture production that is marine species. **Data sources:** NOAA, National Marine Fisheries Service, 2004				
Regulatory infrastructure regarding importations (country level, all species)	Pathways Primary Politics and regulations	National government has no health requirements in place for fish or fish product imports (requirements include testing, health certificates, quarantines, etc.)	National government has health requirements in place for one or more fish or fish product imports (requirements include testing, health certificates, quarantines, etc.)	National government has import requirements in place for all fish or fish product imports (requirements include testing, quarantines, health certificates, etc.) and has a risk assessment and risk management process in place to collect and assess international information regarding fish and fish product imports	No importations of fish or fish products are allowed

Pathways Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
	Rationale: Import regulations play a significant role in mitigating risk caused by importations of live fish and fish products. In addition to having import regulations in place, a country must have the infrastructure to implement, enforce, and amend those regulations over time. **Data sources:** Government Web sites and personal contacts.				
Total imports of all live food finfish during most recent year (country level)	Pathways Primary Social and cultural	Import value 50 percent or greater of world imports	Import value 5 percent or more of world imports, but less than 50 percent	Import value less than 5 percent of world imports	No imports
	Rationale: Total volume of live food finfish indicates that a pathway exists. The higher the proportion of world production, the more likely that a pathogen may be imported. Importation of live food finfish is a pathway for the introduction of a disease agent along with the fish. The amount of live food finfish imported indicates the potential level of risk for this pathway. The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. Data for most countries do not record import volume by number of live finfish or weight; therefore, value must be used to evaluate the flow of trade in live food finfish. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Total import value of all live ornamental fish during most recent year (country level, all ornamental species)	Pathways Primary Social and cultural	Import value 20 percent or greater of world imports	Import value 1 percent or more of world imports, but less than 20 percent	Import value less than 1 percent of world imports	No imports
	Rationale: Ornamental fish imports represent a risk for all aquaculture species because of the potential for these animals to be released or escape into the wild water systems. Historically, pet shops and pet fish owners may flush or set free their pets after they are no longer wanted. The more ornamental fish entering the United States, the greater the potential for releases to occur. Data for most countries do not record import volume by number of live ornamental fish or weight, therefore, value must be used to evaluate the flow of trade in live ornamental finfish. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Change in imports of all live food finfish, most recent 3 years (country level)	Pathways Primary Social and cultural	Rate of change 10 percent or greater for value	Rate of change 3 percent or greater and less than 10 percent for value	Rate of change less than 3 percent or negative for value	No imports
	Rationale: A significant increase in the importation of live food finfish results in a larger pathway for potentially risky fish to be introduced into the United States. Rate of change is assessed because it is an indicator of change in the movement of fish species into the United States. Increasing imports (i.e., a growing pathway) may be an indicator of increased risk because new buyers may be entering the market, import protocols may not be sufficient either for increased volume or new species, and fish may be sourced from riskier areas to meet the demand. A decrease in imports indicates that the pathway is shrinking and therefore the risk is decreasing. The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. Data for most countries do not record import volume by number of live finfish or weight; therefore, value must be used to evaluate the flow of trade in live food finfish. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Change in imports of live ornamental fish over most recent three years (country level, all ornamental species)	Pathways Primary Social and cultural	Increase in value 50 percent or greater	Increase in value 10 percent or greater, but less than 50 percent	Increase in value less than 10 percent	Either 0 percent or negative rate of change

Pathways Element						
		Definition of Risk Level				
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
	Rationale: A significant increase in the importation of live ornamental fish results in a larger pathway for potentially risky product to be introduced into the United States. It also means fish could be coming from new areas to meet the greater demand, which could have a higher pathogen level, or new species of ornamental fish could be in demand, which can transmit pathogens and microbes to aquaculture. Rate of change is assessed because it is an indicator of change in the movement of fish species into the United States. Increasing imports, a growing pathway, may be an indicator of increased risk because new buyers may be entering the market and import protocols may not be sufficient for increased volume or new species. A decrease in imports indicates that the pathway is shrinking and therefore the risk associated with increasing imports is not present. Data for most countries do not record import volume by number of live ornamental fish or weight, therefore, value must be used to evaluate the flow of trade in live ornamental finfish. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Geographic diversity of imports of live food finfish and live ornamental fish	Pathways Primary Social and cultural	Live fish imports originate from 50 percent or more of the countries in the world	Live fish imports originate from less than 50 percent but more than 10 percent of the countries	Live fish imports originate from less than 10 percent of the countries in the world	No imports
	Rationale: Countries from which imports originate represent distinct geographic locations that have associated microbial flora. Trade provides a pathway for microbes to move from one geographic location to another geographic location. The greater the number of geographic locations from which imports originate, the greater the diversity of microbes and the greater the risk of importation of microbes not already present. The same rationale applies to live shellfish; however, this factor only addresses live food finfish because world trade data do not separate live shellfish from dead shellfish. **Data sources:** *World Trade Atlas, 2006.*				
Secondary Factors					
Presence of OIE-listed diseases in country from which the largest share of imports (by volume) of whole food finfish and shellfish originate (fresh or frozen) (country level)	Pathways Secondary Agent, host, and vector biology	Any OIE-listed diseases reported during past three years in the country from which the largest share of imports originate OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past three years for species being assessed, but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed) diseases during past three years
	Rationale: Risk of disease transmission is increased if the country of origin for the largest share of fresh or frozen whole food finfish and shellfish imports has reported the presence of OIE-listed diseases during the past 3 years. The OIE Collaborating Centre for Information on Aquatic Animal Diseases is the clearinghouse for information about aquaculture diseases in OIE member countries. (See note under Disease Evolution, Agent, Host, and Vector Biology, Reported Aquaculture Disease Burden for information about the OIE disease categorization scheme). **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006; OIE, Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Migratory and predatory birds (country level)	Pathways Secondary Ecology, environment, and climate	Greater than 75 percent of aquaculture production produced in open production systems (e.g., mariculture, raceways, uncovered ponds)	Production produced in open and closed systems and does not meet the criteria for a high or low risk level	Greater than 75 percent of aquaculture production produced in closed production systems (e.g., RAS)	N/A

Pathways Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
	Rationale: Birds may act as both biological and mechanical vectors for certain aquaculture diseases. Open production systems such as mariculture, raceways, and uncovered ponds are at greater risk to disease transmission via birds than closed systems such as RAS. **Data sources:** Proxy is type of production system				
Imports of fish feed containing fish products during most recent year (country level)	Pathways Secondary Economics and industry	Yes	N/A	N/A	No
	Rationale: Contaminated feed is a direct pathway for disease movement. The greatest risk occurs with a product that results in feeding one type of animal to itself, such as fish feed that contains fish. The HS codes (0511910000, 2301200010, and 2301200090) included here are flours, meals or pellets made of fish, crustaceans, mollusks, or other aquatic invertebrates. **Data sources:** *World Trade Atlas, 2006.*				
Imports of used aquaculture production equipment	Pathways Secondary Politics and regulations	Imports common and not regulated	Doesn't meet definition for high, low, or no defined risk	Minimal imports or imports regulated	No imports
	Rationale: Used equipment may be contaminated with pathogens/microbes and may be a vehicle of disease transmission (Jarp and Karlsen 1997). **Data sources**: Expert opinion, industry literature				
Total imports of whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species, fresh and frozen)	Pathways Secondary Social and cultural	Import volume 30,000 MT or greater	Import volume 1,000 MT or greater, but less than 30,000 MT	Import volume less than 1,000 MT	No imports
	Rationale: Whole food finfish and shellfish imports are a pathway for disease emergence in the importing country because waste from further processing has the potential to contaminate water or domestic aquaculture operations. Commercial processing of waste into marketable by-products, such as fish feed, likely reduces this risk because the processing often includes processes, such as heat treating, which inactivate pathogens and microbes. **Data sources:** FAO, Fishstat Plus, 2006; *World Trade Atlas,* 2006.				
Change in imports of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Pathways Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three-year period	No imports
	Rationale: A significant increase in the importation of whole food finfish, fish livers and roe, and shellfish results in a larger pathway for potentially risky product to be introduced into the U.S. Rate of change is assessed since it is an indicator of change in the movement of these products into the U.S. Increasing imports, i.e. a growing pathway, may be an indicator of increased risk since new buyers may be entering the market, import protocols may not be sufficient for increased volume, and products may be sourced from riskier areas to meet the demand. A decrease in imports indicates that the pathway is shrinking and therefore the risk is decreasing.				

Pathways Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Geographic diversity of imports of whole food finfish and shellfish originate (fresh and frozen)	Pathways Secondary Social and cultural	Imports originate from 50 percent or more of the countries in the world	Imports originate from 10 percent or more of the countries in the world, but less than 50 percent	Imports originate from less than 10 percent of the countries in the world	No imports
	Rationale: Countries from which imports originate represent distinct geographic locations that have associated microbial flora. Trade provides a pathway for microbes to move from one geographic location to another. The greater number of geographic locations from which imports originate, the greater the diversity of microbes and the greater the risk of importation of microbes not already present. **Data sources:** *World Trade Atlas,* 2006.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Movement of fish caused by predation and major weather events (assessed species)	Spread Primary Ecology, environment, and climate	Greater than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	Greater than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
	Rationale: Movement of aquaculture species from their normal location to new locations, such as nearby waterways or other aquaculture ponds, results in contacts that would not have otherwise occurred. These new contacts would result in increased likelihood of spread of any pathogens and microbes the moved fish were harboring. Weather disasters (e.g., hurricanes, floods) and predation by birds are ways in which this movement can occur. Numbers of significant weather disasters occurring in a country is tracked by NOAA and can be quantified; however, data regarding the amount of movement caused by predation are unavailable. Therefore, to define the risk level for this risk factor, a proxy of the type of production system for the species being evaluated was used. Closed systems, such as RAS, are much less open to the environment, making the level of predation and impact from weather events much lower than for systems that are very open to the environment, such as uncovered ponds. **Data sources:** Industry literature				
Quality of source water (assessed species)	Spread Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMP developed for water uptake	N/A

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
	Rationale: Uptake water is a potential vehicle for farmers to introduce pathogens and microbes or stressors (change in temperature, chemical, gaseous, or nutrient balance of water) to aquaculture operations. Filtering or monitoring of uptake water will reduce the potential for microbial contamination, therefore, BMPs regarding uptake water that are followed by an aquaculture industry should mitigate the risk from this factor. **Data sources:** Industry literature.				
Intentional movement of fish associated with production practices (assessed species)	Spread Primary Economics and industry	Fish have different owners and reside at different operations during life or are wild-caught (based on how greater than one-third of industry operates)	Multiple movements by same owner within an operation, which could be multisite but all the same "farm" (based on how greater than one-third of the industry operates)	Movements within an operation at the same location (based on how greater than one-third of the industry operates)	N/A
	Rationale: Movement of fish, either between operations or between ponds on the same operation, is stressful for fish. The more stressed the fish are, the more susceptible they are to infection by pathogens and microbes. Movements between different operations may be more stressful because of longer distances to be moved. In addition, movement of fish into a new location may introduce pathogens and microbes from the source location. The more movements that occur during the life of the fish, the greater the level of risk. **Data sources:** Industry practices and expert opinion.				
Content and processing of feed fed (assessed species)	Spread Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (dead or live)	N/A	No feeding of uncooked or unprocessed fish waste or fish (dead or live)	N/A
	Rationale: Fish feed represents a potential method for the spread of a pathogen; however, most feed produced from cooked fishmeal is likely not a disease risk. Various expert sources and books indicate that fishmeal is produced through a chemical process that heats whole fish waste to a temperature that is high enough to kill most pathogens and microbes. After the fish waste is heated, the fish oil is separated from the solid protein product. Fishmeal therefore seems to present relatively little risk of transmitting pathogens and microbes, unless there is an error in the production practice. Of greater concern than thoroughly processed fish feed is the feeding of raw, waste, or unprocessed fish feeds. Reports of the use of by-products from salmon processing suggests that raw by-products do occasionally enter the U.S. aquaculture feed marketplace (Ellis, 2006). The use of processed fish feed or fishmeal is considered low risk, while feeding of raw or live products is of the greatest concern. **Data sources:** Industry literature and expert opinion.				
State regulations regarding live-hauling (assessed species if possible)	Spread Primary Politics and regulations	No regulations exist	Regulations exist but without enforcement	Regulations exist with enforcement	N/A
	Rationale: Regulations regarding live-hauling exist, especially for salmonid species, but enforcement and compliance is indeterminable. Evidence from industry experts indicates that live-haulers seek to arrive at their destination with the maximum number of live fish possible; however, what happens to the water after arrival, whether the trucks are cleaned, and how they are cleaned between hauls is unknown. Enforcement does not appear to occur for the newer aquacultured species (tilapia, hybrid striped bass, shrimp). Live-hauling is a significant disease risk because water-dumping restrictions are not consistent across states resulting in the possibility that dead fish and water can be dumped where convenient. Fish from multiple locations may also share water within the live-haul truck, which can then be transferred to tanks at the destination. Water from retailers who sell live fish may be dumped directly into local waterways or sewer systems, which may not control for aquaculture specific pathogens and microbes. **Data sources:** State governments.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Types of sales of products from farms (assessed species)	Spread Primary Social and cultural	25 percent or more of industry makes sales to live-haulers	50 percent or more of industry makes direct sales to consumers (live, fresh, or frozen) and the definition for high risk level is not met	All else	N/A
	Rationale: Unregulated or minimally regulated sales of fresh or live aquacultured species have the potential to spread pathogens and microbes. Of most concern are sales to live-haulers because the fish and the water they travel in may be transferred to a naïve system. Direct sales to consumers are of less concern because these sales are usually made for at-home consumption; however, disposal of waste products from these fish may not occur in appropriate ways and some of the fish sold directly to consumers could end up in contact with other live fish. Sales to processors are considered low risk because their purpose is to manufacture the fresh fish into human food products typically with the appropriate management and disposal of waste practices. **Data sources**: Web sites, expert opinion, and industry/press reports.				
Secondary Factors					
Geographic concentration of production (assessed species)	Spread Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area greater than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
	Rationale: A high density of premises located within a defined geographic region favors spread of disease. A high density can lead to more efficient mechanical or airborne transmission of pathogens and microbes between and within production units. It can also lead to increased efficiency in movement of fish because of predatory birds or weather disasters, thus spreading any existing disease. **Data sources:** *Student Atlas of World Geography* 1999; USDA, National Agricultural Statistics Service, 2005.				
Level of stocking in lakes and streams during most recent year (assessed species)	Spread Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is between 25 and 100 percent of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or less of the number of assessed species produced for food by aquaculture	No stocking
	Rationale: Breeding of fish in hatcheries and releasing these domestically bred fish into lakes and rivers is a common practice. In the United States, individual states are responsible for determining the species, numbers, and locations of stocking. Although hatcheries seek to raise and release disease-free fish, there is always the potential that disease could be introduced into the wild from the hatcheries (e.g., whirling disease of trout). **Data sources:** State agencies responsible for stocking fish provided by 50 states for 2002–04.				
Total number of farms (assessed species)	Spread Secondary Economics and industry	1,000 farms or more involved in the production of the species	More than 100 but less than 1,000 farms involved in the production of the species	100 farms or less involved in the production of the species	N/A

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
	Rationale: A large number of farms involved in the production of a given species provide more opportunity for biological and mechanical transmission of infected hosts (and therefore pathogens and microbes among those farms). The greater the number of production facilities, the greater the number of opportunities for disease spread to take place. **Data sources:** USDA, National Agricultural Statistics Service, 2005; industry experts and literature.				
Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years (assessed species)	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
	Rationale: An increase in the amount of production of an aquacultured species implies that more operations are producing the species or that a same or smaller number of operations are producing fish at a more concentrated level. Either situation can result in greater potential for disease spread. The higher the number of operations, the more opportunities that exist for spread. Higher concentration can mean that a disease that infiltrates a single operation has more potential to spread quickly throughout the operation. Because some fish pathogens can infect multiple species, production volume of those species that are susceptible to similar pathogens to the species being assessed are necessary to fully assess this risk factor. When production is rapidly decreasing, producers may exit the industry by releasing stock, or improperly destroying fish or feed, which could lead to spread of existing pathogens. Another mode by which producers may exit the industry is by selling their operation to other producers, which could entail movement of fish and equipment, and thus spread of disease. When multiple species are assessed, a weighted average of production should be used: [Production Species A * 3-yr rate of change] + [Production Species B * 3-yr rate of change]. **Data sources:** FAO, Fishstat Plus, 2006.				
Change in production volume of all aquacultured species, over most recent three years (country level, all species)	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
	Rationale: An increase in the amount of production of all aquacultured species implies that more operations are producing fish or crustaceans or that a same or smaller number of operations are producing aquacultured products at a more concentrated level. Either situation can result in more potential for disease spread. The greater the number of operations, the more opportunities exist for spread. Higher concentration can mean that a disease that does infiltrate a single operation has more potential to spread quickly throughout the operation. Total overall aquaculture production increase implies that more movement of fish, more feed, and more people are involved in the industry. The larger the number of players, the larger the potential spread of disease because many support industries for aquaculture will operate across multiple species and multiple locations. When production is rapidly decreasing, producers may exit the industry by releasing stock, or improperly destroying fish or feed, which could lead to spread of existing pathogens. Another mode by which producers may exit the industry is by selling their operation to other producers, which could entail movement of fish and equipment, and thus spread of disease. **Data sources:** FAO, Fishstat Plus, 2006.				

Spread Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Production system used (assessed species)	Spread Secondary Economics and industry	Greater than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	Greater than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
	Rationale: Because of the access to predators, birds, and weather, outdoor or uncovered production practices are considered to present the greatest risk for spread of pathogens and microbes. Open ponds, raceways, and mariculture systems present the greatest risk because the water itself and the fish within the water are not protected. Disease spread within the facility or to other facilities either by water discharge or because of animal access is possible in the open systems. RAS are considered much safer both from becoming exposed to pathogens and microbes and from spreading existing pathogens and microbes. **Data sources:** Industry literature.				
Disease management practices at the industry level (assessed species)	Spread Secondary Health management	No industry BMPs for disease management	Existence of industry BMPs for disease management, but little adherence or compliance measures	Existence of industry BMPs for disease management with compliance measures	N/A
	Rationale: The value of sound, scientifically and economically based BMPs, including biosecurity practices, to other animal health industries (e.g., pork, beef, poultry) and their impact on improving animal health has been documented clearly. If an industry has developed a BMP and biosecurity practices for production of their species, this indicates the industry is conscious of the impacts that common industry practices have on the potential for disease occurrence and transmission. This factor is intended to be a general indicator of overall industry concern about disease prevention and management, rather than a definitive descriptor of disease management within an industry. **Data sources**: Industry groups, expert opinion, and BMPs.				
Handling of mortalities (assessed species)	Spread Secondary Health management	Proper handling of mortalities is practiced by 50 percent or less of the industry	Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the industry	Proper handling of mortalities is practiced by 75 percent or more of the industry	N/A
	Rationale: Mortalities that occur during production can be a source of infection and can spread infection if not handled properly. Factors in the proper handling of mortalities to decrease disease spread risk include the frequency of removal, storage, and disposal methods. Proper handling of mortalities requires at least weekly mortality removal and daily removal during a disease situation, storage remotely from the site in sealed leak-proof containers with no access to scavengers, and disposal in a landfill, or by composting or rendering. **Data sources:** Expert opinion.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Treatment of discharge water (assessed species)	Spread Secondary Politics and regulations	Government regulations or industry BMP do not exist for discharge water (can use percent compliant with regulations if data exist) OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water (can use percent compliant with regulations if data exist)	N/A
	Rationale: When an industry as a rule discharges water with little or no filtering, the potential exists to spread pathogens and microbes through waterways. Varying types of production systems have varying levels of risk regarding discharge water. For example, net pens in open bodies of water provide a direct mechanism for mixing of species or transmission of pathogens and microbes between the species inside and outside the nets. Although dilution does occur and mitigating measures can be taken to reduce this risk (such as those that might be defined in a BMP), significant risk still exists. Knowledge of government regulations and levels of compliance is difficult to obtain, so information from a BMP program can be used instead to assess the industry attitude to the treatment of discharge water and therefore the likely risk of transmitting pathogens and microbes by releasing raw water into a watershed. **Data sources:** Industry literature.				

Notes: BMPs = best management practices; BSE = Bovine Spongiform Encephalopathy; FAO = Food and Agriculture Organization of the United Nations; MT = metric ton; N/A = not applicable; NOAA = National Oceanic and Atmospheric Administration; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix B. Catfish Results and Documentation

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Reported aquaculture disease burden (assessed species)	Evolution Primary Agent, host, and vector biology	Any OIE-listed disease reported during past five years for species being assessed, OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past five years for species being assessed, but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed) diseases during past five years
Risk level = Low	**Documentation:** Catfish are not susceptible to any of the 10 current OIE-listed diseases of fish (2005). Channel catfish are susceptible to two of the OIE previously listed diseases: channel catfish virus disease and enteric septicemia of catfish. The United States reported to the OIE in 2003 that both enteric septicemia and channel catfish virus disease were known to be present. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Quality of source water (assessed species)	Evolution Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMP developed for water uptake	N/A
Risk level = Low	**Documentation: :** Well water (aquifer) was the source of water for 72.5 percent of operations. *Sources:* USDA, Animal and Plant Health Inspection Service 2003; Tucker, Avery, Engle, and Goodwin 2004.				
Polyculture practiced (assessed species)	Evolution Primary Economics and industry	50 percent or more of industry	10 percent or more but less than 50 percent of industry	Less than 10 percent of industry	No polyculture practiced
Risk level = High	**Documentation:** Polyculture is the practice of producing more than one species in the same aquaculture environment. More than 50 percent (53.3%) of catfish operations engage in the practice of polyculture, with at least five other species of fish being stocked in addition to the catfish. These species are threadfin shad, red ear sunfish, fathead minnow, black carp, and grass carp. Grass carp were stocked in catfish ponds on 42.1 percent of operations during 2003, significantly more than any of the other species. *Source:* USDA, Animal and Plant Health Inspection Service 2003.				
Broodstock source (assessed species)	Evolution Primary Economics and industry	Wild-caught	Mixed source	Domesticated breeding	N/A
Risk level = Low	**Documentation:** The catfish industry practices domesticated breeding to provide stock. The broodstock, fry, fingerlings, and growers are produced on the same operation, or operations may specialize in producing fish for a specific stage of production. Brood fish are commonly obtained from food-fish grower ponds that contain large fish, or they are obtained from existing broodstock that appeared to perform well on other farms. *Sources:* USDA, Animal and Plant Health Inspection Service 2003; Tucker, Avery, Engle, and Goodwin 2004.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Content and processing of feed fed (assessed species)	Evolution Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = High	**Documentation:** No evidence that the industry feeds uncooked or unprocessed fish waste, however, 11 percent of catfish producers stock live fish (flathead minnows) in ponds as a food source, therefore, this factor is ranked as high. *Sources:* USDA, Animal and Plant Health Inspection Service 2003; personal communication with Bruce Wagner, 2006.				
Waste fertilization practiced (assessed species)	Evolution Primary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Animal or human waste is not being used to fertilize catfish production facilities in the United States. *Source:* Personal communication with Bruce Wagner, 2006.				
Secondary Factors					
Reported total aquaculture disease burden (country level, all species)	Evolution Secondary Agent, host, and vector biology	Any OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years, OR country does not report to OIE	N/A	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported and no credible reports of other (non-OIE-listed) diseases during past three years
Risk level = High	**Documentation:** The United States reported 12 of the 24 listed diseases of fish, mollusks, and crustaceans during the past three (2003–05) years. Diseases reported by the United States were as follows: infectious hematopoietic necrosis, infectious salmon anemia, spring viremia of carp, viral hemorrhagic septicemia, *Bonamia ostrea, Mikrocytos mackini, Xenohaliotis californiensis,* infectious hypodermal and hematopoietic necrosis, tetrahedral baculovirosis, Taura syndrome, white spot disease, and yellowhead disease. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Length of life cycle (assessed species)	Evolution Secondary Agent, host, and vector biology	Life cycle is two years or more	Life cycle is greater than six months and less than two years	Life cycle is six months or less	N/A
Risk level = High	**Documentation:** The catfish life cycle exceeds two years. *Source:* Tucker, Avery, Engle, and Goodwin 2004.				
Geographic concentration of production (assessed species)	Evolution Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area greater than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = High	**Documentation:** At least 75 percent of U.S. catfish production is located in a 250,000-square-mile area (Alabama, Arkansas, Louisiana, Mississippi). *Source:* USDA, Animal and Plant Health Inspection Service 2003.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Latitude at which production takes place (assessed species)	Evolution Secondary Ecology, environment, and climate	Between 20 degrees north and 20 degrees south latitude	20 degrees north to 50 degrees north OR 20 degrees south to 50 degrees south	Above 50 degrees north or below 50 degrees south	N/A
Risk level = Medium	**Documentation:** Catfish production in the continental United States is concentrated in the Southeastern states. All states in the continental United States, and all states involved in catfish production, are located at latitudes between 20 degrees north and 50 degrees north. The geographic location of production has remained constant for 20 to 30 years and there are no indications of a significant shift in this location. *Sources:* USDA, NASS, Catfish production 2005; *Student Atlas of World Geography* 1999.				
Level of stocking in lakes and streams during most recent year (assessed species)	Evolution Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or more, but less than 100 percent, of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is less than 25 percent of the number of assessed species produced for food by aquaculture	No stocking
Risk level = Low	**Documentation:** Total stocking of all catfish species in lakes and streams was 0.52 percent of total aquacultured catfish inventory in 2005. Stocking of all catfish species in lakes and streams decreased 49 percent between 2002 and 2004. *Sources:* USDA, NASS, Catfish production 2005; State agencies responsible for stocking fish provided by 50 states for 2002–04.				
Introduction of nonindigenous species (region or states where assessed species is produced)	Evolution Secondary Ecology, environment, and climate	Number of nonindigenous species introductions in any of the top species-producing states is five or more during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing states is two, three, or four during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing states is one during the most recent five years	No nonindigenous species introductions in any of the top species-producing states during the most recent five years
Risk level = High	**Documentation:** From 2001–05, the total number of nonindigenous species introductions in the five top catfish-producing states ranged from zero in Mississippi to nine in Louisiana. *Source:* Personal communication with Pam Fuller, 2006.				
Occurrence of major weather disasters (top-producing states for assessed species)	Evolution Secondary Ecology, environment, climate	25 percent or more of production takes place in states that experienced hurricanes during the past five years	25 percent or more of production takes place in states that are in the top tertile for flooding, based on the past five years	Did not meet criteria for high or medium	N/A
Risk level = High	**Documentation:** Leading catfish-producing states include Alabama, Arkansas, Louisiana, Mississippi, and North Carolina. Hurricanes impacted Alabama, Louisiana, and North Carolina during the past five years. *Sources:* NOAA, Coastal Services Center, 2005; NOAA, National Climate Data Center, 2005.				
Change in production volume, over most recent three years (assessed species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	Change, up or down, of 3 percent or more, but less than 5 percent, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Production of food-size catfish in the United States increased by 11 percent between 2001 and 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Change in production volume of all aquaculture, over most recent three years (country level, all species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total aquaculture production in the United States increased by 13 percent between 2001 and 2003. Species included are baitfish, catfish, salmon, striped bass, tilapia, trout, clams, crawfish, mussels, oysters, shrimp, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				
Level of stocking density (assessed species)	Evolution Secondary Economics and industry	Industry tends to overstock	High-density stocking but no discernable negative impact on production	All else	N/A
Risk level = Medium	**Documentation:** The catfish industry stocks at a high density, but these high stocking rates do not appear to result in negative impacts. *Sources:* Tucker, Avery, Engle, and Goodwin 2004; personal communication with Bruce Wagner, 2006.				
Introduction to new environment during life cycle (moving to a different type of production system, i.e., RAS to open ponds) (assessed species)	Evolution Secondary Economics and industry	Live in three or more types of environments during life	N/A	Live in two types of environments during life	Live in one type of environment during life
Risk level = Low	**Documentation:** Both open ponds and recirculating aquaculture systems (RAS) are used in catfish production. Catfish fry are hatched, reared in hatchery tanks for 2 to 10 days, then they are translocated to ponds. Several translocations within the pond system may occur as fingerlings are moved gradually to growout ponds. *Source:* Tucker, Avery, Engle, and Goodwin 2004.				
New technology or management practice used in production (assessed species)	Evolution Secondary Economics and industry	More than 50 percent of producers implemented a new technology or management practice during the past year	10 to 50 percent of producers implemented a new technology or management practice during the past year	Less than 10 percent of producers implemented a new technology or management practice during the past year	Static technology
Risk level = Low	**Documentation:** A series of presentations at the Aquaculture America meeting in 2005 indicated that some new production practices for catfish are being investigated. These include modular or all-in, all-out phased production, different pond depths, polyculture, different stocking densities, and alternate feeds. The new practices are being used by a small number of producers (<10%). *Source:* Aquaculture America Meeting 2005.				
Production in new area during last three years (assessed species)	Evolution Secondary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Catfish production in the United States continues to be concentrated within a few states in the Southeast. During recent years, no new states have been added to the NASS list of states with catfish production. *Source:* USDA, NASS, Catfish production 2005.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Production system used (assessed species)	Evolution Secondary Economics and industry	Greater than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** More than 98 percent of the channel catfish produced in the United States are grown in uncovered earthen ponds. *Source:* Tucker, Avery, Engle, Goodwin 2004.				
Industry changes to different production system (assessed species)	Evolution Secondary Economics and industry	On an annual basis, 10 percent or more of industry producers changed to a new production system	N/A	On an annual basis, less than 10 percent of industry producers changed to a new production system	No usage of new production systems
Risk level = No defined risk	**Documentation:** There does not seem to be any evidence that catfish producers are moving away from open-pond production for channel catfish in the United States. Production in the United States is limited to areas where temperatures do not fall below the temperatures at which catfish can survive. *Source:* USDA, NASS, Catfish production 2005.				
Phased production used (assessed species)	Evolution Secondary Economics and industry	Less than 25 percent of industry using all-in, all-out production	25 percent or more, but less than 75 percent, of industry using all-in, all-out production	75 percent or more, but less than 90 percent, of industry using all-in, all-out production	90 percent or more of the industry using all-in, all-out production
Risk level = High	**Documentation:** All-in, all-out production has not been used in catfish production to any significant level. Eighty-three percent (83%) of catfish operations stocked fingerlings directly into catfish ponds that already contained food-size fish. *Source:* USDA, Animal and Plant Health Inspection Service 2003.				
Acceptable use of drugs, chemicals, vaccines (assessed species)	Evolution Secondary Health management	Country had a trade ban imposed for sanitary reasons against the assessed species during the past year	Country had a trade ban imposed for sanitary reasons against the assessed species during the past five years, but not during the past year	Country has had no trade bans imposed for sanitary reasons against the assessed species during the past five years	Country does not export the assessed species
Risk level = Low	**Documentation:** The catfish industry has not had any trade bans for sanitary reasons imposed on fish or fish products being exported from the United States. *Source:* Personal communication with Bruce Wagner, 2006.				
Level of health management (assessed species)	Evolution Secondary Health management	Little use or availability of certified aquaculture health professionals of any kind	Some availability and use of certified aquaculture health professionals of any kind	Good availability and use of certified aquaculture health professionals of any kind	N /A
Risk level = High	**Documentation:** There is little use or availability of certified aquaculture health professionals in the catfish industry. *Source:* Personal communication with Bruce Wagner, 2006.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Treatment of discharge water (assessed species)	Politics and regulations	Government regulations or industry BMP do not exist for discharge water OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water	N/A
Risk level = High	**Documentation:** The catfish industry's major producer groups do not currently have a catfish BMP on water discharge. A BMP for the Alabama catfish industry is currently under development. It is likely that this BMP will be the de facto industry BMP when completed. Compliance or industry awareness with BMPs is unknown. Many states have water discharge BMPs, but these programs are often voluntary so compliance or adherence to programs is unknown. Risk factor is level is assessed as high because the usage of these BMPs is unknown. *Source:* Auburn University and USDA, Natural Resources Conservation Service, 2004.				
Commercial production of a new species (country level, all species)	Social and cultural	Production of new species has occurred for one to two years	Production of new species has occurred for three to seven years	Production of new species has occurred for more than 7 years but less than 10 years	Production of new species has occurred for 10 years or more
Risk level = Medium	**Documentation:** The newest aquaculture species in production in the United States. is the cobia. Cobia has been in production for three to seven years (since 2003). *Source:* Kaiser and Holt 2005.				
Total imports of live food finfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import value is 10 percent or more of world import value	Import value is 1 percent or greater, but less than 10 percent, of world import value	Import value is less than 1 percent of world import value	No imports
Risk level = Low	**Documentation:** The total value of U.S. imports of live food fish (carp, eel, trout, live fish NESOI) in 2004 was $4,681,859 or 0.4 percent of total world imports of live food fish. This includes all food fish species that were imported. *Sources:* USDA, Foreign Agricultural Service, 2006; FAO, Fishstat Plus, 2006.				
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
Risk level = High	**Documentation:** The U.S. share of world imports of fresh whole food finfish, fish livers and roe, and shellfish in 2004 was 10.7 percent. *Sources:* USDA, Foreign Agricultural Service, 2006; FAO, Fishstat Plus, 2006.				
Change in import value of live food finfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase over the most recent three-year period in the import value of live food finfish production	3 percent or greater increase, but less than 5 percent, in the import value of live food finfish over the most recent three-year period	Less than 3 percent increase in the import value of live food finfish over the most recent three-year period	No imports
Risk level = Low	**Documentation:** U.S. imports of live food finfish (trout, eel, carp, and live fish NESOI) decreased 23.3 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service, 2006.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
Risk level = High	**Documentation:** U.S. imports of fresh whole food finfish, fish livers and roe, and shellfish increased 5.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service, 2006.				

Spread Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Primary Factors					
Movement of fish caused by predation and major weather events (assessed species)	Spread Primary Ecology, environment, and climate	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** More than 98 percent of catfish in the United States are grown in uncovered, earthen ponds. *Source:* Tucker, Avery, Engle, and Goodwin 2004.				
Quality of source water (assessed species)	Spread Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMP developed for water uptake	N/A
Risk level = Low	**Documentation:** Well (aquifer) water was the source of water for 72.5 percent of operations. *Sources:* USDA, Animal and Plant Health Inspection Service 2003; Tucker, Avery, Engle, and Goodwin 2004.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Intentional movement of fish associated with production practices (assessed species)	Spread Primary Economics and industry	Fish have different owners and reside at different operations during life or are wild-caught (based on how more than one-third of industry operates)	Multiple movements by same owner within an operation, which could be multisite but all the same "farm" (based on how more than one-third of the industry operates)	Movements within an operation at the same location (based on how more than one-third of the industry operates)	N/A
Risk level = High	**Documentation:** Approximately 70 percent of all catfish operations purchased fingerlings from another operation, and 17.5 percent of all operations purchased fry from another operation. Therefore, more than one-third of catfish operations move fish onto their operation from another operation. *Source:* USDA, Animal and Plant Health Inspection Service 2003.				
Content and processing of feed fed (assessed species)	Spread Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = High	**Documentation: :** No evidence that the industry feeds uncooked or unprocessed fish waste, however, 11 percent of catfish producers stock live fish (flathead minnows) in ponds as a food source, therefore, this factor is ranked as high. *Sources:* USDA, Animal and Plant Health Inspection Service 2003; personal communication with Bruce Wagner 2006.				
State regulations regarding live-hauling (assessed species if possible)	Spread Primary Politics and regulations	No regulations exist	Regulations exist but without enforcement	Regulations exist with enforcement	N/A
Risk level = High	**Documentation:** No regulations were found addressing live-hauling of catfish.				
Types of sales of products from farms (assessed species)	Spread Primary Social and cultural	25 percent or more of industry makes sales to live-haulers	50 percent or more of industry makes direct sales to consumers (live, fresh, or frozen) and the definition for high risk level is not met	All else	N/A
Risk level = Low	**Documentation:** More than 90 percent of catfish sales from the farm are directly to processors. Less than 10 percent of sales occur from pond-side directly to live-haulers for retail sales and to live-haulers for the purpose of stocking for recreational purposes (i.e., fishing). *Source:* Tucker, Avery, Engle, and Goodwin 2004.				
Secondary Factors					
Geographic concentration of production (assessed species)	Spread Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area greater than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = High	**Documentation:** At least 75 percent of U.S. catfish production is located in a 250,000-square-mile area (i.e., AL, AR, LA, MS). *Source:* USDA, Animal and Plant Health Inspection Service 2003.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Level of stocking in lakes and streams during most recent year (assessed species)	Spread Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is between 25 and 100 percent of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or less of the number of assessed species produced for food by aquaculture	No stocking
Risk level = Low	**Documentation:** The total of all catfish species that were stocked in lakes and streams was 0.52 percent of the total aquacultured catfish inventory in year 2005. *Source:* U.S. State agencies responsible for stocking fish provided by 50 States for 2002–04.				
Total number of farms (assessed species)	Spread Secondary Economics and industry	1,000 farms or more involved in the production of the species	More than 100 but less than 1,000 farms involved in the production of the species	100 farms or less involved in the production of the species	N/A
Risk level = High	**Documentation:** Catfish are produced on more than 1,000 farms. *Source:* USDA, NASS, Census of Aquaculture 2002.				
Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Using the OIE disease lists, catfish are not susceptible to any diseases to which other species aquacultured in the United States are also susceptible. Rate of change in production volume for catfish between 2001 and 2003 was 10.8 percent. *Sources:* OIE Collaborating Centre for Information on Aquatic Animal Diseases, 2006; NOAA, National Marine Fisheries Service 2004.				
Change in production volume of all aquacultured species, over most recent three years (country level, all species)	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, tilapia, baitfish, clams, crawfish, mussels, oysters, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				
Production system used (assessed species)	Spread Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** More than 98 percent of catfish in the United States are grown in uncovered, earthen ponds. *Source:* Tucker, Avery, Engle, and Goodwin 2004.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Disease management practices at the industry level (assessed species)	Spread Secondary Health management	No industry BMPs for disease management	Existence of industry BMPs for disease management, but little adherence or compliance measures	Existence of industry BMPs for disease management with compliance measures	N/A
Risk level = Medium	**Documentation:** The Alabama Catfish Producers (ACP) organization has adopted 21 BMPs. The Catfish Farmers of America (CFA) has not formally adopted BMPs for catfish production; however, they do endorse those BMPs of the ACP. Whether the BMPs are used in states other than Alabama is unknown. *Source:* Auburn University and USDA, Natural Resources Conservation Service 2004.				
Handling of mortalities	Spread Secondary Health management	Proper handling of mortalities is practiced by 50 percent or less of the industry	Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the industry	Proper handling of mortalities is practiced by 75 percent or more of the industry	N/A
Risk level = High	**Documentation:** Proper handling of mortalities is practiced by 50 percent or less of the industry. *Source:* Personal communication with Bruce Wagner, 2006.				
Treatment of discharge water (assessed species)	Spread Secondary Politics and regulations	Government regulations or industry BMP do not exist for discharge water (can use percent compliant with regulations if data exist) OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water (can use percent compliant with regulations if data exist)	N/A
Risk level = High	**Documentation:** The catfish industry's major producer groups do not currently have a catfish BMP on water discharge. A BMP for the Alabama catfish industry is currently under development. It is likely that this BMP will be the de facto industry BMP when completed. Many States have generic water discharge BMP, but these programs are often voluntary and are not specific to catfish, so industry awareness, compliance, or adherence to programs is unknown. *Sources:* Search of catfish industry and State Web sites; personal communication with Bruce Wagner 2006.				

Notes: ACP = Alabama Catfish Producers; BMPs = best management practices; CFA = Catfish Farmers of America; FAO = Food and Agriculture Organization of the United Nations; N/A = not applicable; NASS = National Agricultural Statistic Service; NESOI = not elsewhere specified or included; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix C. Salmon Results and Documentation

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Reported aquaculture disease burden (assessed species)	Evolution Primary Agent, host, and vector biology	Any OIE-listed disease reported during past five years for species being assessed, OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past five years for species being assessed, but credible reports of one or more other (non-OIE-listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed) diseases during past five years
Risk level = High	**Documentation:** Salmon are susceptible to 7 of the 10 OIE-listed diseases of fish (2005): bacterial kidney disease, epizootic hematopoietic necrosis, gyrodactylosis, infectious hematopoietic necrosis, infectious pancreatic necrosis, infectious salmon anemia, and viral hemorrhagic septicemia. Three of these diseases, infectious hematopoietic necrosis, infectious salmon anemia, and viral hemorrhagic septicemia have occurred in the United States in the past five years. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006.				
Quality of source water (assessed species)	Evolution Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMP developed for water uptake	N/A
Risk level = High	**Documentation:** Salmon are kept in net pens in natural bodies of water. *Source:* Forster 2003.				
Polyculture practiced (assessed species)	Evolution Primary Economics and industry	50 percent or more of industry	10 percent or more but less than 50 percent of industry	Less than 10 percent of industry	No polyculture practiced
Risk level = Low	**Documentation:** In 2005, there were limited polyculture trials at three salmon-farm sites in the Northeast United States, amounting to less than 5 percent of the industry in the Northeast. There is no polyculture practiced in the salmon industry on the west coast of the United States. *Sources:* Personal communication with Stephen Ellis 2006 and Jill Roland 2006.				
Broodstock source (assessed species)	Evolution Primary Economics and industry	Wild-caught	Mixed source	Domesticated breeding	N/A
Risk level = Medium	**Documentation:** Salmon broodstock are selected from high-performing production fish, which are taken from sea pens and are exposed to the wild, therefore risk is rated as medium. *Source:* Forster 2003.				
Content and processing of feed fed (assessed species)	Evolution Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** Salmon feed is made using a cooking extrusion process. No evidence in industry literature indicating use of uncooked or unprocessed feed. *Source:* Forster 2003.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Waste fertilization practiced (assessed species)	Evolution Primary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Animal or human waste is not being used to fertilize salmon production facilities in the United States. *Source:* Industry literature				
Secondary Factors					
Reported total aquaculture disease burden (country level, all species)	Evolution Secondary Agent, host, and vector biology	Any OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years, OR country does not report to OIE	N/A	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past three years
Risk level = High	**Documentation:** The United States reported 12 of the 24 listed diseases of fish, mollusks, and crustaceans during the past three (2003–05) years. Diseases reported by the United States were infectious hematopoietic necrosis, infectious salmon anemia, spring viremia of carp, viral hemorrhagic septicemia, *Bonamia ostrea, Mikrocytos mackini, Xenohaliotis californiensis,* infectious hypodermal and hematopoietic necrosis, tetrahedral baculovirosis, Taura syndrome, white spot disease, and yellowhead disease. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006.				
Length of life cycle (assessed species)	Evolution Secondary Agent, host, and vector biology	Life cycle is two years or more	Life cycle is greater than six months and less than two years	Life cycle is six months or less	N/A
Risk level = High	**Documentation:** The salmon life cycle exceeds two years. *Source:* Forster 2003.				
Geographic concentration of production (assessed species)	Evolution Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area greater than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = No defined risk	**Documentation:** Salmon production is split with about 60 percent in Washington and 40 percent in Maine (2003). National production has decreased 21.5 percent from 2001 to 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				
Latitude at which production takes place (assessed species)	Evolution Secondary Ecology, environment, and climate	Between 20 degrees north and 20 degrees south latitude	20 degrees north to 50 degrees north OR 20 degrees south to 50 degrees south	Above 50 degrees north or below 50 degrees south	N/A
Risk level = Medium	**Documentation:** Salmon production in the continental United States is located at latitudes between 40 degrees north and 50 degrees north. *Sources: Student Atlas of World Geography* 1999; Forster 2003.				

Disease Evolution Element

		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Level of stocking in lakes and streams during most recent year (assessed species)	Evolution Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or more, but less than 100 percent, of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is less than 25 percent of the number of assessed species produced for food by aquaculture	No stocking
Risk level = High	**Documentation:** The number of salmon stocked into U.S. waters in 2003 was 328,321,745. Salmon inventory numbers are not available for the United States, so to serve as a proxy, the production in pounds was multiplied by a "pounds per fish" conversion factor. The U.S. production level of salmon in 2003 was 35,967,000 pounds. Dividing this number by 5.5 pounds per fish is 6,539,455 fish. The number of stocked salmon is 500 percent of the number of salmon produced for food. *Sources:* State agencies responsible for stocking fish provided by 50 states for 2002–04; Alaska Department of Fish and Game 2004.				
Introduction of nonindigenous species (region or states where assessed species is produced)	Evolution Secondary Ecology, environment, and climate	Number of nonindigenous species introductions in any of the top species-producing states is five or more during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing states is two, three, or four during the most recent five years	Number of nonindigenous species introductions in any of the top species-producing states is one during the most recent five years	No nonindigenous species introductions in any of the top species-producing states during the most recent five years
Risk level = Medium	**Documentation:** From 2001 to 2005, there were a total of two nonindigenous species introductions in Washington and no introductions in Maine. *Source:* Personal communication with Pam Fuller 2006.				
Occurrence of major weather disasters (top-producing states for assessed species)	Evolution Secondary Ecology, environment, and climate	25 percent or more of production takes place in states that experienced hurricanes during the past five years	25 percent or more of production takes place in states that are in the top tertile for flooding, based on the past five years	All else	N/A
Risk level = Low	**Documentation:** There have been no hurricanes in Maine and Washington during the past five years. Maine and Washington were both in the bottom tertile of states for floods, based on the past five years. *Sources:* NOAA, Coastal Services Center 2005; NOAA, National Climate Data Center 2005.				
Change in production volume, over most recent three years (assessed species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	Change, up or down, of 3 percent or more, but less than 5 percent, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Production of salmon in the United States decreased by 21.5 percent from 2001–03. *Source:* NOAA, National Marine Fisheries Service 2004.				
Change in production volume of all aquaculture, over most recent three years (country level, all species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, and tilapia. *Source:* NOAA, National Marine Fisheries Service 2004.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Level of stocking density (assessed species)	Evolution Secondary Economics/industry	Industry tends to overstock	High-density stocking but no discernable negative impact on production	All else	N/A
Risk level = Medium	**Documentation:** Within the ISA zone of Maine, stocking density is limited to 18 kg of smolts per cubic meter. This is enforced by the State of Maine's stocking permits, issued by the Department of Maine Resources. In the ISA-free zones in Maine, double and even triple density stocking is practiced. There seems to be no discernable negative impact to production because of overstocking. Washington uses a stocking figure of 15–18 kg per cubic meter near harvest time. When the fish are smaller, the farmers typically double or triple stock, then split them out as they grow. Vaccinations to prevent disease have allowed stocking densities to be increased. Again, there seems to be no discernable negative impact to production because of overstocking. *Sources:* Personal communication with Stephen Ellis (for Maine) 2006 and Hugh Mitchell (for Washington) 2006.				
Introduction to new environment during life cycle (moving to a different type of production system, i.e., RAS to open ponds) (assessed species)	Evolution Secondary Economics and industry	Live in three or more types of environments during life	N/A	Live in two types of environments during life	Live in one type of environment during life
Risk level = High	**Documentation:** Salmon hatcheries utilize two environments, an initial hatching tank and then raceways. For growout, salmon are moved to net pens in natural waterways. Thus, salmon live in three types of environments during their life cycle. *Source:* Forster 2003.				
New technology or management practice used in production (assessed species)	Evolution Secondary Economics and industry	More than 50 percent of producers implemented a new technology or management practice during the past year	10 to 50 percent of producers implemented a new technology or management practice during the past year	Less than 10 percent of producers implemented a new technology or management practice during the past year	Static technology
Risk level = No defined risk	**Documentation:** During the past year, the salmon industry has not introduced new technology or management practices. *Source:* Personal communication with Stephen Ellis 2006.				
Production in new area during last three years (assessed species)	Evolution Secondary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Maine and Washington are the leading salmon-producing states. In the last three years, there has not been production in new areas. *Source:* Forster 2003.				
Production system used (assessed species)	Evolution Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Salmon producers in Maine and Washington use net pen operations in the ocean (mariculture). *Source:* Forster 2003.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Industry changes to different production system (assessed species)	Evolution Secondary Economics and industry	On an annual basis, 10 percent or greater of industry producers changed to a new production system	N/A	On an annual basis, less than 10 percent of industry producers changed to a new production system	No usage of new production systems
Risk level = No defined risk	**Documentation:** The salmon industry is not using any new production systems. *Source:* Industry literature.				
Phased production used (assessed species)	Evolution Secondary Economics and industry	Less than 25 percent of industry using all-in, all-out production	25 percent or more, but less than 75 percent, of industry using all-in, all-out production	75 percent or more, but less than 90 percent, of industry using all-in, all-out production	90 percent or more of the industry using all-in, all-out production
Risk level = Low	**Documentation:** All-in, all-out production is a common practice in the salmon industry, with at least 75 percent of the industry utilizing all-in, all-out production. *Sources:* Personal communication with Stephen Ellis (for Maine) 2006; and Kevin Amos with NOAA (for Washington) 2006.				
Acceptable use of drugs, chemicals, vaccines (assessed species)	Evolution Secondary Health management	Country had a trade ban imposed for sanitary reasons against the assessed species during the past year	Country had a trade ban imposed for sanitary reasons against the assessed species during the past five years, but not during the past year	Country has had no trade bans imposed for sanitary reasons against the assessed species during the past five years	Country does not export the assessed species
Risk level = Low	**Documentation:** The salmon industry has not had any trade bans for sanitary reasons imposed on fish or fish products being exported from the United States. *Source:* Industry Literature.				
Level of health management (assessed species)	Evolution Secondary Health management	Little use or availability of certified aquaculture health professionals of any kind	Some availability and use of certified aquaculture health professionals of any kind	Good availability and use of certified aquaculture health professionals of any kind	N /A
Risk level = Low	**Documentation:** The salmon industry has more certified health professionals than any other aquaculture industry. *Source:* Personal communication with Stephen Ellis 2006.				
Treatment of discharge water (assessed species)	Politics and regulations	Government regulations or industry BMPs do not exist for discharge water OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMPs exist for discharge water	N/A
Risk level = High	**Documentation:** Salmon are kept in net pens in natural bodies of water. *Source:* Forster 2003.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Commercial production of a new species (country level, all species)	Social and cultural	Production of new species has occurred for one to two years	Production of new species has occurred for three to seven years	Production of new species has occurred for more than 7 years but less than 10 years	Production of new species has occurred for 10 years or more
Risk level = Medium	**Documentation:** The newest aquaculture species in production in the United States is the cobia. Cobia has been in production for three to seven years. *Source:* Kaiser and Holt 2005.				
Total imports of live food finfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import value is 10 percent or more of world import value	Import value is 1 percent or greater, but less than 10 percent, of world import value	Import value is less than 1 percent of world import value	No imports
Risk level = Low	**Documentation:** The U.S. share of world imports of live food finfish in 2004 was 0.4 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
Risk level = High	**Documentation:** The U.S. share of world imports of fresh whole food finfish, fish livers and roe, and shellfish in 2004 was 10.7 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Change in import value of live food finfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase over the most recent three-year period in the import value of live food finfish production	3 percent or greater increase, but less than 5 percent, in the import value of live food finfish over the most recent three-year period	Less than 3 percent increase in the import value of live food finfish over the most recent three-year period	No imports
Risk level = Low	**Documentation:** U.S. imports of live food finfish (trout, eel, carp, and live fish NESOI) decreased 23.3 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				
Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
Risk level = High	**Documentation:** U.S. imports of fresh whole food finfish, fish livers and roe, and shellfish increased 5.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service, 2006.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Movement of fish caused by predation and major weather events (assessed species)	Spread Primary Ecology, environment, and climate	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Salmon are produced in net pens in the ocean, mariculture. *Source:* Forster 2003.				
Quality of source water (assessed species)	Spread Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
Risk level = High	**Documentation:** Salmon are produced in net pens in natural bodies of water. *Source:* Forster 2003.				
Intentional movement of fish associated with production practices (assessed species)	Spread Primary Economics and industry	Fish have different owners and reside at different operations during life or are wild-caught (based on how more than one-third of the industry operates)	Multiple movements by same owner within an operation, which could be multisite but all the same "farm" (based on how more than one-third of the industry operates)	Movements within an operation at the same location (based on how more than one-third of the industry operates)	N/A
Risk level = Medium	**Documentation:** The four active salmon hatcheries in Maine are separated from the growout pens. The hatcheries in Washington are about 60 miles from the locations of the growout pens. Typically, the hatcheries and growout pen locations in both States are owned by the same company. *Sources:* Personal communication with Stephen Ellis (for Maine) 2006; and Kevin Amos (for Washington) 2006.				
Content and processing of feed fed (assessed species)	Spread Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** Salmon feed is made using a cooking extrusion process. No evidence in industry literature indicating use of uncooked or unprocessed feed. *Source:* Forster 2003.				
State regulations regarding live-hauling (assessed species if possible)	Spread Primary Politics and regulations	No regulations exist	Regulations exist but without enforcement	Regulations exist with enforcement	N/A
Risk level = High	**Documentation:** No regulations were found addressing live-hauling of salmon.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Types of sales of products from farms (assessed species)	Spread Primary Social and cultural	25 percent or more of industry makes sales to live-haulers	50 percent or more of industry makes direct sales to consumers (live, fresh, or frozen) and the definition for high risk level is not met	All else	N/A
Risk level = Low	**Documentation:** No evidence was found that salmon are sold to live-haulers or directly to consumers.				
Secondary Factors					
Geographic concentration of production (assessed species)	Spread Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area more than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = No Defined Risk	**Documentation:** Salmon production is split with about 60 percent in Washington and 40 percent in Maine (2003). National production has decreased 21.5 percent from 2001 to 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				
Level of stocking in lakes and streams during most recent year (assessed species)	Spread Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is between 25 and 100 percent of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or less of the number of assessed species produced for food by aquaculture	No stocking
Risk level = High	**Documentation:** The number of salmon stocked into U.S. waters in 2003 was 328,321,745. Salmon inventory numbers are not available for the United States, so to serve as a proxy, the production in pounds was multiplied by a "pounds per fish" conversion factor. The U.S. production level of salmon in 2003 was 35,967,000 pounds. Dividing this number by 5.5 pounds per fish is 6,539,455 fish. The number of stocked salmon is 500 percent of the number of salmon produced for food. *Source:* State agencies responsible for stocking fish provided by 50 states for 2002–04; Alaska Department of Fish and Game 2004.				
Total number of farms (assessed species)	Spread Secondary Economics and industry	1,000 farms or more involved in the production of the species	More than 100 but less than 1,000 farms involved in the production of the species	100 farms or less involved in the production of the species	N/A
Risk level = Low	**Documentation:** Less than 100 farms are involved in the production of salmon in the United States. Industry literature indicates that the number of farms is declining. *Sources:* USDA, NASS, Census of Aquaculture 2002; Forster 2003.				

Spread Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years,	Spread Secondary Economics and industry	5 percent or more change, up or down, over the most recent three-year period	3 percent or more change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Trout are susceptible to many of the same diseases as salmon. Salmon and trout production decreased 21.5 percent and 10.88 percent, respectively, from 2001 to 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				
Change in production volume of all aquacultured species, over most recent three years (country level, all species)	Spread Secondary Economics and industry	5 percent or more change, up or down, over the most recent three-year period	3 percent or more change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, tilapia, baitfish, clams, crawfish, mussels, oysters, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				
Production system used (assessed species)	Spread Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Salmon are produced in net pens in the ocean, mariculture. *Source:* Forster 2003.				
Disease management practices at the industry level (assessed species)	Spread Secondary Health management	No industry BMPs for disease management	Existence of industry BMPs for disease management, but little adherence or compliance measures	Existence of industry BMPs for disease management with compliance measures	N/A
Risk level = Low	**Documentation:** BMPs, health regulations, and compliance measures are in place in Washington to protect the health of the salmon industry. In Maine, an industry-driven management plan describes the appropriate procedures for siting, stocking, surveillance, biosecurity, diving, vessel use and movements, harvest, and other operations. The USDA mandates participation in an IPM plan for sea lice and USDA acts as the INAD coordinators for the only lice medication currently effective and in use. The Maine Department of Marine Resources has a number of BMPs as part of their stocking and transfer permits, as well as new amendments to their State regulations. Each company must submit a biosecurity plan for each site for each segment of their production activities, as well as an ISA action plan in the event they become infected. They must comply with mandatory monthly ISA surveillance using a Maine-licensed and USDA-accredited veterinarian. *Sources:* Personal communication with Stephen Ellis (for Maine) 2006; and Kevin Amos (for Washington) 2006.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Handling of mortalities	Spread Secondary Health management	Proper handling of mortalities is practiced by 50 percent or less of the industry	Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the industry	Proper handling of mortalities is practiced by 75 percent or more of the industry	N/A
Risk level = Medium	**Documentation:** Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the salmon industry. *Source:* Personal communication with Stephen Ellis 2006.				
Treatment of discharge water (assessed species)	Spread Secondary Politics and regulations	Government regulations or industry BMPs do not exist for discharge water (can use percent compliant with regulations if data exist) OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water (can use percent compliant with regulations if data exist)	N/A
Risk level = High	**Documentation:** Salmon are produced in net pens in natural bodies of water. *Source:* Forster 2003.				

Notes: BMPs = best management practices; FAO = Food and Agriculture Organization of the United Nations; INAD = investigative new animal drug; ISA = infectious salmon anemia; IPM = integrated pest management; N/A = not applicable; NASS = National Agricultural Statistic Service; NESOI = not elsewhere specified or included; NOAA = National Oceanic and Atmospheric Administration; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix D. Saltwater Shrimp Results and Documentation

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Reported aquaculture disease burden (assessed species)	Evolution Primary Agent, host, and vector biology	Any OIE-listed disease reported during past five years for species being assessed, OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past five years for species being assessed, but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past five years
Risk level = High	**Documentation:** Shrimp are susceptible to five of the seven crustacean diseases listed by the OIE: infectious hypodermal and hemato-poietic necrosis, tetrahedral baculovirosis, Taura syndrome, white spot disease, and yellowhead disease. All five diseases have occurred in the United States in the past five years. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006.				
Quality of source water (assessed species)	Evolution Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
Risk level = Low	**Documentation:** Most U.S. shrimp production facilities use aquifer water or filtered, treated water. *Source:* Auburn University and USDA, Natural Resources Conservation Service 2004.				
Polyculture practiced (assessed species)	Evolution Primary Economics and industry	50 percent or more of industry	10 percent or more but less than 50 percent of industry	Less than 10 percent of industry	No polyculture practiced
Risk level = Low	**Documentation:** No evidence in industry literature that polyculture is widely practiced in the industry.				
Broodstock source (assessed species)	Evolution Primary Economics and industry	Wild-caught	Mixed source	Domesticated breeding	N/A
Risk level = Low	**Documentation:** U.S. saltwater shrimp producers use genetically improved, disease-resistant, pathogen-free broodstock reared in captivity, not wild-caught. *Source:* Treece 2006.				
Content and processing of feed fed (assessed species)	Evolution Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** No evidence in industry literature indicating use of uncooked or unprocessed feed. *Source:* Treece 2006.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Waste fertilization practiced (assessed species)	Evolution Primary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Waste fertilization is not used for aquaculture ponds in the United States. *Source:* Wurts 2004.				
Secondary Factors					
Reported total aquaculture disease burden (country level, all species)	Evolution Secondary Agent, host, and vector biology	Any OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years, OR country does not report to OIE	N/A	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past three years
Risk level = High	**Documentation:** The United States reported 12 of the 24 listed diseases of fish, mollusks, and crustaceans during the past three (2003–05) years. Diseases reported by the United States were infectious hematopoietic necrosis, infectious salmon anemia, spring viremia of carp, viral hemorrhagic septicemia, *Bonamia ostrea, Mikrocytos mackini, Xenohaliotis californiensis,* infectious hypodermal and hematopoietic necrosis, tetrahedral baculovirosis, Taura syndrome, white spot disease, and yellowhead disease. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases, 2006.				
Length of life cycle (assessed species)	Evolution Secondary Agent, host, and vector biology	Life cycle is two years or more	Life cycle is more than six months and less than two years	Life cycle is six months or less	N/A
Risk level = Low	**Documentation:** The shrimp life cycle is six months. *Source:* Whetstone, Treece, Browdy, and Stokes 2002.				
Geographic concentration of production (assessed species)	Evolution Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area more than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = Medium	**Documentation:** 75 percent of U.S. shrimp production takes place within an area more than 250,000 square miles but less than 1 million square miles (Texas, Florida). *Source:* USDA, NASS, Census of Aquaculture 2002.				
Latitude at which production takes place (assessed species)	Evolution Secondary Ecology, environment, and climate	Between 20 degrees north and 20 degrees south latitude	20 degrees north to 50 degrees north OR 20 degrees south to 50 degrees south	Above 50 degrees north or below 50 degrees south	N/A
Risk level = Medium	**Documentation:** Shrimp production in the United States takes place at latitudes between 20 degrees north and 40 degrees north. *Sources: Student Atlas of World Geography* 1999; USDA, NASS, Census of Aquaculture 2002.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Level of stocking in lakes and streams during most recent year (assessed species)	Evolution Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or more, but less than 100 percent, of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is less than 25 percent of the number of assessed species produced for food by aquaculture	No stocking
Risk level = No defined risk	**Documentation:** Shrimp are not stocked in lakes and streams.				
Introduction of nonindigenous species (region or states where assessed species is produced)	Evolution Secondary Ecology, environment, and climate	Total number of nonindigenous species introductions in any of the top species-producing states is five or more during the most recent five years	Total number of nonindigenous species introductions in any of the top species-producing states is two, three, or four during the most recent five years	Total number of nonindigenous species introductions in any of the top species-producing states is one during the most recent five years	No nonindigenous species introductions in any of the top species-producing states during the most recent five years
Risk level = Low	**Documentation:** Total number of nonindigenenous crustacean introductions in any of the seven top-producing states was one or less during 2001–05. *Source:* Personal communication with Pam Fuller 2006.				
Occurrence of major weather disasters (top-producing states for assessed species)	Evolution Secondary Ecology, environment, and climate	25 percent or more of production takes place in states that experienced hurricanes during the past five years	25 percent or more of production takes place in states that are in the top tertile for flooding, based on the past five years	All else	N/A
Risk level = High	**Documentation:** Nearly 90 percent of shrimp production takes place in Texas, South Carolina, and Florida. All three of these states experienced hurricanes during the past five years. *Sources:* NOAA, Coastal Services Center 2005; NOAA, National Climate Data Center 2005; USDA, National Agricultural Statistics Service 2005.				
Change in production volume, over most recent three years (assessed species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	Change, up or down, of 3 percent or more, but less than 5 percent, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Production of marine shrimp has increased 28.3 percent between 2001 and 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				
Change in production volume of all aquaculture, over the most recent three years (country level, all species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, tilapia, baitfish, clams, crawfish, mussels, oysters, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				

Disease Evolution Element						
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Level of stocking density (assessed species)	Evolution Secondary Economics and industry	Industry tends to overstock	High-density stocking but no discernable negative impact on production	All else	N/A
Risk level = Medium	**Documentation:** Industry literature suggests high levels of stocking without negative impacts. Most shrimp farms in the United States fall in the range of semi-intensive to intensive, which means stocking density is high requiring a high level of management. *Source:* Auburn University Marine Extension and Research Center 1996.				
Introduction to new environment during life cycle (moving to a different type of production system, i.e., RAS to open ponds) (assessed species)	Evolution Secondary Economics and industry	Live in three or more types of environments during life	N/A	Live in two types of environments during life	Live in one type of environment during life
Risk level = Low	**Documentation:** Shrimp hatcheries are generally indoor facilities. Shrimp move from these facilities to outdoor growout ponds. *Source:* Auburn University Marine Extension and Research Center 1996.				
New technology or management practice used in production (assessed species)	Evolution Secondary Economics and industry	More than 50 percent of producers implemented a new technology or management practice during the past year	10 to 50 percent of producers implemented a new technology or management practice during the past year	Less than 10 percent of producers implemented a new technology or management practice during the past year	Static technology
Risk level = No defined risk	**Documentation:** During the past year, the shrimp industry has not introduced new technology or management practices. *Source:* Personal communication with Donald Lightner 2006.				
Production in new area during last three years (assessed species)	Evolution Secondary Economics and industry	Yes	N/A	N/A	No
Risk level = High	**Documentation:** Marine shrimp production continues to move into new states. *Source:* Personal communication with Anthony Ostrowski 2006.				
Production system used (assessed species)	Evolution Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Nearly all shrimp production takes place in open ponds. *Source:* Whetstone, et al. 2002.				
Industry changes to different production system (assessed species)	Evolution Secondary Economics and industry	On an annual basis, 10 percent or greater of industry producers changed to a new production system	N/A	On an annual basis, less than 10 percent of industry producers changed to a new production system	No usage of new production systems
Risk level = Low	**Documentation:** During the past year, less than 10 percent of the shrimp industry has experimented with closed recirculating raceway shrimp culture systems. *Sources:* Aquaculture America Meeting 2006; personal communication with Donald Lightner 2006.				

Disease Evolution Element

		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Phased production used (assessed species)	Evolution Secondary Economics and industry	Less than 25 percent of industry using all-in, all-out production	25 percent or more, but less than 75 percent, of industry using all-in, all-out production	75 percent or more, but less than 90 percent, of industry using all-in, all-out production	90 percent or more of the industry using all-in, all-out production
Risk level = No defined risk	**Documentation:** Nearly all shrimp farms use all-in, all-out production. *Source:* Auburn University Marine Extension and Research Center, 1996.				
Acceptable use of drugs, chemicals, vaccines (assessed species)	Evolution Secondary Health management	Country had a trade ban imposed for sanitary reasons against the assessed species during the past year	Country had a trade ban imposed for sanitary reasons against the assessed species during the past five years, but not during the past year	Country has had no trade bans imposed for sanitary reasons against the assessed species during the past five years	Country does not export the assessed species
Risk level = Low	**Documentation:** The shrimp industry has not had any trade bans for sanitary reasons imposed on shrimp or shrimp products being exported from the United States.				
Level of health management (assessed species)	Evolution Secondary Health management	Little use or availability of certified aquaculture health professionals of any kind	Some availability and use of certified aquaculture health professionals of any kind	Good availability and use of certified aquaculture health professionals of any kind	N /A
Risk level = Low	**Documentation:** The shrimp industry has good availability and use of aquaculture health professionals at state and regional laboratories. Although these certified health professionals seldom visit the farm because of the remoteness of many farms, consultation on health, disease, and diagnostic issues is provided routinely by phone and through sample submission to labs. *Source:* Personal communication with Donald Lightner 2006.				
Treatment of discharge water (assessed species)	Politics and regulations	Government regulations or industry BMPs do not exist for discharge water OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMPs exist for discharge water	N/A
Risk level = High	**Documentation:** On June 30, 2004, the EPA finalized a new rule establishing effluent limitations guidelines for concentrated aquatic animal production in primarily flow-through, recirculating, and net cage systems (not pond culture), which produce 100,000 pounds a year. Therefore, it does not apply to the majority of shrimp farms. Various states have BMPs regarding discharge of aquaculture effluent; however, for some states, these BMPs are not mandatory and the requirements, focus (solids, nutrients), and extent of regulations differs by state. No information on industry compliance with regulations is available.				
Commercial production of a new species (country level, all species)	Social and cultural	Production of new species has occurred for one to two years	Production of new species has occurred for three to seven years	Production of new species has occurred for more than 7 years but less than 10 years	Production of new species has occurred for 10 years or more
Risk level = Medium	**Documentation:** The newest aquaculture species in production in the United States is the cobia. Cobia has been in production for three to seven years. *Source:* Kaiser and Holt 2005.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Total imports of live food finfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import value is 10 percent or more of world import value	Import value is 1 percent or greater, but less than 10 percent, of world import value	Import value is less than 1 percent of world import value	No imports
Risk level = Low	**Documentation:** The U.S. share of world imports of live food finfish in 2004 was 0.4 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
Risk level = High	**Documentation:** The U.S. share of world imports of fresh whole food finfish, fish livers and roe, and shellfish in 2004 was 10.7 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Change in import value of live food finfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase over the most recent three-year period in the import value of live food finfish production	3 percent or greater increase, but less than 5 percent, in the import value of live food finfish over the most recent three-year period	Less than 3 percent increase in the import value of live food finfish over the most recent three-year period	No imports
Risk level = Low	**Documentation:** U.S. imports of live food finfish (trout, eel, carp, and live fish NESOI) decreased 23.3 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				
Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
Risk level = High	**Documentation:** U.S. imports of fresh whole food finfish, fish livers and roe, and shellfish increased 5.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service, 2006.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Movement of fish caused by predation and major weather events (assessed species)	Spread Primary Ecology, environment, and climate	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Nearly all shrimp are produced in open ponds. *Source:* Whetstone, et al. 2002.				
Quality of source water (assessed species)	Spread Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
Risk level = Low	**Documentation:** U.S. shrimp production facilities use either aquifer water or filtered water from other sources. *Source:* Auburn University and USDA, Natural Resources Conservation Service 1996.				
Intentional movement of fish associated with production practices (assessed species)	Spread Primary Economics and industry	Fish have different owners and reside at different operations during life or are wild-caught (based on how more than one-third of industry operates)	Multiple movements by same owner within an operation, which could be multisite but all the same “farm” (based on how more than one-third of the industry operates)	Movements within an operation at the same location (based on how more than one-third of the industry operates)	N/A
Risk level = High	**Documentation:** Shrimp have different owners and reside at different locations during their life cycle. *Source:* Whetstone, et al. 2002.				
Content and processing of feed fed (assessed species)	Spread Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** No evidence found that uncooked or unprocessed feed is used. *Source:* Treece 2006.				
State regulations regarding live-hauling (assessed species if possible)	Spread Primary Politics and regulations	No regulations exist	Regulations exist but without enforcement	Regulations exist with enforcement	N/A
Risk level = High	**Documentation:** No regulations were found addressing live-hauling of shrimp.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Types of sales of products from farms (assessed species)	Spread Primary Social and cultural	25 percent or more of industry makes sales to live-haulers	50 percent or more of industry makes direct sales to consumers (live, fresh, or frozen) and the definition for high-risk level is not met	All else	N/A
Risk level = Low	**Documentation:** No evidence that shrimp are marketed to live-haulers or direct to consumers. Industry literature indicates that most shrimp are sold to processors.				
Secondary Factors					
Geographic concentration of production (assessed species)	Spread Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area more than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = Medium	**Documentation:** 75 percent of U.S. shrimp production takes place within an area more than 250,000 square miles but less than 1 million square miles (Texas, Florida). *Source:* USDA, NASS, Census of Aquaculture 2002.				
Level of stocking in lakes and streams during most recent year (assessed species)	Spread Secondary Ecology, environment, climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is between 25 and 100 percent of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or less of the number of assessed species produced for food by aquaculture	No stocking
Risk level = No defined risk	**Documentation:** Shrimp are not stocked in lakes and streams.				
Total number of farms (assessed species)	Spread Secondary Economics and industry	1,000 farms or more involved in the production of the species	More than 100 but less than 1,000 farms involved in the production of the species	100 farms or less involved in the production of the species	N/A
Risk level = Low	**Documentation:** Fewer than 100 farms produce saltwater shrimp. *Source:* Personal communication with Anthony Ostrowski 2006.				
Change in production volume of assessed species and any other species that is susceptible to the same pathogens as the assessed species, over most recent three years	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Shrimp production increased 28.3 percent from 2001 to 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Change in production volume of all aquacultured species, over most recent three years (country level, all species)	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, tilapia, baitfish, clams, crawfish, mussels, oysters, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				
Production system used (assessed species)	Spread Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** Nearly all shrimp are produced in open ponds. *Source:* Whetstone, et al. 2002.				
Disease management practices at the industry level (assessed species)	Spread Secondary Health management	No industry BMPs for disease management	Existence of industry BMPs for disease management, but little adherence or compliance measures	Existence of industry BMPs for disease management with compliance measures	N/A
Risk level = Low	**Documentation:** The U.S. shrimp industry uses pathogen-free stock, probiotics, species rotation, and biosecurity measures. *Source:* USMSFP 2004.				
Handling of mortalities	Spread Secondary Health management	Proper handling of mortalities is practiced by 50 percent or less of the industry	Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the industry	Proper handling of mortalities is practiced by 75 percent or more of the industry	N/A
Risk level = High	**Documentation:** Shrimp growout farms are typically quite large both in land area and numbers of shrimp; therefore, it is not practical for them to remove mortalities. Shrimp broodstock farms, however, are much smaller, and attempts are made to remove mortalities. Because U.S. broodstock farms make up slightly less than 50 percent of the industry and growout farms make up slightly more than 50 percent of the industry, this factor is ranked as high. *Source:* Personal communication with Donald Lightner 2006.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Treatment of discharge water (assessed species)	Spread Secondary Politics and regulations	Government regulations or industry BMPs do not exist for discharge water (can use percent compliant with regulations if data exist) OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMPs exist for discharge water (can use percent compliant with regulations if data exist)	N/A
Risk level = High	**Documentation:** On June 30, 2004, the EPA finalized a new rule establishing effluent limitations guidelines for concentrated aquatic animal production primarily in flow-through, recirculating, and net cage systems (not pond culture), which produce 100,000 pounds a year. Therefore, it does not apply to the majority of shrimp farms. Various states have BMPs regarding discharge of aquaculture effluent; however, for some states, these BMPs are not mandatory and the requirements, focus (solids, nutrients), and extent of regulations differs by state. No information on industry compliance with regulations is available.				

Notes: BMPs = best management practices; EPA = Environmental Protection Agency; FAO = Food and Agriculture Organization of the United Nations; N/A = not applicable; NASS = National Agricultural Statistic Service; NESOI = not elsewhere specified or included; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix E. Tilapia Results and Documentation

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Reported aquaculture disease burden (assessed species)	Evolution Primary Agent, host, and vector biology	Any OIE-listed disease reported during past five years for species being assessed, OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past five years for species being assessed, but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past five years
Risk level = Low	**Documentation:** Tilapia are not known to be susceptible to any of the current (2005) OIE-listed diseases of fish. In a survey of commercial fish farms in the United States, *Streptococcus iniae* (a non-OIE-listed pathogen of tilapia) was isolated from 3.81 percent of fish sampled. *Source:* Shoemaker, Klesius, and Evans 2001.				
Quality of source water (assessed species)	Evolution Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
Risk level = Low	**Documentation:** Virtually all tilapia producers use non-surface-water sources (groundwater or geothermal groundwater). This water is typically not filtered, but it is not considered a risky source of water that would require treatment or filtering. Any treatment of water is done to change the gas mixture of the water and not to treat for microbes. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Polyculture practiced (assessed species)	Evolution Primary Economics and industry	50 percent or more of industry	10 percent or more but less than 50 percent, of industry	Less than 10 percent of industry	No polyculture practiced
Risk level = Low	**Documentation:** Less than 10 percent of tilapia producers in the United States practice polyculture with other fish species. This number is higher worldwide. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews.				
Broodstock source (assessed species)	Evolution Primary Economics and industry	Wild-caught	Mixed source	Domesticated breeding	N/A
Risk level = Low	**Documentation:** The tilapia industry practices domestic breeding to provide stock to producers. The majority (~90 percent) of broodstock, fry, and fingerlings are produced on site at the same facility where they are grown out. A small but growing number of producers specialize in producing fingerlings for other producers. Broodstock are not caught from wild sources and would not actually be readily available in the wild in the United States. Some evidence suggests that occasional broodstock are imported from international sources via the ornamental fish channels. *Sources:* Fitzsimmons 2003; personal communication with Kevin Fitzsimmons 2006; industry interviews.				

Disease Evolution Element						
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Content and processing of feed fed (assessed species)	Evolution Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** No evidence in industry literature indicating use of uncooked or unprocessed feed.				
Waste fertilization practiced (assessed species)	Evolution Primary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** Animal or human waste is not being used to fertilize tilapia production facilities in the United States.				
Secondary Factors					
Reported total aquaculture disease burden (country level, all species)	Evolution Secondary Agent, host, and vector biology	Any OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years, OR country does not report to OIE	N/A	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported during past three years but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases of any aquacultured species (finfish and/or shellfish) produced in the country reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past three years
Risk level = High	**Documentation:** The United States reported 12 of the 24 listed diseases of fish, mollusks, and crustaceans during the past three (2003–05) years. Diseases reported by the United States were as follows: infectious hematopoietic necrosis, infectious salmon anemia, spring viremia of carp, viral hemorrhagic septicemia, *Bonamia ostrea, Mikrocytos mackini, Xenohaliotis californiensis,* infectious hypodermal and hematopoietic necrosis, tetrahedral baculovirosis, Taura syndrome, white spot disease, and yellowhead disease. *Source:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006.				
Length of life cycle (assessed species)	Evolution Secondary Agent, host, and vector biology	Life cycle is two years or more	Life cycle is more than six months and less than two years	Life cycle is six months or less	N/A
Risk level = Medium	**Documentation:** Tilapia reach market size in approximately 12 months.				
Geographic concentration of production (assessed species)	Evolution Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area more than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = Low	**Documentation:** The top-producing states for tilapia are California, Florida, Idaho, Maryland, New York, North Carolina, and Texas. Seventy-five percent of production does not take place within an area less than 1 million square miles. Tilapia production between 2001 and 2003 increased 12.7 percent. *Sources:* USDA, NASS, Census of Agriculture 2002; NOAA, National Marine Fisheries Service 2004.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Latitude at which production takes place (assessed species)	Evolution Secondary Ecology, environment, and climate	Between 20 degrees north and 20 degrees south latitude	20 degrees north to 50 degrees north OR 20 degrees south to 50 degrees south	Above 50 degrees north or below 50 degrees south	N/A
Risk level = Medium	**Documentation:** Tilapia production in the continental United States is located at latitudes between 20 degrees north and 50 degrees north. *Source: Student Atlas of World Geography* 1999.				
Level of stocking in lakes and streams during most recent year (assessed species)	Evolution Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or more, but less than 100 percent, of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is less than 25 percent of the number of assessed species produced for food by aquaculture	No stocking
Risk level = Low	**Documentation:** Stocking of tilapia for 2004 was 54,193. The estimated inventory of tilapia in aquaculture production in 2003 (based on conversion of pounds of tilapia marketed and 1.5-pound market weight per tilapia) is about 13,000,000. This puts the percentage of stocking in natural waterways at 0.4 percent of tilapia produced for aquaculture. *Sources:* State agencies responsible for stocking fish provided by 50 states for 2002–04; NOAA, National Marine Fisheries Service 2004.				
Introduction of nonindigenous species (region or states where assessed species is produced)	Evolution Secondary Ecology, environment, and climate	Total number of nonindigenous species introductions in any of the top species-producing states is five or more during the most recent five years	Total number of nonindigenous species introductions in any of the top species-producing states is two, three, or four during the most recent five years	Total number of nonindigenous species introductions in any of the top species-producing states is one during the most recent five years	No nonindigenous species introductions in any of the top species-producing states during the most recent five years
Risk level = High	**Documentation:** From 2001 to 2005, the total number of nonindigenous species introductions in the seven top tilapia-producing states ranged from zero in Idaho and New York to six in Florida. *Source:* Personal communication with Pam Fuller 2006.				
Occurrence of major weather disasters (top-producing states for assessed species)	Evolution Secondary Ecology, environment, and climate	25 percent or more of production takes place in states that experienced hurricanes during the past five years	25 percent or more of production takes place in states that are in the top tertile for flooding, based on the past five years	All else	N/A
Risk level = High	**Documentation:** More than 25 percent of tilapia production takes place in Florida, North Carolina, and Texas. Each of these states was affected by hurricane(s) during the past five years. *Sources:* NOAA, Coastal Services Center 2005; NOAA, National Climate Data Center 2005.				
Change in production volume, over most recent three years (assessed species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	Change, up or down, of 3 percent or more, but less than 5 percent, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** U.S. tilapia production increased 12.7 percent between 2001 and 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Change in production volume of all aquaculture, over most recent three years (country level, all species)	Evolution Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, and tilapia. *Source:* NOAA, National Marine Fisheries Service 2004.				
Level of stocking density (assessed species)	Evolution Secondary Economics and industry	Industry tends to overstock	High-density stocking but no discernable negative impact on production	All else	N/A
Risk level = Medium	**Documentation:** Tilapia are stocked densely in production, but they are known to tolerate high density and poor water quality and are considered to be a hardy fish. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Introduction to new environment during life cycle (moving to a different type of production system, i.e., RAS to open ponds) (assessed species)	Evolution Secondary Economics and industry	Live in three or more types of environments during life	N/A	Live in two types of environments during life	Live in one type of environment during life
Risk level = Low	**Documentation:** Approximately 40 percent of tilapia are switched to one new production system during their production life cycle. (This occurs from hatchery to growout.) Hatcheries are typically closed RAS systems, with ~40 percent of fish entering a modified, open RAS system, and the remaining 60 percent staying in a closed, traditional RAS after the hatchery. *Source:* Personal communication with Kevin Fitzsimmons 2006.				
New technology or management practice used in production (assessed species)	Evolution Secondary Economics and industry	More than 50 percent of producers implemented a new technology or management practice during the past year	10 to 50 percent of producers implemented a new technology or management practice during the past year	Less than 10 percent of producers implemented a new technology or management practice during the past year	Static technology
Risk level = Low	**Documentation:** No new technologies other than improvements on previous technology have been introduced in the tilapia industry over the past year. None of the technology improvements are significant enough to consider the changes an actual change in technology, or a new technology. *Source:* Personal communication with Kevin Fitzsimmons 2006; industry literature.				
Production in new area during last three years (assessed species)	Evolution Secondary Economics and industry	Yes	N/A	N/A	No
Risk level = No defined risk	**Documentation:** There is no evidence that tilapia production was implemented in new areas in the past three years. The industry patterns of production appear to be currently stable. *Sources:* USDA, NASS, Census of Agriculture 2002; industry experts.				

Disease Evolution Element

		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Production system used (assessed species)	Evolution Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = Medium	**Documentation:** The tilapia industry uses a mixture of true RAS and modified/open RAS for production. Industry experts estimate that approximately 60 percent of tilapia producers use a true RAS, with the remaining 40 percent using a modified/open RAS. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Industry changes to different production system (assessed species)	Evolution Secondary Economics and industry	On an annual basis, 10 percent or greater of industry producers changed to a new production system	N/A	On an annual basis, less than 10 percent of industry producers changed to a new production system	No usage of new production systems
Risk level = No defined risk	**Documentation:** Research is ongoing into new production systems, but there has been no shift in the past year of at least 10 percent of the tilapia industry changing to a new production system, and there is no evidence of a system being available for such a shift to occur. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry literature.				
Phased production used (assessed species)	Evolution Secondary Economics and industry	Less than 25 percent of industry using all-in, all-out production	25 percent or more, but less than 75 percent, of industry using all-in, all-out production	75 percent or more, but less than 90 percent, of industry using all-in, all-out production	90 percent or more of the industry using all-in, all-out production
Risk level = No defined risk	**Documentation:** At least 90 percent of tilapia producers use all-in, all-out production. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Acceptable use of drugs, chemicals, vaccines (assessed species)	Evolution Secondary Health management	Country had a trade ban imposed for sanitary reasons against the assessed species during the past year	Country had a trade ban imposed for sanitary reasons against the assessed species during the past five years, but not during the past year	Country has had no trade bans imposed for sanitary reasons against the assessed species during the past five years	Country does not export the assessed species
Risk level = Low	**Documentation:** The tilapia industry has not had any trade bans for sanitary reasons imposed on fish or fish products being exported from the United States.				
Level of health management (assessed species)	Evolution Secondary Health management	Little use or availability of certified aquaculture health professionals of any kind	Some availability and use of certified aquaculture health professionals of any kind	Good availability and use of certified aquaculture health professionals of any kind	N /A
Risk level = Medium	**Documentation:** There is some availability and use of certified aquaculture health professionals by tilapia farmers. *Source:* Personal communication with Kevin Fitzsimmons, 2006.				

Disease Evolution Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Treatment of discharge water (assessed species)	Politics and regulations	Government regulations or industry BMPs do not exist for discharge water OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMPs exist for discharge water	N/A
Risk level = Low	**Documentation:** Approximately one-third of tilapia producers fall under the EPA CAAP rule, which establishes effluent limitation guidelines. Tilapia producers who produce more than 100,000 pounds of fish per year must comply. Small RAS facilities are likely to have to comply with local effluent rules because they discharge into local waterways. Tilapia produced in ponds do not have to comply with the CAAP. *Sources:* USDA, NASS, Census of Agriculture 2002; personal communication with Kevin Fitzsimmons 2006.				
Commercial production of a new species (country level, all species)	Social and cultural	Production of new species has occurred for one to two years	Production of new species has occurred for three to seven years	Production of new species has occurred for more than 7 years but less than 10 years	Production of new species has occurred for 10 years or more
Risk level = Medium	**Documentation:** The newest aquaculture species in production in the United States is the cobia. Cobia has been in production for three to seven years. *Source:* Kaiser and Holt 2005.				
Total imports of live food finfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import value is 10 percent or more of world import value	Import value is 1 percent or greater, but less than 10 percent, of world import value	Import value is less than 1 percent of world import value	No imports
Risk level = Low	**Documentation:** The U.S. share of world imports of live food finfish in 2004 was 0.4 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
Risk level = High	**Documentation:** The U.S. share of world imports of fresh whole food finfish, fish livers and roe, and shellfish in 2004 was 10.7 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Change in import value of live food finfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase over the most recent three-year period in the import value of live food finfish production	3 percent or greater increase, but less than 5 percent, in the import value of live food finfish over the most recent three-year period	Less than 3 percent increase in the import value of live food finfish over the most recent three-year period	No imports
Risk level = Low	**Documentation:** U.S. imports of live food finfish (trout, eel, carp, and live fish NESOI) decreased 23.3 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				

Disease Evolution Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Change in import volume of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
Risk level = High	**Documentation:** U.S. imports of fresh whole food finfish, fish livers and roe, and shellfish increased 5.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				

Spread Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Primary Factors					
Movement of fish caused by predation and major weather events (assessed species)	Spread Primary Ecology, environment, and climate	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = Medium	**Documentation:** The tilapia industry uses a mixture of true RAS and modified/open RAS for production. Industry experts estimate that approximately 60 percent of tilapia producers use a true RAS, with the remaining 40 percent using a modified/open RAS. The mixture of the two systems within the industry increases the risk of predation, mixing of outside fish, and exposure to environmental elements. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Quality of source water (assessed species)	Spread Primary Ecology, environment, and climate	Assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	Water source is surface water or other high-risk water source that is untreated (e.g., river or lake water)	Water source is of low risk and does not need treatment or filtering (e.g., aquifer or geothermal water) OR water source is surface water or other high-risk water source and industry has BMPs developed for water uptake	N/A
Risk level = Low	**Documentation:** Virtually all tilapia producers use non-surface-water sources (groundwater or geothermal groundwater). This water is typically not filtered, but it is not considered a risky source of water that would require treatment or filtering. Any treatment of water is done to change the gas mixture of the water and not to treat for microbes. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Intentional movement of fish associated with production practices (assessed species)	Spread Primary Economics and industry	Fish have different owners and reside at different operations during life or are wild-caught (based on how more than one-third of industry operates)	Multiple movements by same owner within an operation, which could be multisite but all the same "farm" (based on how more than one-third of the industry operates)	Movements within an operation, same location (based on how more than one-third of the industry operates)	N/A
Risk level = Low	**Documentation:** Eighty percent of tilapia typically spend their entire production life at one farm and are not moved multiple times. There is movement from the hatchery to the growout tanks within the farm. Hatchery-only farms are becoming more common and require movement to a new location, but they currently do not account for a large portion of the industry. (This sector includes the other 20 percent of the industry.) Fish that do come from the off-site hatcheries will spend the rest of their production life at the growout farm. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry literature.				
Content and processing of feed fed (assessed species)	Spread Primary Economics and industry	Any feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A	No feeding of uncooked or unprocessed fish waste or fish (live or dead)	N/A
Risk level = Low	**Documentation:** Tilapia are fed a commercially produced diet of 25–30 percent protein. The protein source is currently obtained from fishmeal and fish oil. Tilapia are not fed live or raw fish. *Sources:* Industry literature and industry interviews.				
State regulations regarding live-hauling (assessed species if possible)	Spread Primary Politics and regulations	No regulations exist	Regulations exist but without enforcement	Regulations exist with enforcement	N/A
Risk level = Medium	**Documentation:** Some live-hauling regulations exist in states where tilapia are produced, but enforcement of those regulations seems to not be a high priority. However, almost all tilapia are sold live, and the industry does not want to lose their market, so therefore does not cut off their own market channels via illegal activity. *Sources:* Industry literature and industry interviews.				
Types of sales of products from farms (assessed species)	Spread Primary Social and cultural	25 percent or more of industry makes sales to live-haulers	50 percent or more of industry makes direct sales to consumers (live, fresh, or frozen) and the definition for high risk level is not met	All else	N/A
Risk level = High	**Documentation:** Tilapia produced in the United States are sold almost exclusively to live-haulers for live markets and restaurants. *Sources:* Industry literature and industry interviews.				
Secondary Factors					
Geographic concentration of production (assessed species)	Spread Secondary Ecology, environment, and climate	75 percent or more of production (by volume) takes place within a 250,000-square-mile area	75 percent or more of production (by volume) takes place within an area more than 250,000 square miles, but less than 1 million square miles	All else and national production is not decreasing, over the most recent three-year period	All else and national production is decreasing, over the most recent three-year period
Risk level = Low	**Documentation:** The top-producing states for tilapia are California, Florida, Idaho, Maryland, New York, North Carolina, and Texas. Seventy-five percent of production does not take place in an area less than 1 million square miles. Tilapia production between 2001 and 2003 increased 12.7 percent. *Sources:* USDA, NASS, Census of Agriculture 2002; NOAA, National Marine Fisheries Service 2004.				

Spread Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Level of stocking in lakes and streams during most recent year (assessed species)	Spread Secondary Ecology, environment, and climate	The stocking level of the assessed species is 100 percent or more of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is between 25 and 100 percent of the number of assessed species produced for food by aquaculture	The stocking level of the assessed species is 25 percent or less of the number of assessed species produced for food by aquaculture	No stocking
Risk level = Low	**Documentation:** Stocking of tilapia for 2004 was 54,193. The estimated inventory of tilapia in aquaculture production in 2003 (based on conversion of pounds of tilapia marketed and 1.5-pound market weight per tilapia) is about 13,000,000. This puts the percentage of stocking in natural waterways at 0.4 percent of tilapia produced for aquaculture. *Sources:* U.S. state agencies responsible for stocking fish provided by 50 states for 2002–04; NOAA, National Marine Fisheries Service 2004.				
Total number of farms (assessed species)	Spread Secondary Economics and industry	1,000 farms or more involved in the production of the species	More than 100 but less than 1,000 farms involved in the production of the species	100 farms or less involved in the production of the species	N/A
Risk level = Medium	**Documentation:** Nine States produce the majority of tilapia. These states are California, Idaho, Texas, Florida, North Carolina, Maryland, West Virginia, Delaware, and New York. These states have the dozen or so farms that produce 90 percent of tilapia. The other 10 percent of the production occurs at dozens of farms in many states across the United States. The number of farms likely does not exceed 1,000. *Sources:* USDA, NASS, Census of Agriculture 2002; personal communication with Kevin Fitzsimmons, 2006.				
Change in production volume of assessed species and any other aquacultured species that is susceptible to any of the same pathogens as the assessed species, over most recent three years	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Tilapia are not known to be susceptible to any of the current (2005) OIE-listed diseases of fish. Because tilapia are not susceptible to any of these diseases, change in production of other species that are susceptible is not relevant. Tilapia production increased 12.7 percent between 2001 and 2003. *Sources:* OIE (Office International des Epizooties) Collaborating Centre for Information on Aquatic Diseases, 2006; NOAA, National Marine Fisheries Service 2004.				
Change in production volume of all aquacultured species, over most recent three years (country level, all species)	Spread Secondary Economics and industry	5 percent or greater change, up or down, over the most recent three-year period	3 percent or greater change, up or down, but less than 5 percent change, over the most recent three-year period	Less than 3 percent change, up or down, over the most recent three-year period	Zero change over the most recent three-year period
Risk level = High	**Documentation:** Total volume of U.S. aquaculture production grew by 13.1 percent between 2001 and 2003. Species included are catfish, trout, salmon, hybrid striped bass, shrimp, tilapia, baitfish, clams, crawfish, mussels, oysters, and miscellaneous species. *Source:* NOAA, National Marine Fisheries Service 2004.				

Spread Element

Factor	Risk Factor Category	Definition of Risk Level: High	Medium	Low	No defined risk
Production system used (assessed species)	Spread Secondary Economics and industry	More than 75 percent of industry uses open production systems (e.g., mariculture, raceways, uncovered ponds)	The industry uses open and closed production systems and does not meet the criteria for a high or low risk level	More than 75 percent of industry uses closed production systems (e.g., RAS)	N/A
Risk level = Medium	**Documentation:** The tilapia industry uses a mixture of true RAS and modified/open RAS for production. Industry experts estimate that approximately 60 percent of tilapia producers use a true RAS, with the remaining 40 percent using a modified/open RAS. The mixture of the two systems within the industry increases the risk of predation, mixing of outside fish, and exposure to environmental elements. *Sources:* Personal communication with Kevin Fitzsimmons 2006; industry interviews and industry literature.				
Disease management practices at the industry level (assessed species)	Spread Secondary Health management	No industry BMPs for disease management	Existence of industry BMPs for disease management, but little adherence or compliance measures	Existence of industry BMPs for disease management with compliance measures	N/A
Risk level = Medium	**Documentation:** The tilapia industry appears to have concern for disease management and has BMPs promoted by the industry association. *Sources:* Fitzsimmons 1999; industry experts; industry literature.				
Handling of mortalities	Spread Secondary Health management	Proper handling of mortalities is practiced by 50 percent or less of the industry	Proper handling of mortalities is practiced by more than 50 percent but less than 75 percent of the industry	Proper handling of mortalities is practiced by 75 percent or more of the industry	N/A
Risk level = Low	**Documentation:** More than 75 percent of tilapia farmers remove mortalities at least daily and dispose of mortalities properly. *Source:* Personal communication with Kevin Fitzsimmons, 2006.				
Treatment of discharge water (assessed species)	Spread Secondary Politics and regulations	Government regulations or industry BMP do not exist for discharge water (can use percent compliant with regulations if data exist) OR assessed species are kept in pens within a natural body of water (i.e., net pens in bays)	N/A	Government regulations or industry BMP exist for discharge water (can use percent compliant with regulations if data exist)	N/A
Risk level = Low	**Documentation:** Approximately one-third of tilapia producers fall under the EPA CAAP rule, which establishes effluent limitations guidelines. Tilapia producers who produce more than 100,000 pounds of fish per year must comply. Small RAS facilities are likely to have to comply with local effluent rules because they discharge into local waterways. Tilapia produced in ponds do not have to comply with the CAAP. *Sources:* USDA, NASS, Census of Agriculture 2002; personal communication with Kevin Fitzsimmons 2006.				

Notes: BMPs = best management practices; EPA = Environmental Protection Agency; CAAP = Concentrated Aquatic Animal Production; FAO = Food and Agriculture Organization of the United Nations; N/A = not applicable; NASS = National Agricultural Statistic Service; NESOI = not elsewhere specified or included; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix F. Pathways Element Results and Documentation

Pathways Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Primary Factors					
Presence of OIE-listed diseases in country from which the largest share of imports (by value) of live food finfish originate	Pathways Primary Agent, host, and vector biology	Any OIE-listed diseases reported during past three years in the country from which the largest share of imports originate OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past three years for species being assessed, but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past three years
Risk level = High	**Documentation:** The largest share of live food finfish imports (by value) to the United States came from Canada in 2005. During the past three years, Canada has reported three OIE-listed diseases of fish: infectious hematopoietic necrosis (2005), infectious salmon anemia (2003), and viral hemorrhagic septicemia (2005). *Sources:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006; *World Trade Atlas* 2006.				
Ballast-water dumping in assessed country	Pathways Primary Ecology, environment, and climate	Marine species production constitutes 50 percent or more of total aquaculture production	Marine species production constitutes 25 percent or more but less than 50 percent of total aquaculture production	Marine species production constitutes less than 25 percent of total aquaculture production	N/A
Risk level = Low	**Documentation:** In the United States, marine species production constituted 8.6 percent of total aquaculture production in 2003 (excludes miscellaneous category). *Source:* NOAA, National Marine Fisheries Service 2004.				
Regulatory infrastructure regarding importations (country level, all species)	Pathways Primary Politics and regulations	National government has no health requirements in place for fish or fish product imports (requirements include testing, health certificates, quarantines, etc.)	National government has health requirements in place for one or more fish or fish product imports (requirements include testing, health certificates, quarantines, etc.)	National government has import requirements in place for all fish or fish product imports (requirements include testing, quarantines, health certificates, etc.) and has a risk assessment and risk management process in place to collect and assess international information regarding fish and fish product imports	No importations of fish or fish products are allowed
Risk level = Medium	**Documentation:** The United States currently has import restrictions in place only on live fish, fertilized eggs, and gametes of fish species that are susceptible to spring viremia of carp. *Source: Federal Register* 2006.				
Total imports of all live food finfish during most recent year (country level)	Pathways Primary Social and cultural	Import value 50 percent or greater of world imports	Import value 5 percent or more of world imports, but less than 50 percent	Import value less than 5 percent of world imports	No imports
Risk level = Low	**Documentation:** The U.S. share of world imports of live food finfish in 2004 was 0.4 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				

Pathways Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Total imports of all live ornamental fish during most recent year (country level, all ornamental species)	Pathways Primary Social and cultural	Import value 20 percent or greater of world imports	Import value 1 percent or more of world imports, but less than 20 percent	Import value less than 1 percent of world imports	No imports
Risk level = Medium	**Documentation:** The U.S. share of world imports of live ornamental fish in 2004 was 14.4 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Change in imports of all live food finfish, most recent three years (country level)	Pathways Primary Social and cultural	Rate of change 10 percent or greater for value	Rate of change 3 percent or greater and less than 10 percent for value	Rate of change less than 3 percent or negative for value	No imports
Risk level = Low	**Documentation:** U.S. imports of live food finfish (trout, eel, carp, and live fish NESOI) decreased 23.3 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				
Change in imports of live ornamental fish over most recent three years (country level, all ornamental species)	Pathways Primary Social and cultural	Increase in value 50 percent or greater	Increase in value 10 percent or greater, but less than 50 percent	Increase in value less than 10 percent	Either 0 percent or negative rate of change
Risk level = Medium	**Documentation:** U.S. imports of live ornamental fish increased 10.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				
Geographic diversity of imports of live food finfish and live ornamental fish	Pathways Primary Social and cultural	Live fish imports originate from 50 percent or more of the countries in the world	Live fish imports originate from less than 50 percent but more than 10 percent of the countries	Live fish imports originate from less than 10 percent of the countries in the world	No imports
Risk level = Medium	**Documentation:** The United States imported live food finfish and live ornamental fish from 74 of the 193 countries in the world, or 38 percent or the world's countries in 2004. *Source:* World Trade Atlas 2006.				
Secondary Factors					
Presence of OIE-listed diseases in country from which the largest share of imports (by volume) of whole food finfish and shellfish originate (fresh or frozen) (country level)	Pathways Secondary Agent, host, and vector biology	Any OIE-listed diseases reported during the past three years in the country from which the largest share of imports originate OR country does not reliably report to OIE	N/A	No OIE-listed diseases reported during past three years for species being assessed, but credible reports of one or more other (non-OIE-listed or previously listed) diseases	No OIE-listed diseases reported and no credible reports of other (non-OIE-listed or previously listed) diseases during past three years
Risk level = High	**Documentation:** The largest share of whole food finfish and shellfish imports (by value) to the United States came from Canada in 2005. During the past three years, Canada has reported three OIE-listed diseases of fish (infectious hematopoietic necrosis in 2005, infectious salmon anemia in 2003, and viral hemorrhagic septicemia in 2005) and two OIE-listed diseases of mollusks (*Bonamia ostrea* in 2005 and *Mikrocytos mackini* in 2004). *Sources:* OIE Collaborating Centre for Information on Aquatic Animal Diseases 2006; *World Trade Atlas* 2006.				

Pathways Element

Factor	Risk Factor Category	Definition of Risk Level			
		High	**Medium**	**Low**	**No defined risk**
Migratory and predatory birds (country level)	Pathways Secondary Ecology, environment, and climate	More than 75 percent of aquaculture production produced in open production systems (e.g., mariculture, raceways, uncovered ponds)	Production produced in open and closed systems and does not meet the criteria for a high or low risk level	More than 75 percent of aquaculture production produced in closed production systems (e.g., RAS)	N/A
Risk level = High	**Documentation:** In the United States, the only aquaculture industry with a significant proportion of production raised in a closed production system is tilapia. Tilapia production represented only 1.3 percent of total U.S. aquaculture production (by quantity) in 2003, therefore 99.7 percent of U.S. aquaculture production (excluding the miscellaneous category) was produced in open production systems in 2003. *Source:* NOAA, National Marine Fisheries Service 2004.				
Imports of fish feed containing fish products during most recent year (country level)	Pathways Secondary Economics and industry	Yes	N/A	N/A	No
Risk level = High	**Documentation:** The U.S. import volume of fish feed in 2005 was 93,708 metric tons. Items included were products of dead fish or crustaceans; herring or pilchard meal; and flours, meals, or pellets of fish or crustaceans. *Source:* USDA, Foreign Agricultural Service 2006.				
Imports of used aquaculture production equipment	Pathways Secondary Politics and regulations	Imports common and not regulated	Does not meet definition for high, low, or no defined risk	Minimal imports or imports regulated	No imports
Risk level = Low	**Documentation:** In the Northeast United States, companies with salmon farms operate in Maine. Salmon farms also operate in Canada, so vessel and used equipment movements (such as feeding systems and cages) are not uncommon. However, each movement of such vessels and equipment requires a permit; a complete, hauled-out cleaning and disinfection; and inspection by either USDA or New Brunswick personnel or the company-licensed accredited veterinarian. Importation of used equipment by other aquaculture industries in the United States is uncommon. *Source:* Personal communication with Stephen Ellis 2006.				
Total imports of fresh whole food finfish, fish livers and roe, and shellfish during most recent year (country level, all species)	Evolution Secondary Social and cultural	Import volume is 10 percent or more of world imports	Import volume is 1 percent of greater, but less than 10 percent, of world imports	Import volume is less than 1 percent of world imports	No imports
Risk level = High	**Documentation:** The U.S. share of world imports of fresh whole food finfish, fish livers and roe, and shellfish in 2004 was 10.7 percent. *Sources:* USDA, Foreign Agricultural Service 2006; FAO, Fishstat Plus 2006.				
Change in imports of fresh whole food finfish, fish livers and roe, and shellfish over most recent three years (country level, all species)	Evolution Secondary Social and cultural	5 percent or greater increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	3 percent or greater increase, but less than 5 percent, in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	Less than 3 percent increase in import volume of fresh whole food finfish, fish livers and roe, and shellfish over the most recent three-year period	No imports
Risk level = High	**Documentation:** U.S. imports of fresh whole food finfish, fish livers and roe, and shellfish increased 5.4 percent from 2002 to 2004. *Source:* USDA, Foreign Agricultural Service 2006.				

Pathways Element					
		Definition of Risk Level			
Factor	**Risk Factor Category**	**High**	**Medium**	**Low**	**No defined risk**
Geographic diversity of imports of whole food finfish and shellfish originate (fresh and frozen)	Pathways Secondary Social and cultural	Imports originate from 50 percent or more of the countriesin the world	Imports originate from 10 percent or more of the countries in the world, but less than 50 percent	Imports originate from less than 10 percent of the countries in the world	No imports
Risk level = High	**Documentation:** The United States imported whole food finfish and shellfish from 103 of the 193 countries in the world, or 53 percent or the world's countries in 2004. *Source:* World Trade Atlas 2006.				

Notes: FAO = Food and Agriculture Organization of the United Nations; N/A = not applicable; NESOI = not elsewhere specified or included; OIE = Office International des Epizooties; RAS = recirculating aquaculture systems; USDA = U.S. Department of Agriculture.

Appendix G: List of Acronyms for Phase II and III

bacterial kidney disease	BKD
best management practices	BMPs
Collaborating Centre for Information on Aquatic Animal Diseases (OIE)	CCIAAD
Food and Agriculture Organization (United Nations)	FAO
infectious hematopoietic necrosis	IHN
infectious pancreatic necrosis	IPN
infectious salmon anemia	ISA
koi herpesvirus	KHV
World Organisation for Animal Health	OIE
recirculating aquaculture systems	RAS
ribonucleic acid	RNA
United States Department of Agriculture	USDA
variant Creutzfeldt-Jakob disease	vCJD
white spot shrimp virus	WSSV

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