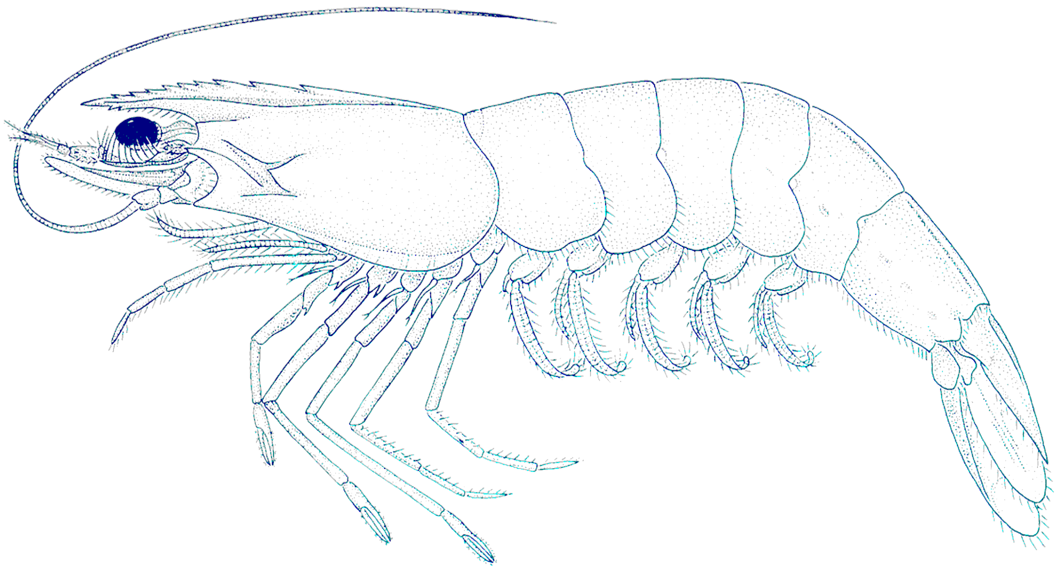
An Evaluation of Potential Shrimp Virus Impacts on Cultured Shrimp and Wild Shrimp Populations in the Gulf of Mexico and Southeastern U.S. Atlantic Coastal Waters



A Report to the Joint Subcommittee on Aquaculture
Prepared by the JSA Shrimp Virus Work Group

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LIST OF ACRONYMS

APHIS	Animal and Plant Health Inspection Service
BOD	Biochemical oxygen demand
CSREES	Cooperative State Research, Education, and Extension Service
DOC	U.S. Department of Commerce
EPA	U.S. Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
HH	High Health
IHHNV	Infectious Hypodermal and Hematopoietic Necrosis Virus
JSA	Joint Subcommittee on Aquaculture
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
PCR	Polymerase chain reaction
SPF	Specific Pathogen Free
ssRNA	Single-stranded ribonucleic acid
TSV	Taura Syndrome Virus
USDA	U.S. Department of Agriculture
WSSV	White Spot Syndrome Virus
YHV	Yellow Head Virus

PREFACE

Worldwide, shrimp aquaculture has suffered substantial economic losses due to pathogenic viruses, and the U.S. shrimp aquaculture industry is no exception. Although posing no threat to human health, the growing threat to shrimp aquaculture, concerns for possible effects on wild shrimp populations, and other species that depend on them have prompted action by the Joint Subcommittee on Aquaculture (JSA). The JSA is a Federal interagency advisory group formed under auspices of the President's Office of Science and Technology Policy. In March 1996, the JSA Executive Committee held an emergency meeting to discuss the shrimp virus situation and agreed to form a Shrimp Virus Work Group. In May 1996, the Shrimp Virus Work Group recommended to the JSA that the work group's primary task should be to develop an interagency strategy to address the shrimp virus issue. JSA accepted this recommendation and, in addition, decided to pursue the actions listed below.

- Identify existing authorities among Federal agencies.
- Identify research underway on shrimp viruses, their mode of transmission, and potential for introduction into U.S. waters.
- Support information exchange and education (i.e. workshop).
- Develop a risk assessment.
- Determine actions needed by the U.S. to avert introductions, etc.

The first three items were addressed during a June 1996 workshop. This workshop was jointly sponsored by: the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (DOC/NOAA/NMFS); U.S. Department of Agriculture, Cooperative State Research, Education and Extension Service (DOA/CREES) and Agricultural Research Service (DOA/ARS); and the U.S. Environmental Protection Agency (EPA), Gulf of Mexico Program and supported by the Gulf States Marine Fisheries Commission.. Workshop participants included environmentalists, shrimp farmers, shrimpers, processors and consumers as well as state and Federal regulators from both the U.S. and Mexico. The workshop presented the state of knowledge on the shrimp viruses and the threat they pose to both the shrimp culture industry and the wild shrimp populations in the Gulf of Mexico and southeastern U.S. Atlantic coastal waters. One of the highest priority recommendations made by workshop participants was to assess the disease, financial, and economic risks associated with the introduction and spread of exotic shrimp viruses to the wild shrimp fishery and shrimp farming industry.

Both workshop participants and the JSA have recommended that the risks associated with shrimp viruses be assessed, and this report is a first step towards that goal. Assembled by the Shrimp Virus Work Group, this report provides a summary of potential exposures to and effects of viruses on shrimp, especially wild shrimp populations. This report is structured according to (and draws material from) recently proposed processes for ecological risk assessment (Risk Assessment and Management Committee, 1996; U.S. EPA, 1996a).

Although this document is <u>not</u> a risk assessment, it is organized by elements of the risk assessment process. This approach:

- Provides a structure for analyzing and interpreting available information and for adding new information as it becomes available;
- Defines major risk-relevant data gaps, uncertainties, and research needs; and
- Indicates major pathways for virus introductions.

This report is intended to provide the JSA with a basis for discussing and selecting among a range of options for conducting a risk assessment.

EXECUTIVE SUMMARY

Recent evidence indicates that threats to the sustainability of U.S. marine resources due to exotic shrimp viruses are increasing. New, highly virulent diseases have been documented in foreign shrimp aquaculture operations. With its ever-increasing consumer demand, the U.S. has greatly increased importation of shrimp from areas of the world where shrimp viruses are endemic. Although these viruses pose no threat to human health, recent catastrophic outbreaks on U.S. shrimp farms, the appearance of diseased shrimp in U.S. commerce, and new information on the susceptibility of shrimp and other crustaceans to these viruses have prompted calls for investigation into the actual risks to domestic resources.

The Joint Subcommittee on Aquaculture formed the Shrimp Virus Work Group to assess the risks associated with these emerging pathogens. Risk assessments identify, organize, and prioritize information on potential risks. The Shrimp Virus Work Group produced this report to organize readily available information and expert opinion on the shrimp virus issue. This report closely follows the structure of a risk assessment while providing a summary of available risk-relevant information. To formulate the problem, this report includes an overview of economic impacts, a conceptual model for the assessment, stressors affecting shrimp populations, potential pathways for the exposure of wild shrimp to pathogenic viruses, basic life history of shrimp, and effects of viruses on shrimp and other aquatic species. Several options for completing an ecological risk assessment are proposed.

The economic significance of the shrimp virus problem should not be understated. Shrimp harvesting and processing in the United States is a $3 billion dollar a year industry. A substantial portion of this industry includes harvesting of wild shrimp (200 million pounds of shrimp [tails] annually). Additionally, imports of shrimp into the U.S. for processing exceed 600 million pounds (tails) annually.

Exotic shrimp viruses may pose a risk to Gulf of Mexico and southeastern U.S. Atlantic fisheries, including economically-important penaeid shrimp as well as other crustaceans and fisheries that depend upon these shrimp. In fact, the impact of one virus on a wild shrimp fishery in Mexico has been documented. Beginning in 1987, harvestable populations of *Penaeus stylirostris* (as well as other less prevalent species) occurring in the upper and middle Gulf of California declined to levels which could not support commercial harvests until 1994, in association with the observed occurrence of Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) infection. This fishery only began to recover in 1994. Moreover, newly-identified Asian viruses (e.g., White Spot Syndrome Virus [WSSV] and Yellow Head Virus [YHV]) appear to be more virulent to U.S. native shrimp than viruses thought to be endemic to South and Central America (e.g., IHHNV and Taura Syndrome Virus [TSV]). However, these viral diseases have not yet been positively identified in U.S. wild shrimp populations. Research has not been conducted to characterize the risks of these viruses to the U.S. wild shrimp industry or to other ecologically important species, but techniques to identify these pathogens have only recently become available.

This report evaluates four major pathogenic shrimp viruses: IHHNV, TSV, WSSV and YHV. These four were selected not only because of their ecological and economic importance but also to cover a range of virulence and geographic origin, in view of available information. The findings of the Shrimp Virus Work Group are summarized below. While some of this information is not yet fully supported by scientific evidence, the potential severity and newness of the problem warrants the inclusion of all available information to highlight the importance of the issues and stimulate further investigation. Conducting a risk assessment will require experts in crustacean virology and biology and other related disciplines to evaluate the available data herein as well as to identify and utilize new and better sources of information. The strengths and limitations of the available data and information will be evaluated in the risk assessment.

Findings:

- Shrimp viral diseases are widespread throughout the world, both in wild and cultured shrimp. IHHNV and TSV are endemic in wild populations of shrimp throughout much of Central and South America. WSSV and YHV are endemic throughout much of Asia.
- In at least one incident, viral disease has been associated with drastic reductions in wild shrimp harvests. Beginning in 1987, one viral disease (IHHNV) was associated with a decline in the Gulf of California shrimp fishery to levels that could not support commercial harvests until 1994.
- Although these viruses have not yet been positively identified in native U.S. shrimp populations, very little effort has been expended to look for them. Where investigations have been conducted, analytical methods (if available) or sampling intensities may have been inadequate to detect infection.
- Viruses have affected cultured shrimp throughout the world, often with catastrophic effects on production. For example, imports from Chinese aquaculture operations dropped substantially (1990 to 1995) due in part to viral disease. Outbreaks in 1995 and 1996 on U.S. shrimp farms caused a 50 to 95 percent loss of production at affected farms.
- Despite extensive efforts to prevent outbreaks on U.S. farms by the U.S. Marine Shrimp Farming Program, state agencies, and producers, numerous disease outbreaks have occurred in 1995, 1996, and early 1997.
- There are major economic concerns at stake. The U.S. shrimp processing industry employs over 11,000 people in 182 companies. Any new requirements that may be necessary to reduce disease risks will increase costs to producers and processors, and ultimately to consumers.
- Some foreign aquaculture operations harvest their ponds immediately upon finding disease and export the infected shrimp. This management practice, combined with tremendous increases in shrimp importation, may increase risks to U.S. natural resources. Infected shrimp are now routinely found in U.S. retail markets.
- Shrimp may become infected from many sources. Major potential exposure pathways to wild shrimp in the U.S. include shrimp processing plant wastes and wastes and escapement from aquaculture ponds. Other potential viral sources include infected bait shrimp, ship

ballast water, non-shrimp translocated animals, and natural spread of the virus. Fishing vessels and intentional introductions are also possible sources.

- Domestic shrimp are vulnerable. Specific life stages of all of the principal U.S. shrimp species are highly susceptible to infection and disease from one or more of the four subject viruses as demonstrated in laboratory tests and outbreaks at aquaculture facilities. Recently discovered Asian viruses appear to be more virulent to domestic shrimp species than those viruses thought to be endemic to South and Central America.
- Species other than shrimp may be at risk. One or more of these viruses have been found in samples of other crustaceans from around the world, including copepods, crabs, shore flies and crayfish. A number of alternate host species for the viruses have been identified.

In response to these findings, the Shrimp Virus Work Group recommends that an ecological risk assessment be conducted. A formal risk assessment will help address international trade issues (e.g., World Trade Organization), national and state regulatory obligations, and the needs of other interested parties (e.g., industry, environmental groups, and the public). To make the best use of resources and time available, the Shrimp Virus Work Group recommends that a tiered approach be considered for conducting a shrimp virus ecological risk assessment. All interested parties (stakeholders) should be involved in both the initial planning phase of the risk assessment, risk characterization, and in subsequent discussions of risk mitigation options.

The Shrimp Virus Work Group recommends the following steps prior to initiating the risk assessment.

- Publish a scoping notice to inform the public about the issues and the availability of this report.
- Hold at least two public meetings to inform the public and to facilitate stakeholder input to management goals and the risk assessment process.
- Convene a workshop to develop a problem formulation for the risk assessment, using this report and additional information (e.g., from stakeholder meetings). This workshop should include experts from a range of disciplines and affiliations.

Other actions are needed to effectively manage the shrimp virus problem. The Shrimp Virus Work Group recommends increased coordination among Federal agencies having appropriate expertise and authority to protect U.S. marine resources from pathogenic shrimp viruses. These agencies need to work collaboratively to better utilize the resources currently available and to better define roles and responsibilities of individual agencies. Existing Federal statutory authority may not be adequate to prevent further disease outbreaks, and new authorities may be necessary. However, statutory authorities alone will not be sufficient to control new diseases. There is a need to implement complementary programs across the responsible Federal agencies as well as to enhance research and technology to effectively reduce the risk of disease outbreaks. The shrimp virus work group recommends that representatives of the responsible

Federal agencies work closely with the aquaculture, processing, and harvesting industries (as well environmental organizations and other interested parties) to explore a variety of opportunities to reduce the risks posed by shrimp viruses.

1 INTRODUCTION

The worldwide shrimp industry has grown at a tremendous rate since the 1950's, and consumer demand for shrimp continues to grow at a rate of 7-9% annually. Because naturally-occurring ("wild") shrimp appear to have reached maximum harvest, the demand for shrimp has been met largely through expansion of shrimp aquaculture. Unfortunately, the increase in aquaculture operations has been accompanied by numerous outbreaks of disease-causing shrimp viruses, causing catastrophic mortalities and economic losses throughout the aquaculture industry.

Although posing no threat to human health, exotic viruses (viruses not indigenous to U.S. or Mexico) have affected U.S. shrimp culture operations. The Taura Syndrome Virus (TSV), first identified in Ecuador, has occurred in disease outbreaks in Hawaii (1994), Texas (1995), South Carolina, and again in Texas (1996) (Lightner, 1996a, 1996b). There have been some unsubstantiated reports that TSV has infected some wild broodstock in Mexico and some wild caught seed in Ecuador. Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) was first identified in Hawaii (Lightner et al., 1983a, 1983b). IHHNV has also occurred in Mexico, South Carolina, Texas, and Florida (Fulks and Main, 1992). Other exotic pathogens, White Spot Syndrome Virus (WSSV) and the Yellow Head Virus (YHV), that commonly occur in Southeast Asia, China, and India, have recently been reported at a shrimp farm in Texas (Lightner, 1996a, 1996b). It has been shown that IHHNV, TSV, WSSV, and YHV are carried by some live shrimp, and have been found in imported frozen shrimp, shrimp by-products, and in a number of non-penaeid shrimp and other crustacean species (Lightner, 1996a, 1996b).

The threat of these viruses to shrimp farms is well known. However, there is little or no information on the potential impact of these viruses on wild shrimp fisheries. Environmentalists, shrimpers, shrimp farmers, processors and consumers have expressed serious concerns over the spread of shrimp viruses (e.g., potential law suits in Texas, court injunctions in South Carolina, and a topic of various scientific and trade meetings and numerous local news articles).

The U.S. harvest and processing industries are of considerably greater economic value than the U.S. shrimp aquaculture industry and are also potentially threatened. Currently, the U.S. harvests approximately 200 million pounds (tails) of shrimp and imports another 600 million pounds (tails), collectively valued at over $3 billion. Exotic viruses from either aquaculture operations, processing streams of imported shrimp, or other sources, may challenge the sustainability of the shrimp fishery and the other fisheries that depend on it.

The JSA recognized the importance of assessing the risks associated with these shrimp viruses. Although not an actual risk assessment, this report takes a first step towards that goal by assembling readily available information in a format consistent with the ecological risk assessment process (Risk Assessment and Management Committee, 1996; U.S. EPA, 1996a). Accordingly, this report is organized by major phases of ecological risk assessment (U.S. EPA, 1996a): planning and problem formulation (sections 2 and 3), analysis (section 4), and risk characterization (section 5). A summary section (section 6) highlights major data gaps and research needs as well as key findings of this report. Section 7 proposes future actions, including options for conducting a risk assessment, publication of a scoping notice to provide information on the risk assessment, stakeholder meetings, an expert workshop to initiate the risk assessment process, and interagency coordination.

This report focuses primarily on developing the approach for the problem formulation phase of an ecological risk assessment. Specific topics are listed below.

- Economic impacts of the shrimp virus problem and the roles and responsibilities of risk managers and stakeholders (sections 2.1 and 2.2), followed by a discussion of management goals and assessment endpoints relevant to the primary focus of the report: direct and indirect effects of exotic shrimp viruses on cultured shrimp and on wild populations of penaeid shrimp in the Gulf of Mexico and the southeastern U.S. Atlantic coastal waters (section 2.3)
- Major (assessment) endpoints and a simple conceptual model that links virus sources, pathways, and effects on the endpoints (section 3.1)

The following problem formulation sections expand upon various elements of the conceptual model.

- Potential sources and pathways by which viruses could potentially reach wild shrimp populations (section 3.2)
- Stressors impacting (or potentially impacting) wild shrimp populations, including viruses and other human-introduced stressors (sections 3.3 and 3.4)
- Environmental and ecological factors influencing wild shrimp populations (section 3.5)
- Information on the life history and ecology of penaeid shrimp relevant to viral exposure and effects (section 3.6)
- Potential effects of viruses on shrimp and other crustaceans (section 3.7)
- The analysis plan that would be prepared for a risk assessment (section 3.8)

2 PLANNING THE ASSESSMENT: THE ECONOMIC AND MANAGEMENT CONTEXT

A risk assessment can be used to evaluate potential effects of exotic viruses on shrimp in aquaculture or wild shrimp. But a risk assessment is only a part of the overall environmental decision-making process. To make management decisions concerning shrimp viruses, economic, social, and political factors must be considered. For example, the shrimp industry includes the shrimp farming industry, the commercial shrimp fisheries, and the processing and distribution sectors of the seafood industry. If a risk assessment provides data indicating key control points for shrimp virus exposures, implementation of risk mitigation actions will require discussion and action by a diverse group of interested parties ("stakeholders"), including industry, trade associations, environmental and other nongovernmental organizations, and state and Federal agencies.

This section describes the management context for the shrimp virus problem. Key points include the economic significance of the shrimp industry and the key roles and responsibilities that different organizations have in managing the risks posed by shrimp viruses. In addition, the Shrimp Virus Work Group developed a draft management goal for a shrimp virus risk assessment. The draft goal is intended to initiate dialogue on the purpose, scope, and use of a risk assessment. Discussion and possible revision of the management goal would be one topic for future stakeholder meetings that are considered an important prerequisite for a risk assessment (see section 7.3).

2.1 Economic Aspects of the Shrimp Industry

Currently, the U.S. shrimp industry is valued at over $3 billion, and consumer demand for shrimp is growing at 7 to 9 percent yearly (National Fisheries Institute, 1995). In the U.S., imported shrimp account for over 80% of the market (720 million pounds [tails] in 1995, worth $2.6 billion). The U.S. domestic market is dominated by the wild shrimp fishery (190 million pounds [tails] in 1995; NMFS, 1995); domestic aquaculture operations account for a much smaller amount, ranging from 2 to 4 million pounds (tails) annually from 1992 to 1994 (figure 1). U.S. marine shrimp aquaculture production decreased in 1994 because of outbreaks of IHHNV and TSV at hatchery facilities and outbreaks of the bacterial disease hepatopancreatitis in Texas aquaculture (Rosenberry, 1994).

U.S. Shrimp Production. Landings of wild shrimp in the U.S. vary by geographic area, species, and season. In 1995, about 85% of total U.S. landings (190 million pounds [tails]) were penaeid shrimp from the Gulf of Mexico and the southeastern Atlantic (NMFS, 1995; figure 2). Although a major fishery for the Pacific and New England coasts, pandalid shrimp production, from the colder offshore waters of these regions, constitutes only about 10% of total U.S. shrimp production.

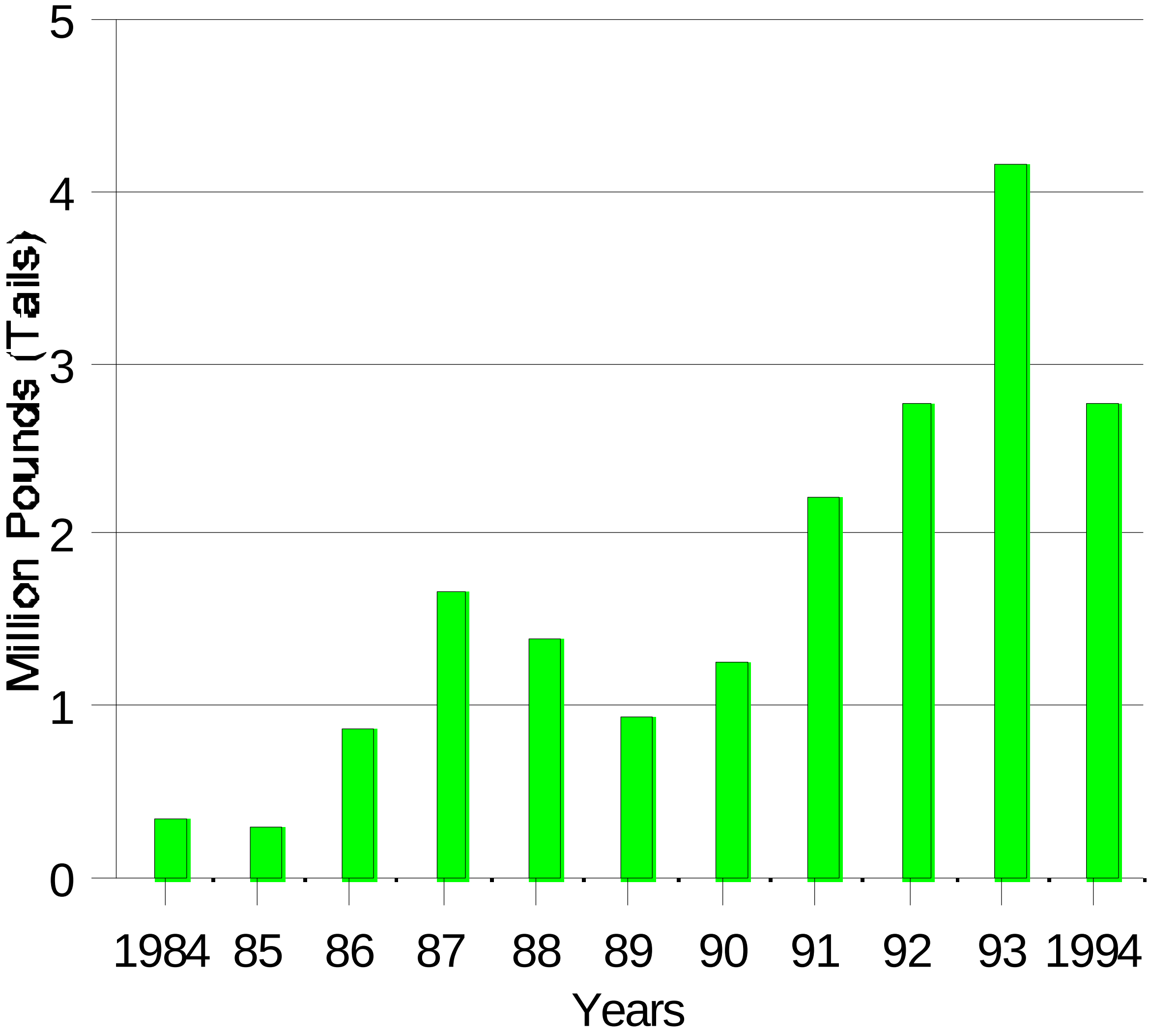

Figure 1. U.S. marine shrimp aquaculture, 1984-1994 (NMFS, 1995)

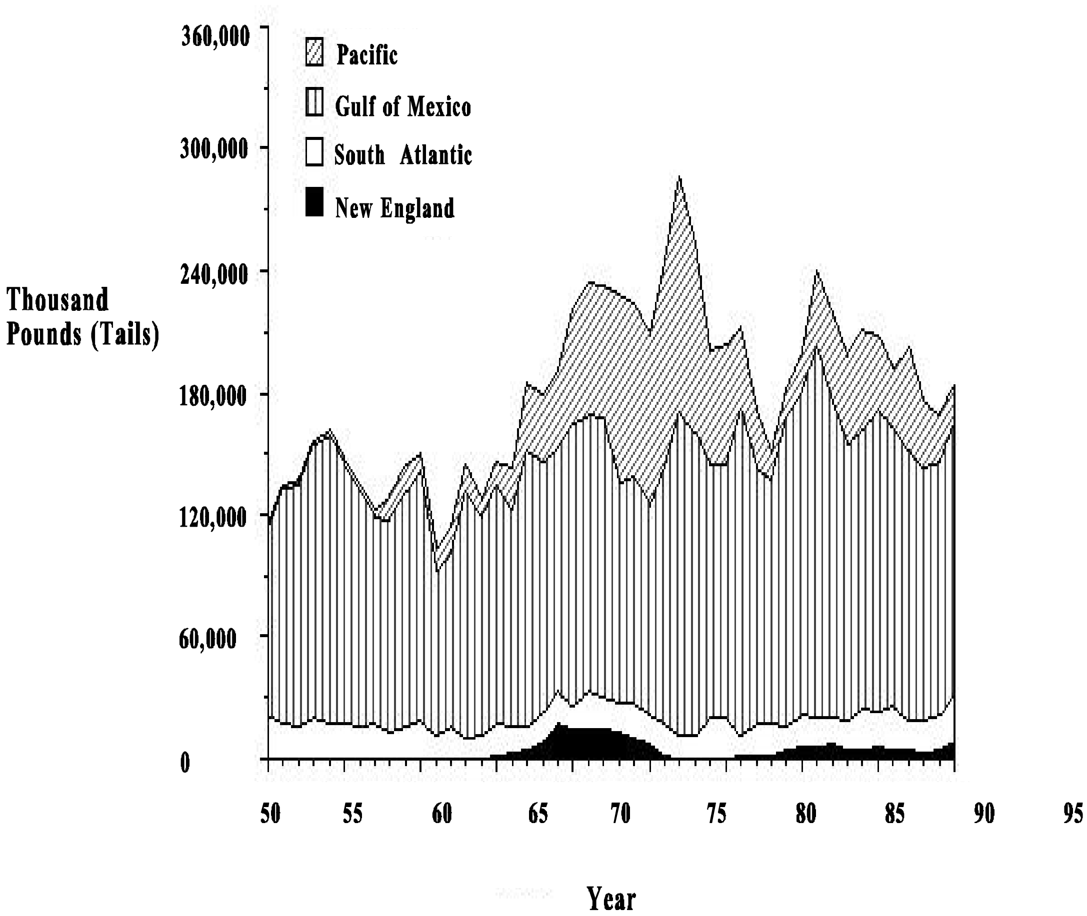

Figure 2. Approximate U.S. landings of marine shrimp by region, 1950-1995 (NMFS, Unpublished)

The three major penaeid shrimp species are the white shrimp *Penaeus setiferus*, the brown shrimp *P. aztecus* and the pink shrimp *P. duorarum*. Due to differences in their life histories, responses to environmental factors, seasonality, and variations in species distribution (see section 3.6), catches of these three species may not peak in the same year or at the same time during a single year (Nance and Nichols, 1988). This is reflected in the variability of penaeid shrimp production in the Gulf of Mexico, which since 1960 has ranged from a low of about 60 million pounds (tails; 1961) to a high of about 190 million pounds (tails; 1985). Brown shrimp constitute the majority (~ 60%) of the Gulf of Mexico catch, with most of these originating from the Texas-Louisiana coast. White shrimp are the dominant species in Louisiana coastal waters and along the southeastern U.S. Atlantic coasts. The pink shrimp fishery is smallest (poundage), but represents the major penaeid fishery off the west coast of Florida.

Domestic wild-caught shrimp are processed locally, with shrimp landed either directly at dockside, or offshore onto a mother ship, which then makes port with the catch from several craft. Almost 400 firms in shrimp-related industries are located throughout the Gulf of Mexico states, and more than two-thirds (268) of these are located in the states of Louisiana and Texas.

U.S. Aquaculture. In the U.S., aquaculture operations in Texas and South Carolina have suffered significant losses due to viral diseases, even though Specific Pathogen Free (SPF) stocks were used to avoid the introduction of these diseases. In 1995, TSV caused greater than a 95% loss of *P. vannamei* crops. Less severe losses with that species occurred in 1996. Outbreaks in 1996 resulted in estimated losses of up to 30 -50% in affected South Carolina shrimp farms. More recently, based on very limited data, YHV and WSSV have been found at the Waddell Mariculture Center for Research in South Carolina. In addition to the loss of income from diseased crops in 1996, aquaculturists had additional expense when restocking with the native white shrimp later in the season. Further indirect costs were associated with attempts to disinfect ponds.

Imported Shrimp. Increasing consumer demand for shrimp and a flattened rate of growth in U.S. shrimp fisheries have led to a sharp rise in shrimp imports. Since 1950, imports have constituted an increasingly large percentage of domestic consumption (30-40%), and have exceeded domestic production since 1960 (figure 3). By 1995, imports exceeded domestic production by almost four to one. The largest share of this imported production comes from aquaculture operations in Asia and Latin America (figure 4).

A combination of decreasing worldwide shrimp supplies and increasing demand kept shrimp prices high in 1996. Disease outbreaks have affected foreign aquaculture facilities and available supplies to varying degrees. Imports from aquaculture in Ecuador reached 114 million pounds (tails) in 1995, despite recent virus-related disease problems. Mexico has remained a steady supplier of both wild and cultured shrimp. Over the last two years, Mexican shrimp exports to the U.S. have risen 28 million pounds (tails); however, most of the increase comes from exports to the U.S. of wild-caught shrimp. Asian imports from Thailand, Indonesia, and the Philippines, major producers in shrimp aquaculture, were all lower. In 1995, Chinese exports to the U.S.

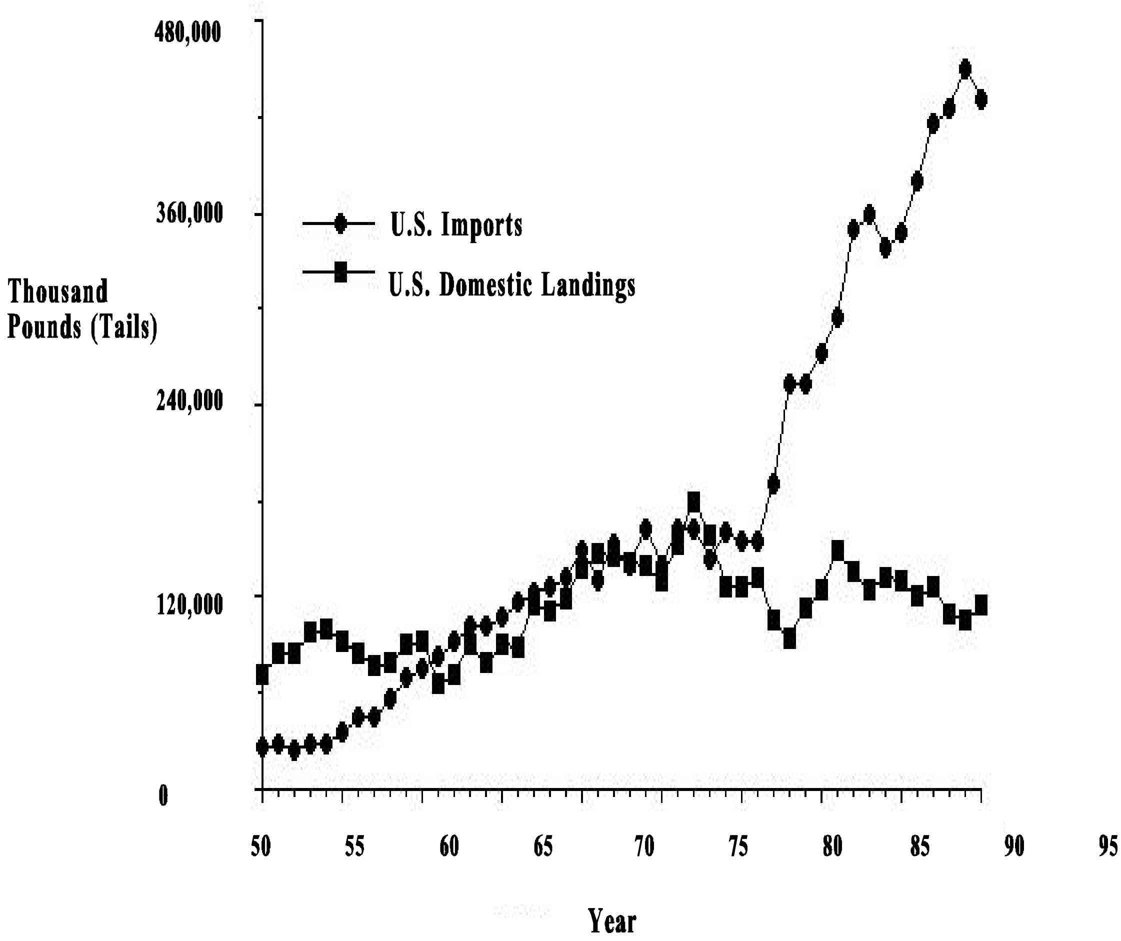

Figure 3. Approximate U.S. imports and domestic landings of marine shrimp, 1950 - 1995 (NMFS, Unpublished)

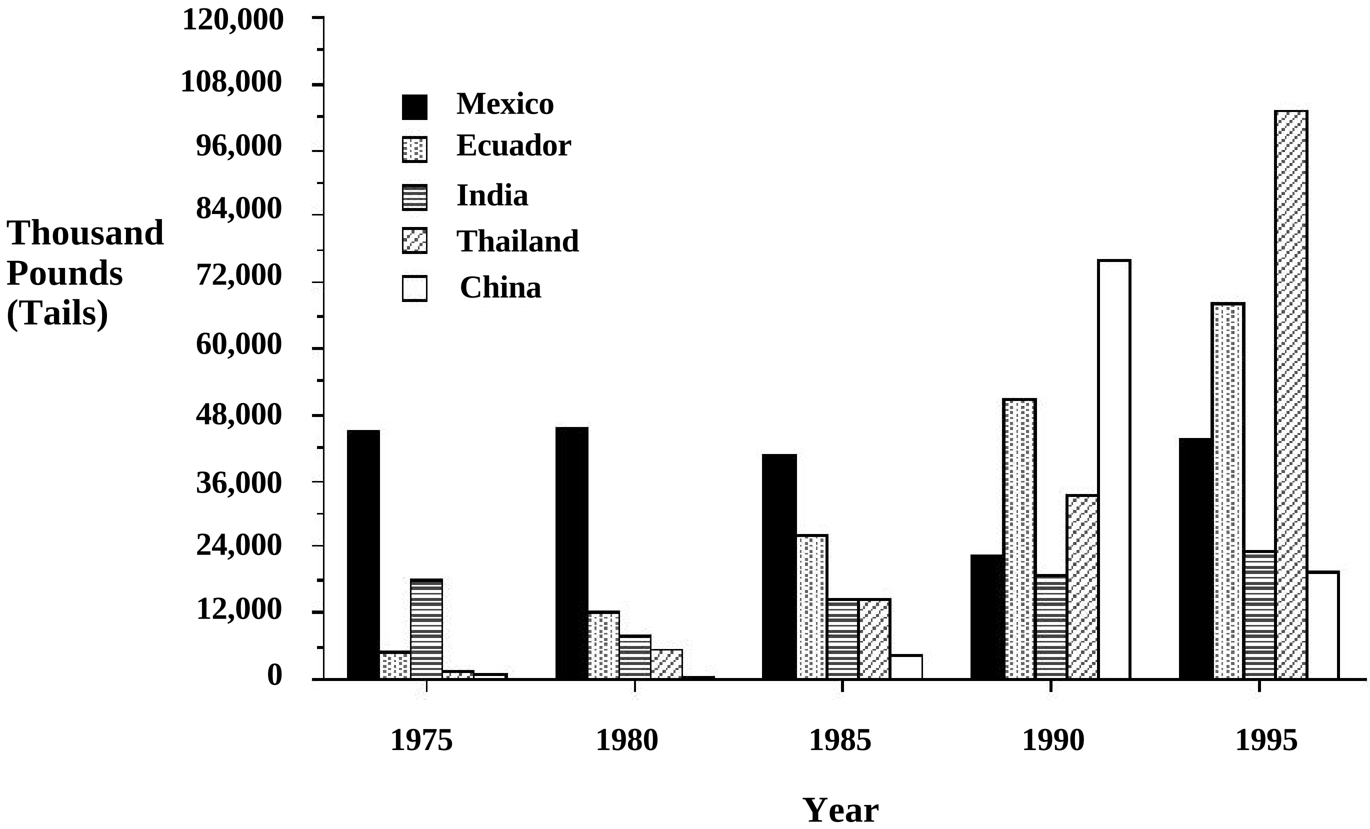

Figure 4. Approximate U.S. imports of shrimp by country, 1975 - 1995 (NMFS, Unpublished)

declined by 75% from the peak export year of 1990 because of disease impacts on shrimp aquaculture operations and increasing Chinese domestic demand for shrimp (USDA, 1996).

Disease outbreaks in foreign aquaculture operations can increase costs to the U.S. shrimp industry. As international aquaculture expands to meet growing demand, there is a greater risk that U.S. processing plants will receive shrimp infected with pathogenic viruses. For example, when some foreign growers detect the presence of disease in their stocks, they may immediately harvest the diseased shrimp and send them to U.S. processing plants. Costs to U.S. processors will increase if new detection, control, and treatment procedures are implemented to prevent the environmental release of contaminated wastes. Also, increased viral disease outbreaks in foreign aquaculture may result in more widespread occurrence of pathogenic viruses in wild shrimp stocks worldwide. This may result in decreased availability of virus-free breeder stocks and increased costs to develop SPF stocks.

Risk Managers and Stakeholders
(U.S. EPA, 1996a)

"Risk managers are individuals and organizations that take responsibility for, or have the authority to take action or require action, to mitigate an identified risk. The expression "risk manager" is often used to represent a decisionmaker in agencies like EPA or state environmental offices who has the authority to protect or manage a resource. However, risk managers often represent a diverse group of interested parties that influence the outcome of resource protection efforts. Particularly as the scope of environmental management expands to communities, the meaning of risk manager significantly expands to include decision officials in Federal, state, and local governments, as well as private-sector leaders in commercial, industrial, and private organizations. Risk managers may also include constituency groups, other interested parties, and the public."

"The involvement of all interested and affected parties, which "stakeholder" is commonly used to represent, is important to the development of management goals for some risk assessments. The greater the involvement, the broader the base of consensus about those goals. With strong consensus on management goals, decisions are more likely to be supported by all community groups during implementation of management plans."

2.2 Risk Managers and Stakeholders

Disease problems in the shrimp industry may have potentially far-reaching effects. In addition to the monetary value of the shrimp, many individuals rely on the shrimp industry for their livelihood. For example, the shrimp processing industry has over 11,000 employees in 182 companies (NMFS, unpublished; estimate based on a voluntary survey - actual numbers may be higher). With so much at stake and in view of the complexity of the shrimp disease problem, managing the potential risks will require a cooperative effort by a diverse group of interested parties, including industry, related trade associations, environmental and other nongovernmental organizations, and local, state and Federal agencies. This section summarizes the responsibilities, tools, and recent efforts of many of these important groups to deal with the shrimp virus problem.

Aquaculture Industry. A voluntary SPF broodstock and shrimp seed program is used in the United States to help prevent contamination of commercial aquaculture operations by pathogenic viruses. The U.S. SPF-based aquaculture industry uses animals known to be free of specified pathogens.

High Health (HH) facilities are an important part of the SPF-based industry. These facilities produce seed for growout. To help prevent pathogen introductions, seed should be procured from a HH supplier that can produce a documented history of pathogen surveillance. If adequate documentation is lacking, on-site quarantine should be implemented. In addition to HH seed, other elements necessary to complete an industry disease prevention strategy include farm biosecurity practices and a quick response to disease outbreaks. The term biosecurity refers to practices that will reduce the probability of pathogen introduction and its subsequent spread from one place to another (Lotz, In Press).

The U.S. Marine Shrimp Farming Program, funded by the USDA Cooperative State Research, Education, and Extension Service (CSREES) and cooperating institutions, consists of the Oceanic Institute, Gulf Coast Research Laboratory, Tufts University, Texas A and M Agricultural Experiment Station, South Carolina's Department of Natural Resources (Marine Resources Division), Waddell Mariculture Center, and the University of Arizona. The U.S. Marine Shrimp Farming Program operates a Nucleus Breeding Center and quarantine centers, and supplies SPF shrimp stocks to the U.S. shrimp industry (Dill et al., 1994; Pruder et al., 1995). These facilities supply seed for commercial use. Currently, nine viruses and numerous other pathogens are monitored in either primary or secondary broodstock, or in seed for commercial use (Lotz et al., 1995). Even so, disease outbreaks have occurred in the U.S. No Federal animal health certification protocols are currently in existence or required for U.S. commercial shrimp aquaculture operations.

State Governments. States have responsibilities to protect the shrimp fishing industry and to prevent the introduction of exotic shrimp viruses. Wildlife conservation agencies in all states along the Gulf of Mexico and the southeastern U.S. Atlantic coast regulate imported fish, crustaceans, or mollusks. In the shrimp farming states of Hawaii, Texas, and South Carolina, protocols have been implemented to prevent the introduction of pathogenic viruses through movement of imported shrimp seed and brood fish for aquaculture. For example, basic requirements in South Carolina include: facility design approval (including facility placement, escapement prevention, and effluent treatment); broodstock and seed supplier certification; record keeping of both stock imports, pond harvests, and daily pond monitoring (including immediate reporting of unusual occurrences); chemical and/or mechanical treatment of effluent; quarantine of incoming stock and nurseries; contingency plans for unusual occurrences or disease (including cessation of discharge); broodstock and seed from suppliers with a minimum of 12 and 6 months (respectively) free of listed diseases; and routine inspections. In addition to these kinds of procedures, states also attempt to enhance yield of wild shrimp harvests by regulating gear type, nets and mesh size, and the season and time of day when fishing is permitted.

Federal Government. Recent evidence indicates that exotic pathogenic shrimp viruses have been imported into the U.S. Because these pathogenic viruses have the potential to be spread through interstate commerce, the Federal government has regulatory authority in this area. Numerous Federal agencies have different statutory authorities, roles, and overlapping responsibilities for regulating the importation and movement of aquatic animals and products in commerce. Although human health and food safety are clearly provided for under existing Federal statutes, the health of U.S. domestic shrimp, other crustaceans, and other susceptible "wild" animals may not be adequately protected from diseases that may result from the importation of aquatic animals or animal products into the U.S. Under the Lacey Act (16 U.S.C. §§ 3371 to 3378; 18 U.S.C. 42), the importation of plants or animals that are considered injurious to humans, to the interests of agriculture, horticulture, forestry, or to the fisheries and wildlife resources of the U.S. is prohibited. The implementing regulations of the Lacey Act include Title 50 (50 CFR Part 16), which lists species of mammals, birds, fishes, mollusks, and crustaceans that are either prohibited entry or that are subject to special provisions. Part 16.13 of Title 50 applies to importation of live or dead fish, mollusks, and crustaceans, or their eggs. The current version prohibits importation of live walking catfish, mitten crabs, or zebra mussels. Other species of live or dead fish, mollusks, crustaceans, and their parts or gametes are allowed importation, transportation, and possession (but not release into the wild), with the exception of live salmonid fish, their fertilized eggs, viable gametes, and uneviscerated carcasses that are prohibited entry unless accompanied by a health certificate issued in accordance with procedures specified under Title 50.

To prevent future threats to aquaculture, indigenous species, and aquatic ecosystems, Federal agencies need to better define and coordinate their roles in a number of areas, including importation, interstate movement, release of live animals, and waste management. A variety of Federal statutes give several different agencies responsibilities for managing risks associated with shrimp viruses; however, as discussed above, these statutes do not specifically reference shrimp pathogens. Those Federal departments or agencies that may have relevant authority include the Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS), the Animal and Plant Health Inspection Service (APHIS), and the Environmental Protection Agency (EPA).

Fish and Wildlife Service. The Fish and Wildlife Service, under the Lacey Act (18 U.S.C. 42) and Title 50 (50 CFR Part 16), has the responsibility to protect fish health from disease transfers in live imports. Shrimp containing pathogens can be restricted from import under Title 50 in the injurious wildlife listing. When pathogens, including viruses, are determined to be harmful, the specific pathogen can be added to the injurious wildlife listing as needed. Under a separate authority, these viruses could be considered non-indigenous aquatic nuisance species, and therefore could be subject to the Non-Indigenous Aquatic Nuisance Species Prevention and Control Act of 1990. Under this act, any affected agency or entity may recommend that the Aquatic Nuisance Species Task Force initiate a control effort. A number of factors must be considered before the Task Force initiates such an effort. These factors include: 1) Is the non-indigenous organism already established, and if so, for how long ? 2) Is the introduction planned and deliberate? 3) Are risks associated with specific identified pathways? 4) Is the likelihood of permanent establishment significant? 5) Would establishment create significant economic or environmental harm? 6) Does opportunity exist to manage the organism and prevent introduction and establishment?

National Marine Fisheries Service. The NMFS has the authority for the regulation and protection of the wild shrimp resources in the waters of the U.S. Exclusive Economic Zone and cooperates with the States and other Federal agencies to protect these resources. The NMFS can use the Lacey Act (16 U.S.C. § et seq 3371; Reorganization plan 4 of 1970 (84 Stat. 2090) {5 U.S.C. § 903}; Amended Nov. 16, 1981, P-L 97-79, § 2, 95 Stat. 1073) to prevent the movement and importation of exotic shrimp, if a state law has been violated, and the state so requests. Also, under Title 50 (50 CFR Part 16), NMFS can act to include an injurious organism following the processes established under the Lacey Act. In the implementation of regulatory Shrimp Fishery Management Plans, the NMFS participates and provides technical support to the South Atlantic and the Gulf of Mexico Fishery Management Councils. Further, NMFS conducts regular assessments of the shrimp stocks in the Gulf of Mexico and the southeastern U.S. Atlantic coastal waters. NMFS also conducts basic research on methods for pathogen detection, pathogen transmission, and in development of disease control methods. The NMFS has developed, implemented, and presently supports a voluntary seafood inspection program. Finally, the NMFS cooperates with the Mexican Government to manage shared resources in the Gulf of Mexico and participates in the International Commission on the Exploration of the Seas to develop transport protocols for marine organisms.

Animal and Plant Health Inspection Service. The USDA's Animal and Plant Health Inspection Service (APHIS), under authority of the plant and animal quarantine laws (a complete listing of these laws is beyond the scope of this document) and the Agricultural Marketing Act of 1946 (7 U.S.C. 1622, 1624) § 203, 205 as amended, is responsible for preventing the introduction and spread of foreign diseases and pests detrimental to agriculture. The APHIS has authority to regulate importation and interstate movement of diseased and contaminated animals and has field offices in each state and at all U.S. ports of entry. It is the lead agency in international negotiations regarding animal health sanitary issues and is recognized by the European Union and other trading partners. The APHIS has experience negotiating international zoosanitary regulations for traditional agricultural species such as livestock and poultry, eradicating introduced pests and pathogens, and in certifying the health status of exported animals and animal products. In addition, APHIS works with the states and with industry on cooperative programs to address animal health issues and oversees the licensing of vaccines and other veterinary products. The USDA's Office of General Counsel is currently investigating whether existing statutes and executive orders can be interpreted to provide APHIS the authority to regulate the importation and interstate movement of shrimp and shrimp products to prevent and control shrimp viruses.

Environmental Protection Agency. The EPA can use its authority under the Clean Water Act (CWA) to regulate discharges of virus-containing effluents. Prior to the discharge of shrimp processing wastewater to surface waters, the EPA or designated state programs can impose physical screening or other primary treatment, at a minimum (under § 301, 402 of CWA; 40 CFR

Part 125 Subpart A). To protect receiving waters designated as water quality limited, additional treatment (i.e., beyond the minimum technology-based standards) can be imposed to meet water quality standards and implementation plans (under § 131, 302, 402 of CWA; 40 CFR Part 125). Based on these requirements and standards, permits for effluent discharge(s) are issued under the National Pollution Discharge Elimination System (NPDES; under § 402 of CWA; 40 CFR Part 122 - 125). Ocean discharge criteria (under § 403 of CWA; 40 CFR Part 125 Subpart M) may also be applicable.

Regarding control of shrimp or shellfish disease organisms, NPDES permits have neither addressed shrimp viruses as pollutants, nor have they required additional treatment technology. However, NPDES permits have addressed human disease organisms as pollutants in order to protect shellfishing waters, bathing beaches, and drinking water supplies. Thus, the NPDES permitting process provides a potential mechanism for addressing shrimp viruses as pollutants.

Collaborative Activities. Besides the regulatory activities of state and Federal agencies, there have been a number of cooperative efforts among risk managers and stakeholders to address the shrimp virus issue. One example is a recent workshop on shrimp viral pathogens held in June 1996, sponsored by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (DOC/NOAA/NMFS); U.S. Department of Agriculture, Cooperative State Research, Education and Extension Service (DOA/CREES) and Agricultural Research Service (DOA/ARS); and the U.S. Environmental Protection Agency (EPA), Gulf of Mexico Program. This workshop included individuals from all major stakeholder groups as well as representatives of the Mexican government. Workshop participants discussed the shrimp pathogen problem and recommended research priorities aimed at controlling threats to cultured and wild shrimp stocks in North and Central America.

Joint research programs will play an increasingly important role in addressing the shrimp virus problem. One example is research sponsored by the USDA under the U.S. Marine Shrimp Farming Program. A consortium formed through this program has been extensively involved in research addressing the issue of shrimp viruses. Projects include developing viral diagnostic techniques, as well as establishing a monitoring system to evaluate the health status of various commercial culture systems and to track SPF stocks. Recommendations are being developed for the exclusion, containment, and control of imported pathogens via the shrimp culture industry.

Another significant joint research effort is the virus containment research sponsored by NMFS under the Saltonstall-Kennedy Grants program. Through this joint effort, research is conducted on shrimp viruses. Grants have been awarded for basic research on virus virulence and bioassay technique. In-house work on virus control strategies, risk assessment, and monitoring is also underway.

There are many tools now available to address the challenges posed by the introduction of exotic pathogenic viruses to U.S. wild shrimp populations. Preventing the introduction, establishment, and spread of pathogenic viruses to the wild shrimp fisheries and aquaculture industries will be achieved only by a collaborative effort, i.e., a combination of voluntary industry action and the application of existing or modified regulations. Collaboration and cooperation among stakeholders and risk managers are essential to protect commercial shrimp fisheries from possible pathogens, assure the viability of the U.S. shrimp aquaculture industry, and provide for sustainable growth of the entire shrimp industry.

Planning a Risk Assessment and Setting Management Goals

The initial planning stages of an ecological risk assessment are critical for ensuring that the results of the risk assessment will be useful for environmental decision-making (EPA, 1996a). Planning helps to (1) establish management goals that are agreed on, clearly articulated, and contain a way to measure success; (2) define the decisions to be made within the context of the management goals; and (3) agree on the scope, complexity, and focus of the risk assessment, including the expected output and the technical and financial support necessary for its completion.

Both risk managers and risk assessors are responsible for coming to agreement on the goals, scope, and timing of a risk assessment, as well as the resources that are available and will be necessary to achieve the goals. Together, they use information on the ecological systems of concern, any regulatory endpoints, and publicly perceived societal (environmental) values to interpret the goals for use in the ecological risk assessment. Management goals are generally formed as a consensus based on many diverse values reflected in Federal, state, and local regulations, constituency group views, and public concerns. Significant interactions among a variety of stakeholders are required to generate agreed-on management goals for the resources of concern.

2.3 Management Goals

A risk assessment is initiated by planning activities involving both risk assessors and risk managers. At this stage, early in the risk assessment process, it is important to establish management goals, define the management decisions to be made within the context of the goals; and to agree on the scope of the assessment (see text box). While the scope and management goals for a shrimp virus risk assessment must still be determined (section 7), the Shrimp Virus Work Group developed a draft management goal to initiate discussions and provide a focus for this report:

Prevent the establishment of new disease-causing viruses in wild populations of shrimp in the Gulf of Mexico and southeastern U.S. Atlantic coastal waters, while minimizing possible impacts on shrimp importation, processing, and aquaculture operations.

Although the focus of this report is on the impacts of pathogenic viruses on wild shrimp populations, these viruses also pose substantial risks to the U.S. aquaculture, importation, and processing industries. This report identifies and discusses pathways of viral pathogens both to and from these industries. The focus of this report is on the Gulf of Mexico and the southeastern U.S.

coastal waters because they represent the largest volume of U.S. landings of wild shrimp (figure 2). However, shrimp industries in other geographic areas of the U.S. also may be affected by pathogenic viruses, and there may be significant impacts on the local economies of those areas as well.

3 ECOLOGICAL RISK ASSESSMENT: PROBLEM FORMULATION

Ecological risk assessment includes three primary phases: problem formulation, analysis, and risk characterization (see figure 5 and text box). This report provides much of the information relevant to developing the problem formulation phase of the shrimp virus risk assessment. While it is premature to describe in detail the analysis or risk characterization phases for a shrimp virus risk assessment, a general description of these phases is provided in sections 4 and 5. Three steps important for problem formulation are described below.

- Define assessment endpoints. Assessment endpoints are "explicit expressions of the actual environmental value that is to be protected" (U.S. EPA, 1992). An example is "survival, growth, and reproduction of wild penaeid shrimp populations". Selecting appropriate assessment endpoints helps to ensure that the risk assessment addresses important scientific issues while being responsive to management concerns.
- Develop the conceptual model. Conceptual models portray the relationships between stressors, their sources, and the ecological effects they may cause. Frequently shown as a diagram, a conceptual model helps risk assessors focus a risk assessment on the most important sources, stressors, and effects.
- Develop an analysis plan. In the analysis plan, risk assessors identify what will be done in an assessment. The analysis plan also describes the data and measures to be used, the analyses to be performed, and how risks will be characterized.

Ecological Risk Assessment
(U.S. EPA, 1996a)

Problem formulation is the initial planning phase of an ecological risk assessment, where assessment endpoints are selected, a conceptual model is prepared, and a plan for the assessment is developed. Next, during the analysis phase, exposure and effects data are evaluated to determine the relationship between stressor levels and ecological effects. In the risk characterization phase, risks are estimated by integrating exposure and effects information and major uncertainties are evaluated. Finally, risks are described by discussing any relevant lines of evidence and the potential for ecologically adverse consequences. Interactions between risk assessors, risk managers, and stakeholders at the beginning and end of the risk assessment are critical for ensuring that the results of the assessment can and will be used to support a management decision.

3.1 Assessment Endpoints and the Conceptual Model

The previous section proposes a management goal for a shrimp virus risk assessment. In this section, that goal is linked to assessment endpoints, i.e., formal expressions of environmental

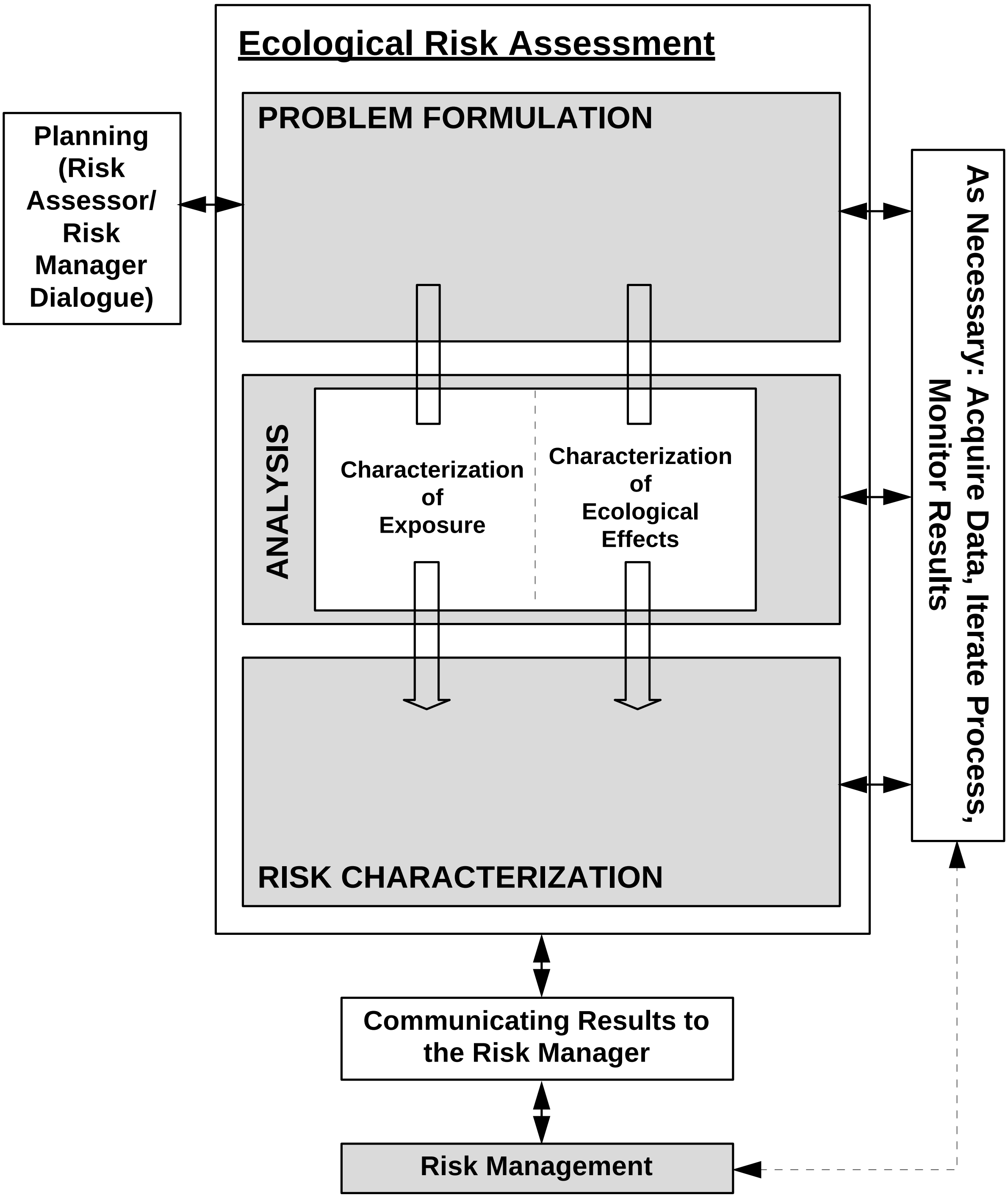

Figure 5. The ecological risk assessment process.

values to be protected (see text box). Information contained in this report is directed primarily toward the following assessment endpoint:

Survival, growth, and reproduction of wild penaeid shrimp populations in the Gulf of Mexico and southeastern U.S. Atlantic coastal waters.

The focus of this report is on wild penaeid shrimp because of their societal and ecological importance (section 2.1) and because of their known susceptibility to the identified stressors (viruses, section 3.3). While population-level effects on shrimp (e.g., mass mortality, disease) are the primary concern of this report, it is recognized that shrimp populations cannot be protected without considering the ecological systems they inhabit. Thus, the Shrimp Virus Work Group has proposed a second assessment endpoint:

Ecological structure and function of coastal and near-shore marine communities as they affect wild penaeid shrimp populations.

To illustrate the appropriateness of this secondary endpoint, consider the following example. Other crustaceans such as copepods, amphipods, or crabs are year round residents of coastal marshes where penaeid shrimp spend an important part of their life cycle (i.e., postlarval to juvenile stages). Some of these other crustacean species could be alternate hosts for the viruses, thus serving as a potential reservoir and vector for transmission of the viruses for infection of penaeid shrimp during susceptible life stages. In Asia, for example, WSSV has already been found in field samples of several species of crabs, copepods, shore flies, and crayfish (section 3.7). If these other species are themselves affected by the virus, resulting ecological effects (e.g., removal of copepods as a food source) could be detrimental to penaeid shrimp as well as other ecosystem inhabitants (e.g., crabs, fish).

Assessment Endpoints

Assessment endpoints are developed jointly by risk managers and risk assessors in cooperation with a diverse group of stakeholders. Assessment endpoints contain two elements: a valued ecological entity (e.g., wild shrimp) and an attribute of that entity (e.g., population growth and development). Effective assessment endpoints are clearly defined, biologically and socially relevant, accessible to measurement, estimation or prediction, susceptible to environmental stressors of concern, and representative of management goals (Suter, 1990).

For a risk assessment to have scientific validity, assessment endpoints must reflect ecologically important components of the systems they represent. Assessment endpoints that adequately reflect societal values and management goals are more effective in that they increase the likelihood that the risk assessment will be used in environmental management decisions.

Additional information on developing management goals and objectives and assessment endpoint is described elsewhere (U.S. EPA, 1995, 1996a).

Conceptual models show linkages between human activities, stressors, and assessment endpoints that are useful in developing risk hypotheses (see text box). Diagrams are useful tools for communicating important pathways in a clear and concise way and for identifying major sources of uncertainty. The Shrimp Virus Work Group developed a proposed conceptual model diagram (figure 6) to describe the potential scope for a shrimp virus risk assessment. The simple model shows the important links between major potential sources of stressors (viruses and anthropogenic stressors), possible routes of exposure of wild penaeid shrimp, and potential ecological effects of these pathogenic viruses. The first row of boxes shown under virus sources represents major potential pathways by which wild shrimp populations may be exposed to exotic pathogenic viruses. It is conceivable that viruses may be transferred between any of the potential sources via the pathways shown. Later in this report, more detailed descriptions of the major sources and pathways are provided. Other sources thought to be of lessor importance are also described.

Conceptual Models and Risk Hypotheses

Developing a detailed conceptual model helps the risk assessor identify the risk hypotheses to be evaluated in the risk assessment. Risk hypotheses describe predicted relationships between the source, stressor, and potential effects on an assessment endpoint. For example, a simple risk hypothesis might be: diseased shrimp in aquaculture grown from infected seed may escape in pond effluents and reach wild populations of shrimp in the Gulf of Mexico. Risk hypotheses do not necessarily require statistical testing or any particular analytical approach. Risk hypotheses may predict the release of a virus or they may postulate the causes of observed declines in shrimp populations. A complex assessment can lead to a large number of possible hypotheses. Thus, a critical aspect of problem formulation is to select the key hypotheses that will be the focus of the assessment.

The next row of boxes in figure 6 identifies four viruses that are the primary stressors of concern for this report. The potential effects of these viruses on wild shrimp must be determined with consideration of other factors that may significantly affect shrimp populations, including non-viral stressors resulting from human activities and important environmental and ecological factors.

A generalized penaeid shrimp life cycle is provided to emphasize the importance of shrimp life history on exposure to the pathogenic shrimp viruses. Exposure to the virus depends not only on the spatial and temporal patterns of viral entry into coastal and marine systems, but also on the movements and life history patterns of the shrimp. For example, shrimp would most likely be exposed to a virus-contaminated effluent discharged at the inlet to an estuary if the discharges occurred during their seasonal immigration or emigration through the inlet. Finally, the diagram shows that effects (bottom row) on penaeid shrimp populations may occur either directly (through the combined effects of individual mortality), or through direct or indirect effects on other ecological entities (e.g., other susceptible crustaceans).

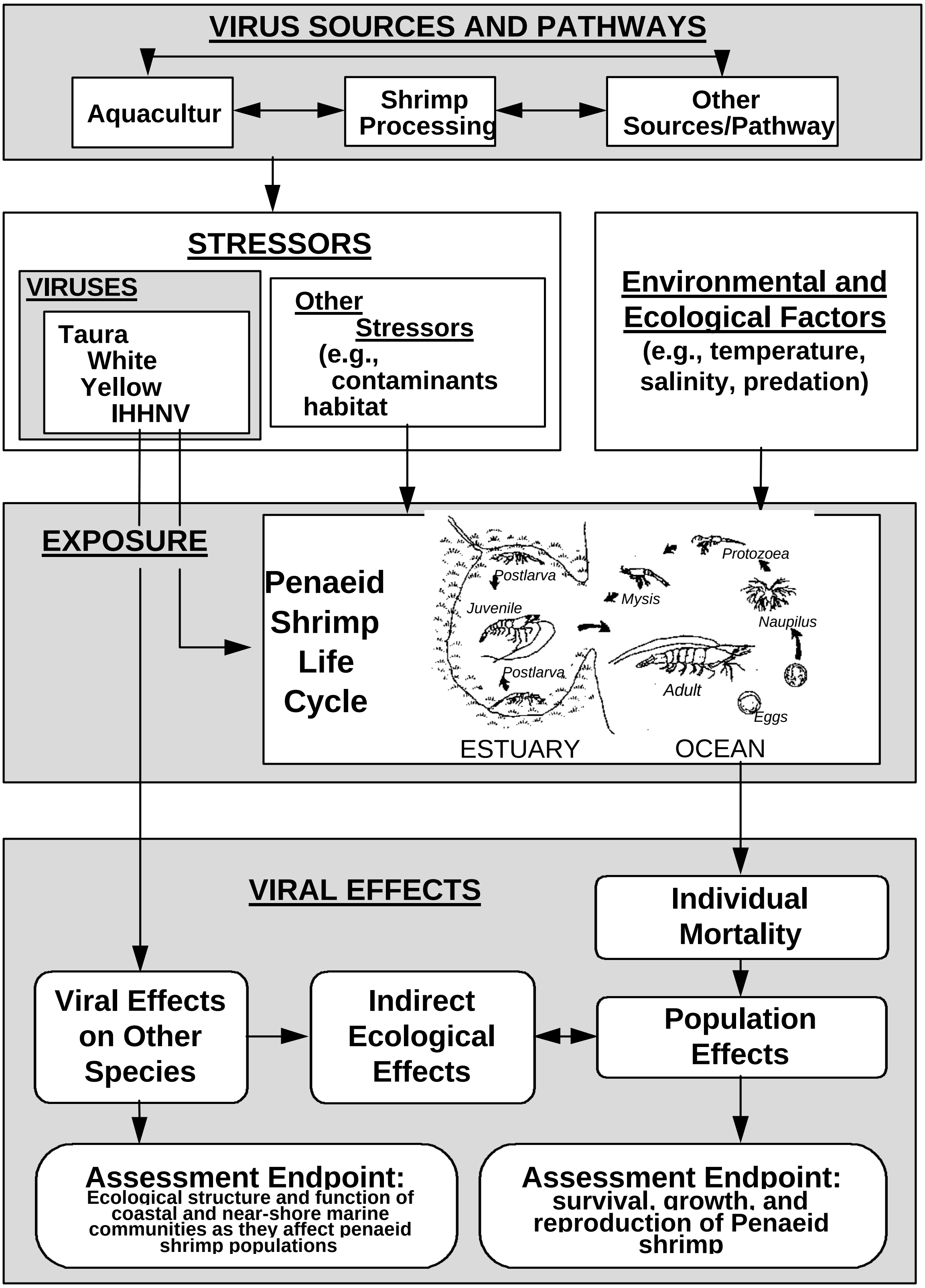

Figure 6. Proposed Shrimp Virus Conceptual Model.

3.2 Virus Sources and Pathways

A critical aspect of evaluating the risks of shrimp viruses is understanding the sources of virus and the pathways to the wild penaeid shrimp. This section provides more detail on two possible sources and potential pathways for the viral effects shown in the conceptual model (figure 6): aquaculture and shrimp processing. The Shrimp Virus Work Group considered these two sources as those with the greatest potential to introduce viral diseases into wild penaeid shrimp populations; this report also describes many other potential sources and pathways that were considered less critical (section 3.2.3).

3.2.1 Aquaculture

Several penaeid shrimp species are reared commercially worldwide, with the largest production in Asia and South America. Intensive penaeid culture was first developed in Japan (Hudinaga, 1942; Fujinaga, 1969) using *P. japonicus*. Later, during the 1970's, penaeid culture was developed as a large-scale industry in the third world. During this period, many U.S. companies that used native species failed because of difficulties spawning broodstock and rearing succeeding generations. However, research in the U.S. has continued with attention devoted to *P. vannamei*, the species most commonly reared in Latin America. *Penaeus monodon*, representing nearly 80% of the world penaeid aquaculture supply, remains the species of choice in Asia.

At present, most penaeid aquaculture in the continental U.S. occurs in Texas and South Carolina. Figure 7 shows the number and distribution of aquaculture facilities located in Texas. There are 17 Texas facilities; 12 of these covering approximately 1625 acres are presently in active penaeid production (Reisinger, Pers. Comm.). In 1994 there were 15 commercial farms operating in South Carolina, including 115 hectares (284 acres) of ponds and supplying 450 metric tons (3,913 kg/hectare) of shrimp. The maximum number of farms ever operating in South Carolina was 18 (Browdy, Pers. Comm.). Some additional commercial rearing of postlarvae occurs in Florida and Hawaii.

Nearly all U.S. aquaculture facilities stocked *P. vannamei* until 1995, when major outbreaks of TSV decimated crops of *P. vannamei* in South Texas (more than 95% loss; Reisinger, Pers. Comm.). In 1996, *P. vannamei* stocks in both Texas and South Carolina were again severely impacted by TSV. As a result, Texas aquaculture facilities began restocking with *P. setiferus*. Following restocking at these facilities, WSSV and YHV occurred for the first time in the western Hemisphere shrimp aquaculture (Lightner, 1996a, 1996b). Prior to November 1995, there had been no documented occurrences of either WSSV or YHV in U.S. commercial facilities, and lethal outbreaks of these viruses had been confined to Asian production facilities.

Although there are few outbreaks with confirmed sources, figure 8 suggests several ways in which viruses may enter aquaculture facilities. For those viral outbreaks in Texas in 1995, it

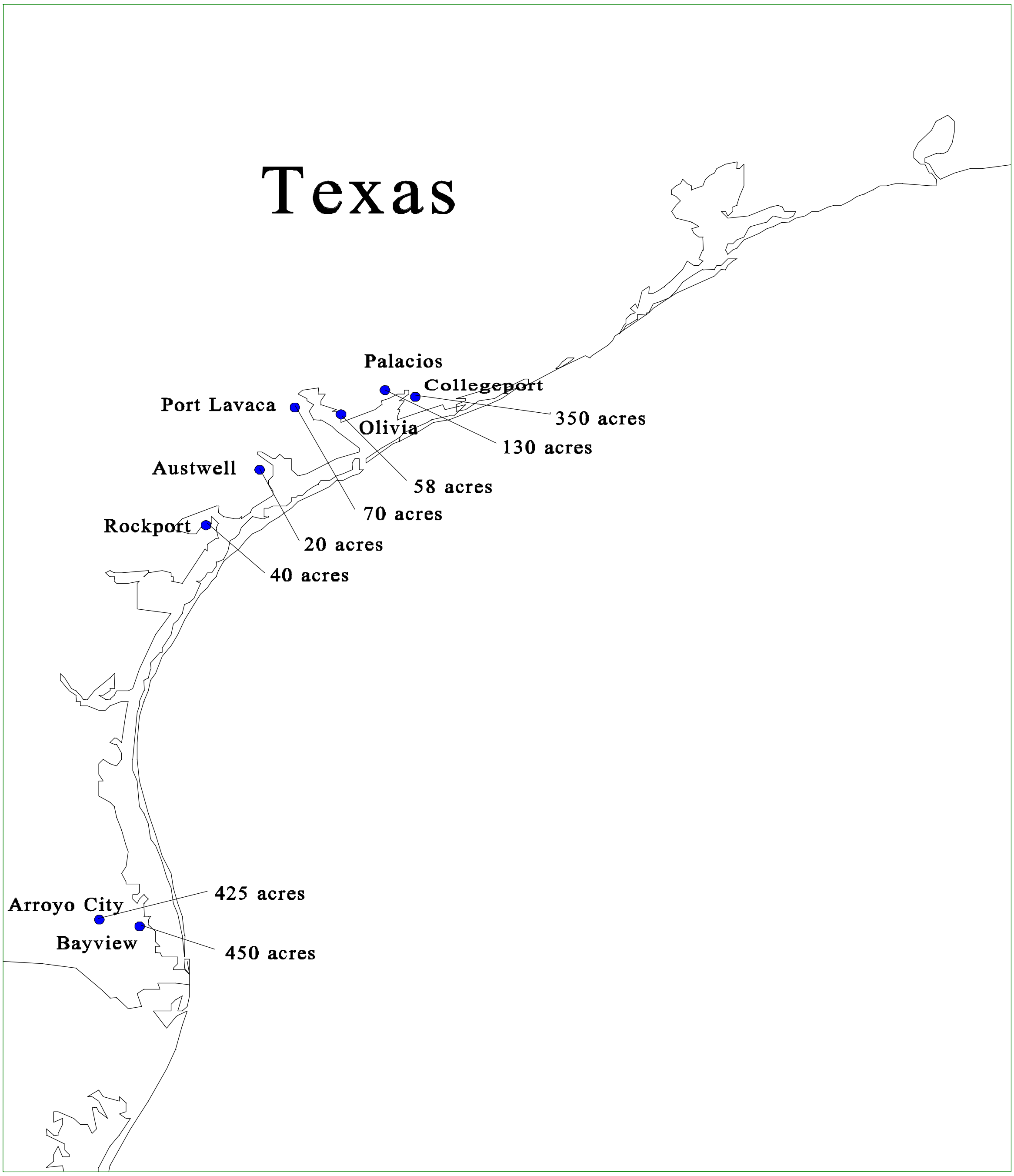

Figure 7. Active commercial shrimp aquaculture facilities on the Gulf Coast of Texas (acreage does not indicate acres stocked)

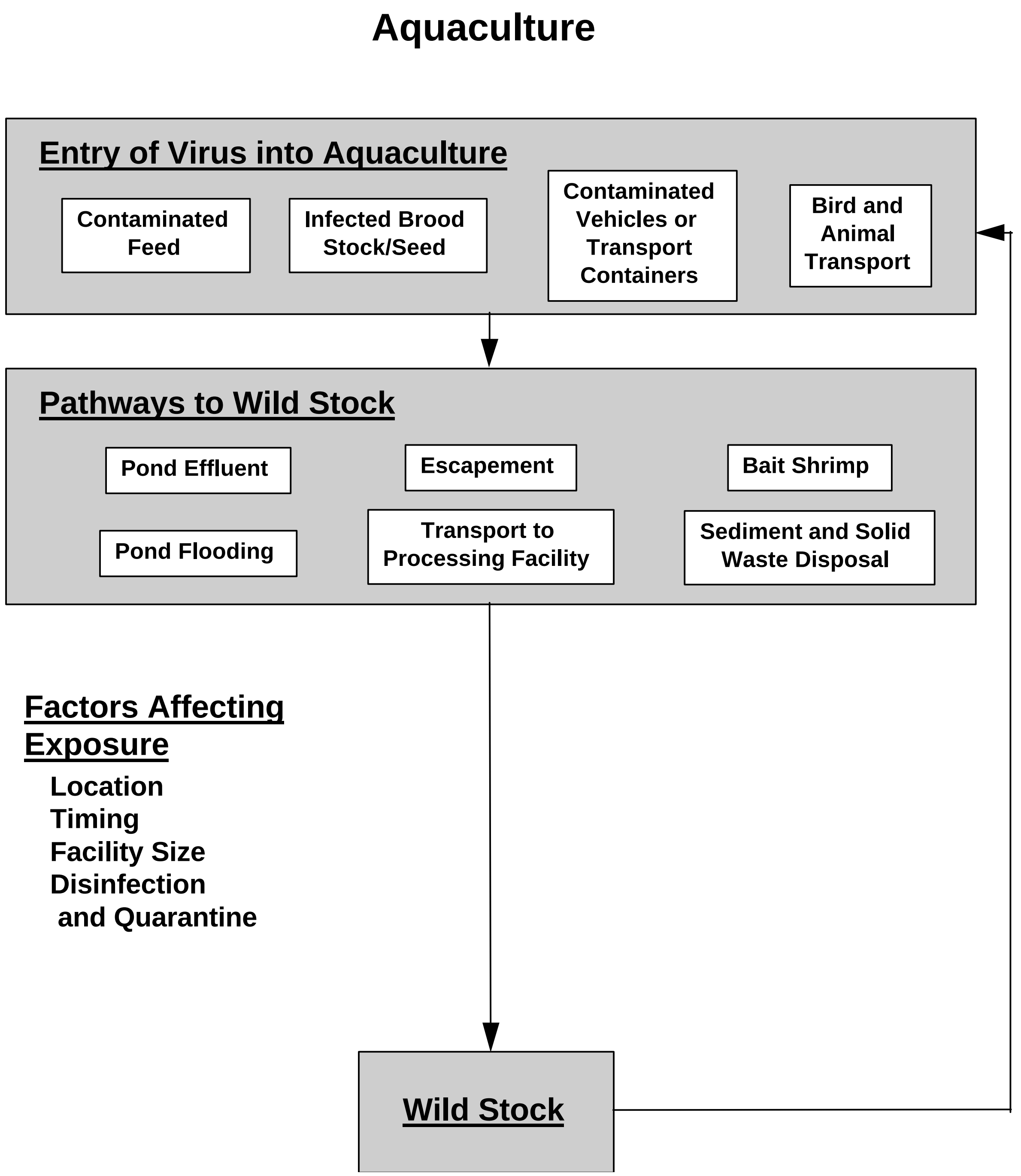

Figure 8. Conceptual model: virus sources and pathways for aquaculture

was speculated that viruses might have been transferred by birds (i.e., by seagulls via feces) to the affected aquaculture facilities. Though never confirmed, nearby shrimp packing plants, major importers and re-processors of large quantities of shrimp from the far east, were suspected as the ultimate source of the imported viruses. Reports that non-shrimp animal species may have been the source of some infections (i.e., either as carriers or transmitters) have been unsubstantiated, but non-shrimp species (e.g., crabs, crayfish, squid, other crustaceans, amphipods, isopods) have only recently been subjected to bioassay and other definitive tests for the presence of viruses.

The 1996 TSV outbreaks in South Carolina and Texas apparently resulted from broodstock that were contaminated after they arrived at a hatchery (Lotz, Pers. Comm.), although the original source of broodstock infection is unknown. Farmers purchased infected seed from this facility, although recommended procedures direct farmers to avoid purchasing seed from a supplier having a recent history of disease. See Pruder (1996) for a further description of these outbreaks. Other potential sources for entry of viruses into aquaculture include contaminated feed (see section 3.2.2) and contaminated vehicles or transport containers (figure 8).

Shrimp used in U.S. commercial aquaculture originate from the U.S. Marine Shrimp Farm Program. A total of 4-5 original groups of wild shrimp have been used to date. Offspring of these are used as the primary source of stock and are kept at the Nucleus Breeding Center at the Oceanic Institute. These are routinely tested for nine viruses, including IHHNV, TSV, WSSV and YHV, and numerous other pathogens. These shrimp are determined to be specific pathogen-free through two generations before use in commercial postlarvae production (Lotz et al., 1995). Shrimp from the Nucleus Breeding Center are provided to Consortium research facilities, commercial suppliers of postlarvae (seed), and to commercial broodstock multiplication centers. Pathogen screening is much reduced once shrimp enter either commercial broodstock multiplication centers or commercial postlarvae producers.

Postlarvae available to commercial growout facilities (i.e., farmers) are purchased from commercial seed producers. Currently, seed are obtained from commercial hatcheries in Hawaii, Texas, and Florida, and research facilities in Mississippi and South Carolina. Although the extent to which postlarvae are screened for pathogens varies from producer to producer, individual shipments are not routinely examined for diseases. South Carolina requires certification that suppliers have a history of at least 6 months free of listed specific pathogens, including TSV, IHHNV, WSSV, YHV. Presently, there is no Federal program to certify individual shrimp shipments or facilities.

Shrimp farmers usually stock postlarvae in the early spring, and harvest at least one crop prior to the onset of cold weather. Though stocking densities vary widely, most U.S. commercial farmers are semi-intensive. As an example, south Texas ponds are usually stocked at about 100,000 - 200,000 postlarvae per ha, and the average pond covers less than 3 ha. Farms are generally located near a source of brackish or saline water, and may recirculate wastewater back to their source waters. Under normal conditions, effluent is held in ponds to settle before discharge. In South Carolina, at the onset of disease, farmers are required to hold water on their farms. Under these conditions, water quality in the ponds is maintained by constant aeration, and wastewater is discharged only after harvest. Once an aquaculture facility becomes infected with a shrimp virus, there are no reliable, generally accepted, or standardized procedures available for pond disinfection.

As shown in figure 8, native shrimp species may be exposed to viruses through a number of pathways from aquaculture, including pond effluents or flooding of ponds, escape of infected shrimp, spills or losses during transport to shrimp processing facilities, disposal of pond sediment or solid waste, or through infected bait shrimp. Wild shrimp may be most susceptible to these exposures during certain critical time periods (see section 3.2). Wild penaeid populations are most dense during immigration of postlarvae (e.g., usually spring and early summer) and emigration of juveniles (e.g., later summer into fall). In addition to these spatial and temporal relationships, other important factors in assessing potential exposures to native shrimp species include the volume of effluent discharges from shrimp farms and processors, as well as disinfection and quarantine procedures used in these facilities. Infected wild shrimp may contaminate aquaculture stocks through the use of infected wild broodstock and postlarvae or from contaminated materials entrained in local water supplies.

Data Gaps:

- **Water exchange with natural waters - protocols for aquaculture operations, water treatment, etc.**
- **Number and size of U.S. aquaculture operations in relationship to receiving waters/habitats harboring native shrimp**
- **Volume, disposal patterns, and treatment for solid wastes from aquaculture**
- **Estimates of the extent of virus contamination of feed, broodstock/seed, vehicles, and birds/animals that could transport virus**

3.2.2 Shrimp Processing

Historically, the shrimp processing industry in the Gulf of Mexico and southeastern U.S. Atlantic coastal area has been a seasonal industry. Shrimp were generally caught in the spring, summer, and fall of each year and were either frozen as green headless shrimp, or canned. They were held through late fall, and as supplies diminished during the winter months, the shrimp were marketed at a premium price. Most of the processing facilities were located adjacent to the fuel and ice docks that supported the fleets, so that during the fishing season the shrimp catch could be off loaded, the boats refueled, iced, and returned to the fishing grounds as quickly as possible. This arrangement cut down on costs and the time required to transport and handle the catch.

Processing plants were generally located on a waterway and any processing wastes, both solids and liquid, were discharged directly into the adjacent waters. During the late '70's, it was recognized that due to waste volume and seasonality, the biochemical oxygen demand (BOD) levels in the processing wastes imposed too great a burden on receiving waters (i.e., because discharges were greater during spring and summer months when light intensity, ambient water temperatures, and biological productivity are higher). To reduce BOD levels, methods were developed to screen out the solids (i.e., heads and shells). After screening, solids were either disposed of in a landfill, or were dried and processed into a shrimp meal or feed, and the remaining process wastewater was discharged directly into local waters. In recent years, efforts have been underway in the southeast to route process effluents through some type of treatment facility before discharge. Because of irregular effluent volumes, the large area over which plants are distributed, and the seasonality of the processing industry, it has been difficult to build treatment facilities to accommodate the needs of this industry.

Increasing demand for shrimp in the U.S. (section 2.1) has had a major impact on the operation of shrimp processing facilities. Prior to about 1955, imports of foreign shrimp were negligible, and processing plants mainly relied on locally produced wild shrimp for their raw product. However, during the 1960's and '70's, U.S. shrimp imports rose dramatically along with increasing market demand. There are approximately 400 firms in shrimp-related industries located along the Gulf of Mexico, and two-thirds (268) of these are located in Louisiana and Texas. These plants are generally larger than those in the past and are in production year round.

Currently, there are over 60 countries exporting both pond-raised and wild shrimp to the U.S. Over one-half of the shrimp processed in the U.S. is imported from Thailand, India, and numerous other countries where viral diseases are a major problem. Some countries harvest shrimp during the early stages of a disease outbreak in order to minimize disease effects on cultured shrimp yield. This strategy effectively avoids high mortality and catastrophic economic losses in those countries, but increases the likelihood that shrimp imported into the U.S. will be contaminated with viable virus particles (Lightner, 1996a, 1996b). In fact, shrimp infected with WSSV, YHV, and TSV have been identified in retail stores in the U.S. (Lightner, unpublished data). Thus, the importation of infected shrimp for processing by the U.S. shrimp industry significantly increases the potential for the introduction of pathogenic viruses into coastal waters adjacent to the processing plants. This pathway may pose a significant threat to wild shrimp populations.

Infected shrimp processed in the U.S. may infect wild shrimp via solid wastes, effluents, bait shrimp, and infected material from processing used in shrimp and fish feed (figure 9). For example, solid wastes from processing facilities are often processed into meal at low temperature (i.e., not sufficient to inactivate pathogenic viruses). This meal is added as a protein source to shrimp feeds. If this contaminated feed is used for animals in aquaculture, and wastewater containing pathogenic viruses from culture facilities is discharged into local receiving waters, local wild shrimp stocks may be at risk from this pathway. Shrimp processing wastes containing viable viruses could also result in the infection of aquaculture facilities through one of the entry mechanisms shown in figure 8. Important factors modifying potential exposures include facility location, seasonal patterns and varying volumes of effluent discharges, the source of potentially

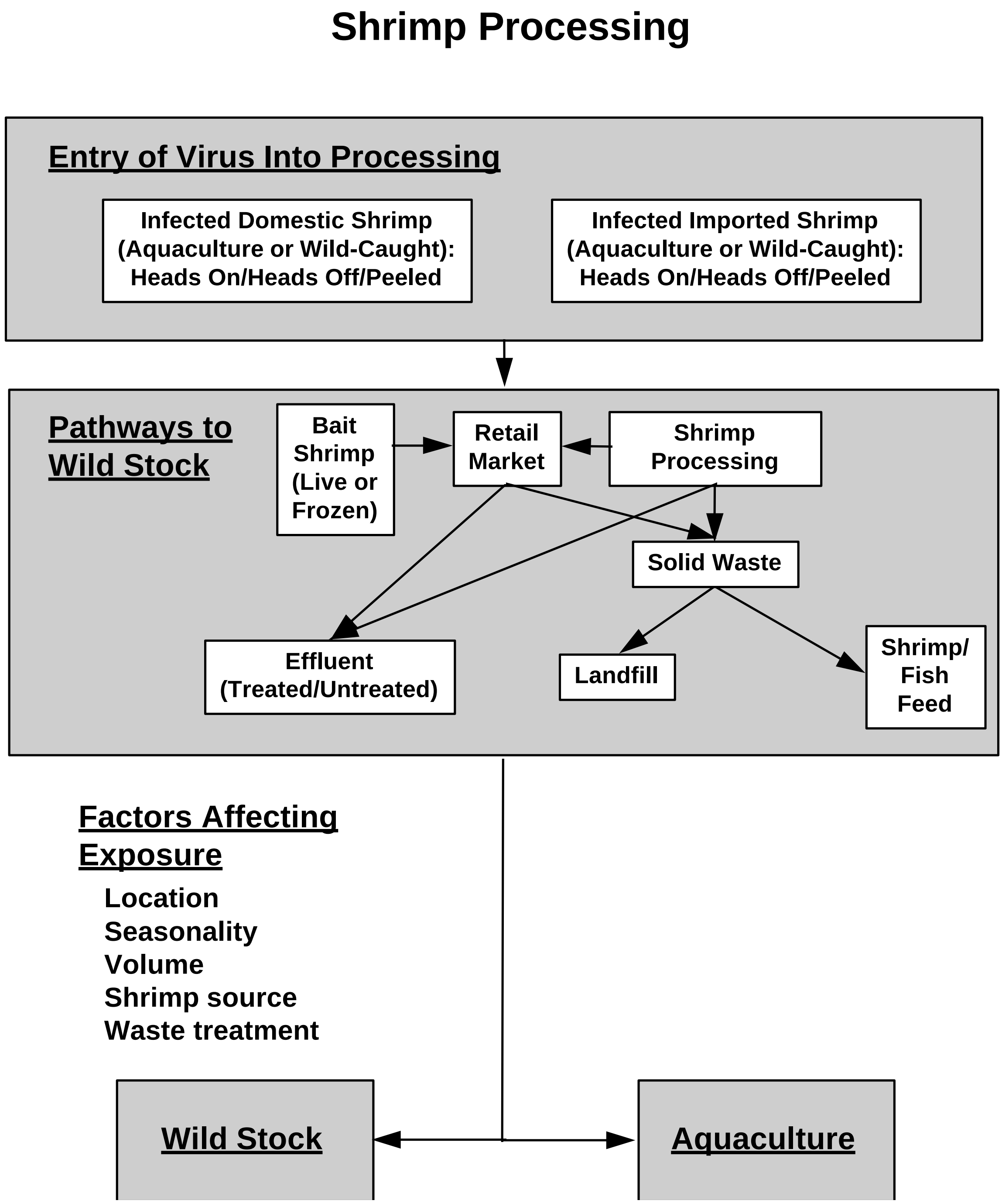

Figure 9. Conceptual model: virus sources and pathways for shrimp processing

contaminated shrimp for processing, and waste treatment procedures used are important for evaluating risks to native shrimp populations.

An approach for controlling potential sources of virus exposure from processing facilities is to apply concepts developed for preventive food safety (Hazard Analysis Critical Control Point program; NACMCF, 1992). A logical extension of this preventive approach could be used to identify specific sources of exposure that may occur during shrimp processing and develop control measures to prevent significant exposures.

Data Gaps:

- **Volume, disposal patterns, and types of treatments for shrimp processing effluents and solid wastes**
- **Number and size of shrimp processing facilities in relationship to receiving waters/habitats harboring wild shrimp**
- **Estimates of the extent of virus contamination of shrimp received for processing**
- **Extent and distribution of contaminated shrimp in retail seafood markets and disposal patterns**
- **Presence of virus in fish and shrimp feed**

3.2.3 Other Sources/Pathways

During preliminary discussions leading to the development of this report, the Shrimp Virus Work Group identified several other virus sources/pathways to wild shrimp. The Shrimp Virus Work Group felt that a risk assessment should focus on the two major sources described above, but it is also important to recognize the potential risks associated with these other less significant sources/pathways.

Bait Shrimp (live or frozen). Pathogenic viruses may be found in infected bait shrimp that could contaminate wild stocks through use in recreational and subsistence fishing. The bait shrimp industry is integral to and is a significant segment of the U.S. shrimp fishery that supports a large and economically-important sportfishing industry in the southeastern United States. For example, in Texas alone, about 1786 bait shrimp licenses were issued in 1996 (Robinson et al., 1996). Bait shrimpers generally target small shrimp in the shallow, muddy estuarine nursery areas. These small shrimp are usually trawl caught (Baxter et al., 1988: Salomon, 1965), kept alive with recirculated seawater on board ship, and are delivered to shore-based facilities, where they are kept in recirculated seawater tanks while being held for sale. Because the demand for bait shrimp is high, especially when local shrimp supplies are limited, many bait shrimpers haul live shrimp between bays within a state or across state lines. This practice could result in the movement of contaminated shrimp from one area to another.

At certain times of the year, the demand for bait shrimp has been so great that suppliers to the recreational fishery have had to depend on imported shrimp to meet the demand. Because these imports may be contaminated with viruses, their use as bait shrimp could provide a potential pathway for the introduction of pathogenic viruses. When contaminated bait shrimp are discarded, wild stocks feeding on these discards could be vulnerable to infection, especially during the spring and summer when postlarval shrimp are immigrating into coastal nursery areas. If the shrimp culture industry expands to meet the needs of the bait shrimp industry, cultured bait shrimp represent another potential pathway for introducing pathogenic viruses into wild shrimp populations.

Ballast Water. The transport of live shrimp in ballast water is well documented (Carlton and Geller, 1993; Williams et al., 1988; see section 3.4). It is estimated that 25 or more species of shrimp have been released to U.S. surface waters from ship ballasts. There is no accurate estimate of the number of shrimp species that, through the movement of ballast water, may have been established worldwide. While many of these shrimp establishments may have been overlooked, a few well-documented records include the Indonesian shrimp (*Exopalaemon styliferus*) from Indonesia/India introduced to the Arabian Gulf; the Korean shrimp (*Palaemon macrodactylus*) introduced to California, Oregon, and Australia; the Asian shrimp (*Exopalaemon modestus*) introduced to the Columbia River in Oregon; the Japanese shrimp (*Salmoneus gracilipes*) introduced to California; and the Atlantic shrimp (*Hippolyte zostericola*) introduced from U.S. Atlantic coast to Colombia, South America (Carlton, Pers. Comm.). The introduction of pathogenic viruses may be possible with the establishment of these new species.

Introduction of pathogenic shrimp viruses to wild stock may result even if exotic shrimp species originating in ballast water do not become established. For example, diseased, dead, or dying shrimp discharged from ballast may be eaten by or come in contact with wild crustaceans. Ballast water can be a source of a mix of crustacean species (e.g., crab larvae, amphipods, and isopods), and some of these may not normally co-occur in nature. The possibility of viral transmission from one crustacean species to another may be amplified under these conditions.

Research and Display. Pathogenic viruses may be unwittingly released in association with wastes, feed, or organisms from research activities at public agencies, universities, or large public aquaria, or by discarded ornamental cultures of shrimp or other crustaceans. Many of these facilities are located in coastal areas in proximity to habitat for wild shrimp populations. Proper quarantine or disinfection procedures for new or exotic organisms (i.e., especially those known to carry pathogens) are critical for preventing the release of pathogenic organisms, but the extent of these procedures varies greatly among research and display facilities.

Non-Shrimp Translocated Animals. Animals other than shrimp may carry viruses that could infect shrimp populations (see section 3.7). Potential pathways for viral entry include international, national, or regional transport of infected live animals, bait, or feed materials. Important factors affecting exposure to wild shrimp include location, seasonality, the number of animals, and the proximity of their habitat relative to wild shrimp. All but the most basic information is unavailable for evaluating the potential exposures these animals represent to wild shrimp.

Natural Spread. While this report considers the importance of anthropogenic pathways for the introduction of pathogenic viruses to wild shrimp, it is possible that the spread of a virus could be enhanced by natural processes. Examples include movements by large scale water currents, hurricane or flood events, and translocation by birds or other animals. Little information is available on this potential pathway for exposure to pathogenic shrimp viruses.

Two other sources are considered less important than the preceding sources: fishing vessels and intentional introductions. When fishing vessels based in U.S. ports return from foreign waters, their nets and other equipment may be contaminated with organisms or materials that harbor pathogenic shrimp viruses. While intentional introduction of a virus is possible, it is not considered likely, and it would be difficult if not impossible to predict or control.

3.3 Viral Stressors

The conceptual model (figure 6) shows types of stressors affecting wild penaeid shrimp populations. This report focuses on four disease-causing viruses: IHHNV, TSV, WSSV, and YHV. There are many other viruses as well as other organisms such as bacteria, fungi, and commensal organisms that may cause disease in shrimp. For each virus, this section describes available information on the following topics: virus taxonomy, where first identified, infectivity, virulence and resistance, transmissibility and carrier status, host range, geographic distribution, and disease symptoms and detection methods.

Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) is a small (20-22 nm), single stranded DNA virus belonging to the Parvovirus group. This disease was first described by Lightner et al. (1983a, 1983b) in postlarval *P. stylirostris* and *P. vannamei* isolated from aquaculture facilities in Hawaii. IHHNV is a highly lethal disease, causing up to 90% mortality in affected populations of susceptible *P. stylirostris*. Some members of the population that survive IHHNV infections and/or epizootics are apparently carriers, passing the virus to progeny and other populations (Lightner, 1996b).

IHHNV has been documented in wild species of shrimp including *P. stylirostris*, *P. vannamei*, *P. occidentalis*, *P. californiensis*, *P. monodon*, *P. semisulcatus*, and *P. japonicus*. All three species (*P. setiferus, P. aztecus*, and *P. duorarum*) native to the U.S. have been infected experimentally (Lightner et al., 1985).

IHHNV is widely distributed in aquaculture facilities in both the Americas and throughout Asia. It is assumed to be enzootic (i.e. endemic) in wild penaeids in the Indo-Pacific and Ecuador. In the Americas, IHHNV has been found in wild penaeids in Ecuador, western Panama, and western Mexico.

Clinical symptoms of IHHNV are not specific. Juvenile *P. stylirostris* show reduced food intake and other behavioral changes. There are buff-colored lesions in the cuticular epidermis.

P. vannamei display runt deformity syndrome, including cuticular deformities. A gene probe (definitive diagnostic method) is available commercially.

Taura Syndrome Virus (TSV) is a small (28-30 nm), single-stranded RNA (ssRNA) virus, belonging to the Picornavirus group (Hasson et al., 1995). The disease, also variously described as Red Tail or Blackspot disease, was originally reported in mid-1992 in cultured *P. vannamei* near the Taura River, Ecuador. This first outbreak resulted in catastrophic mortalities of 80 - 90% of young *P. vannamei*. TSV has been identified in live shrimp postlarvae and brood stocks in hatcheries. TSV has also been identified in seagull feces and water boatmen.

Numerous shrimp species native to the western hemisphere, including the U.S., are susceptible to TSV under experimental conditions. All three species native to the U.S. (*P. setiferus, P. aztecus* and *P. duorarum*) have been infected experimentally (Lightner, 1996a, 1996b; Overstreet et al., 1997). Once infected, *P. setiferus* experiences heavy mortality.

TSV disease has reportedly spread throughout aquaculture facilities located in the Western Hemisphere including Peru, Colombia, Honduras, Guatemala, El Salvador, Brazil and western Mexico (Lightner, 1996a, 1996b) and has been documented in wild postlarval and adult *P. vannamei* from near-shore and off-shore fisheries in Ecuador, El Salvador, and off the Mexican state of Chiapas near the border of Guatemala. It has also been reported in U.S. aquaculture and hatchery facilities in Hawaii, Florida, Texas, and South Carolina (Lightner, 1996a, 1996b).

Gross signs of the disease are red tails and/or appendages, cuticular necrosis, soft shells, and cuticular black spots. Positive identification of acute but not chronic infections can be made through histological examination. Chronic infections can be diagnosed by bioassay with SPF *P. vannamei* or by commercially available gene probe. Definitive diagnostic methods are available and include a gene probe and PCR (polymerase chain reaction). TSV has been identified by bioassay in imported frozen shrimp (Lotz, Pers. Comm.; Lightner, In Press).

White Spot Syndrome Virus (WSSV), a non-occluded baculovirus, is a medium size (100-290 nm), double-stranded DNA virus. The disease, also variously described as Red Disease, China Virus Disease, and Shrimp Explosive Epidemic Disease, was first identified in 1992-93 in China and Taiwan. Where it has been confirmed, WSSV has caused mass mortalities reaching 90-100% in several species of shrimp in aquaculture. This virus has been shown to infect a number of other crustacean species (e.g., amphipods, ostracods, swimming crabs, crayfish, copepods, and shore flies), some of which have transmitted the disease into Asian penaeid aquaculture facilities (Chang et al., In Press a, In Press b; Lo et al., 1996; Wang et al., 1995; Wang et al., In Press, Lan et al., 1996; Flegel et al., 1996). The infection of numerous non-shrimp species and other crustaceans raises concerns that these organisms could act as a reservoir, or intermediate host, presenting a possible pathway to infect not only native shrimp, but also other native marine and freshwater species (see potential effects, section 3.7).

All native U.S. species of shrimp are susceptible to WSSV under experimental conditions (Lightner, 1996a, 1996b). WSSV infects and causes disease in many foreign species of shrimp including *P. monodon, P. semisulcatus, P. merguiensis, P. indicus, P. chinensis, P. penicillatus,* and *P. japonicus*. Outbreaks were recorded in 1994-95 in Thailand, India, Japan, and Korea. WSSV is now believed to infect shrimp farms throughout east Asia, Southeast Asia, Indonesia, India and was reported in Texas in November 1995.

Clinical signs of the disease include a red color to the entire body and appendages along with small subcutaneous white spots. Histological examination reveals prominent intranuclear inclusion bodies in cuticular epithelium, subcutis and connective tissues. Definitive diagnostic techniques have been developed, and include a gene probe and PCR hybridization. WSSV has been identified by bioassay, gross examination, and PCR in imported frozen shrimp products in retail stores in the U.S. (Lightner, In Press; see section 3.2.2).

Yellow Head Virus Syndrome (YHV) is a small to moderate size (44 x 173 nm), ssRNA rhabdo-like virus. The virus was first reported in aquaculture operations of the tiger prawn shrimp (*P. monodon*) in Thailand in 1992. YHV is widespread in cultured *P. monodon* and is suspected as the causal agent of major losses of cultured shrimp production in Taiwan, Indonesia, China, and the Philippines in the late 1980's (Lightner, 1996b).

Juvenile shrimp are apparently the most vulnerable to YHV infection, although earlier and later stages appear to be somewhat resistant. Thus, juvenile stages of *P. setiferus*, *P. aztecus* and *P. duorarum* can be infected experimentally with YHV, although their postlarval stages appear to be resistant (Lightner, 1996b). However, all stages of live shrimp in aquaculture, including nauplii, postlarvae, and broodstock may be carriers of YHV. Asymptomatic YHV carriers were identified in shrimp from Australia, as well as in shrimp showing signs of WSSV disease in Thailand, India and Texas (Lightner, 1996b). YHV has also been found in *P. merguiensis* and *Metapenaeus ensis* in Australia. YHV has been experimentally transferred to *P. vannamei*, *P. stylirostris,* and *P. setiferus,* and has been detected in the carrier state in *Acetes* sp. (krill) and *Palaemon styliferus* (mysid shrimp), both ecologically important species in marine environments. The ability of YHV to infect a number of other genera and species is a warning that YHV could pose a problem to other U.S. marine crustaceans (see section 3.7).

By 1994, YSV had also been identified in India, Malaysia, and Indonesia. In November 1995, YSV was found in aquaculture operations in Texas.

The most obvious clinical sign of the disease is the yellow coloration of the shrimp's head. Histological examination reveals generalized necrosis of lymphoid organs, and connective tissues and cuticular epidermis, with cells showing pyknosis and cytoplasmic inclusions. Available diagnostic techniques include histology, electron microscopy, and bioassay. YHV has been identified by bioassay in imported frozen shrimp (Lightner, In Press).

Data Gaps:

- **Temporal and spatial distributions of wild penaeid shrimp relative to the viruses**
- **Concentrations, frequency, duration, location, and environmental medium of the viruses**
- **Species-specificity of the viruses**
- **Alternative hosts of the viruses**
- **Infectivity, transmissibility, and virulence of viruses**
- **Persistence of viruses in different environmental media**
- **Extent and rate of spread of the viruses among wild shrimp populations**
- **Analogous information from other introductions of exotic diseases**
- **Potential for immunity/resistance and length of any immunity**
- **Carrier status of surviving infected shrimp**

3.4 Other Anthropogenic Stressors on Wild Shrimp Populations

Although this report focuses on the potential effects of pathogenic viruses on wild shrimp populations, other factors acting alone or in conjunction with shrimp viruses may also have detrimental effects. These include natural environmental factors (see section 3.5) as well as other anthropogenic (i.e., human-introduced) stressors such as hypoxia (i.e., low dissolved oxygen), coastal wetland habitat modification, harvesting practices, and the introduction of exotic species. The potential risks from combinations of multiple stressors are also considered.

Hypoxia. Recently, evidence of an increasing area of hypoxia (up to 9500 km^2 in 1993) has been documented, extending west from the mouth of the Mississippi River, along the coast of Louisiana, and into the Gulf of Mexico (Rabelais et al., 1996, U.S. EPA, 1996b). The extent of this hypoxic area varies in both temporal and spatial extent, depending upon environmental and meteorological conditions. These large-scale hypoxic areas are rich in nutrients that can promote phytoplankton blooms. Some of these blooms may create toxic byproducts that could have deleterious ecological impacts.

Because these hypoxic areas often overlap with fishing grounds for both white and brown shrimp (Zimmerman et al., 1996), their potential effects on wild shrimp populations cannot be disregarded. Laboratory studies have shown that penaeid shrimp avoid hypoxic waters (Renaud, 1986a), and field evidence has documented lower shrimp population densities in hypoxic coastal areas (Renaud, 1986b). Recent studies suggest that shrimp landings are negatively affected in areas of hypoxia; shrimp apparently concentrate in near shore areas between the area of hypoxia and the shoreline. This inshore concentration of migrating shrimp near shore-based sources of virus may increase their potential for exposure to disease. Zimmerman et al. (1996) found that diminished catch appeared to extend offshore beyond the hypoxic area, suggesting that these areas may block critical zones through which shrimp migrate.

Habitat Modification. Although the effects are largely unknown, loss of coastal wetland habitat can affect the shrimp populations which utilize them. Juvenile shrimp spend a significant portion of the life cycle in coastal wetland areas, where they grow and develop to high densities (Fast, 1992). These areas of critical habitat, however, are under increasing pressure due to coastal development, levee construction, channelization, and dredge spoil sediment disposal.

Consider, for example, the state of Louisiana. Since 1930, Louisiana has been particularly hard hit by coastal development and habitat modification. Because of man's activities (e.g., marsh inundation, erosion, and such human interventions as construction of canals, levees, and dikes), the state has lost wetland areas amounting to 3950 km^2 (Boesch et al., 1994). As a result of coastal habitat modification, saltwater intrusion has occurred in some areas. The effects of saltwater intrusion, both positive and negative, on migratory fishery fauna (i.e., including shrimp) have been documented elsewhere (Rogers et al., 1994; Herke et al., 1996: Rozas, 1992; and Rozas and Reed, 1994).

Evidence suggests that marsh edge (i.e., marsh to open water interface), which is important as a source of food, substrate for growth and development, or refugia to avoid predators, is utilized extensively by juvenile shrimp (Minello et al., 1994). Eroding salt marshes have greater available edge; thus, it is thought that coastal development may, at least initially, result in increased shrimp population levels. At some critical threshold however, shrimp populations will be detrimentally affected by increasing losses of critical habitat.

The indirect effects of habitat modification on other ecologically important species may also be significant. As losses become more extensive and as wetland areas become more highly fragmented (or disappear altogether), non-shrimp species that depend on shrimp as a food source may also be severely impacted.

Harvesting Practices. The possible negative effects of shrimp harvesting practices on population levels in Gulf of Mexico and the southeastern U.S. Atlantic coastal waters has been discussed since the early 1930's (Higgins, 1938). Although catch and fishing effort, as well as landings, have increased over the years, catch per unit effort (i.e., yield) of the major shrimp species has not shown a significant decline (Nance and Nichols, 1988). There are several possible explanations for the lack of decline in shrimp yield. These findings assume an annual shrimp crop, but some shrimp live longer than one year, thus increasing the reproductive potential of the population. Also, given the tremendous fecundity of adult shrimp, population levels seem to depend less on adult survival than on many critical environmental factors affecting young shrimp. Environmental factors such as the salinity and temperature of coastal waters, and predation by other organisms, appear to have a greater influence (i.e. higher mortality rates) on the survival of the larval and juvenile shrimp than do current fishing practices.

Introduction of Exotic Species. It is well documented that the introduction, establishment, and spread of non-indigenous species in fresh, estuarine, and marine environments, have had adverse environmental effects (OTA, 1993; NOAA, 1994; EC, 1993; and NEMO, 1994). Data from around the world clearly indicate that the current rate of movement and establishment of exotic organisms in marine and estuarine environments is unprecedented. Changes in the ecological structure and function of estuarine habitats have resulted from such exotic introductions.

In estuaries that have been monitored carefully over time, the establishment of exotic species has caused extensive changes in species composition and structure (Cohen and Carlton, 1995). For example, in San Francisco Bay, exotic species account for 40% to 100% of the common or dominant species in benthic and fouling communities measured at various sites throughout the estuary (Cohen, 1996). One species, the Amur River clam (*Potamocorbula amurensis*) was first detected in San Francisco Bay in October 1986. By the summer of 1987 (nine months later), the Amur River clam had become the most abundant clam in San Francisco Bay, attaining densities of 2,000 clams per square foot. Because the clam can completely filter a volume of water equivalent to the entire bay every few days, it can deplete the phytoplankton that form the base of the food web for many native fish and marine mammals (Cohen, 1996).

Impacts on shrimp populations due to introduced species, could be either direct or indirect. An exotic species may affect the shrimp population directly, as a predator, parasite, or pathogen of shrimp, or as a carrier of parasitic or pathogenic organisms. However, the most damaging exotic species have been those that resulted in indirect ecological effects through habitat alteration. Examples include the zebra mussel (*Dreissena polymorpha*) in the Great Lakes and the ctenophore (*Mnemiopsis leidyi*) in the Black Sea, two of the most devastating exotic invasions of the 20th century.

The ecological structure and function of Gulf of Mexico and southeastern U.S. Atlantic coastal waters are currently threatened by the establishment and spread of many exotic invertebrates (e.g., barnacles, sea squirts, anemones, crabs, and wood-boring crustaceans), seaweeds, and green algae. Problems specific to southeastern U.S. Atlantic coastal areas include the recent establishment of the Japanese shore crab (*Hemigrapsus sanguineus*) and the Indo-Pacific swimming crab (*Charybdis helleri*). The shore crab may threaten salt-marsh ecosystems through its extensive burrowing activity (Geller, 1996), while the swimming crab is a potential competitor of the economically-important blue crab. The Indo-Pacific swimming crab has become established along the Gulf of Mexico. In addition, the exotic brown mussel (*Perna perna*) is quickly spreading along the Gulf Coast, where it has shown the potential to displace native species and has already caused fouling of offshore oil platforms and navigation buoys.

Multiple Stressors. The interactive effects of multiple environmental stressors, both natural environmental parameters and anthropogenic stressors, are very difficult to predict, but may be substantially greater than might be predicted based on an analysis of the individual factors. When any of these environmental stressors are present, either singly, or in combination, the effects on resident populations may be severe. For example, man-made alterations in marsh habitat can alter many important environmental parameters resulting in adverse environmental conditions (e.g., higher temperatures, absence of cover, altered species composition). As the area of marsh available to the species is decreased, both food supply and cover are reduced; thus, increasing the likelihood of predation and disease. Physiological stress imposed by multiple environmental stressors (e.g., hypoxia, habitat modification, exotic introductions, and harvesting practices) acting on individual wild shrimp may increase their susceptibility to, as well as the effects of, infection by pathogenic viruses.

Data Gaps:

- **Relationship between stress and disease susceptibility in shrimp**
- **Evaluating the effects of interactions among multiple stressors**

3.5 Environmental and Ecological Factors Regulating Wild Shrimp Populations

Wild shrimp population dynamics (e.g., mortality, growth, reproduction, and movement) are regulated by environmental and ecological factors (see also section 3.6). Predation is a major ecological regulator of mortality in wild juvenile penaeids (Minello et al., 1989; Minello and Zimmerman, 1991). Changes in environmental factors such as temperature or salinity may be adverse during certain critical life stages (e.g., juvenile stages in the marshes). Species differ, however, in their responses to changes in these environmental factors. For example, white shrimp juveniles tolerate warmer temperatures, but are stressed by temperatures less than 18^{o}, as indicated by decreased growth and survival in laboratory studies.

When changes in environmental factors occur in combination, interactions among stressors may be extremely important (Zein-Eldin and Renaud, 1986). Exposure to extremes of a single factor may be tolerated, however, combinations may be adverse or even lethal. Under these conditions, exposure to additional stressors such as hypoxia, habitat loss, etc., may predispose the animals to infection or disease.

3.6 Shrimp Life History and Ecology

Understanding the life history and ecology of penaeid shrimp is critical for evaluating their exposure to pathogenic viruses as well as the ecological effects of disease on shrimp populations. The life histories of penaeids worldwide are similar, although species differ in distribution, seasonality, and response to various environmental factors. Three penaeid shrimp species are of principal importance to the U.S. commercial fishery: the white shrimp *(P. setiferus*), the brown shrimp, (*P. aztecus*) and the pink shrimp, (*P. duorarum*).

The three species are discontinuously distributed from New Jersey to the Florida Keys, and along the coasts of the Gulf of Mexico from Florida through Texas, and into eastern Mexico (Lindner and Cook, 1970). The white shrimp fishery does not occur along the south and west coasts of Florida, but occurs again around the northwestern and western Gulf as far south as Tampico, Mexico (figure 10). The white shrimp, the principal species in the south Atlantic, is a daytime fishery, usually in waters less than 27 m (Lindner and Anderson 1956).

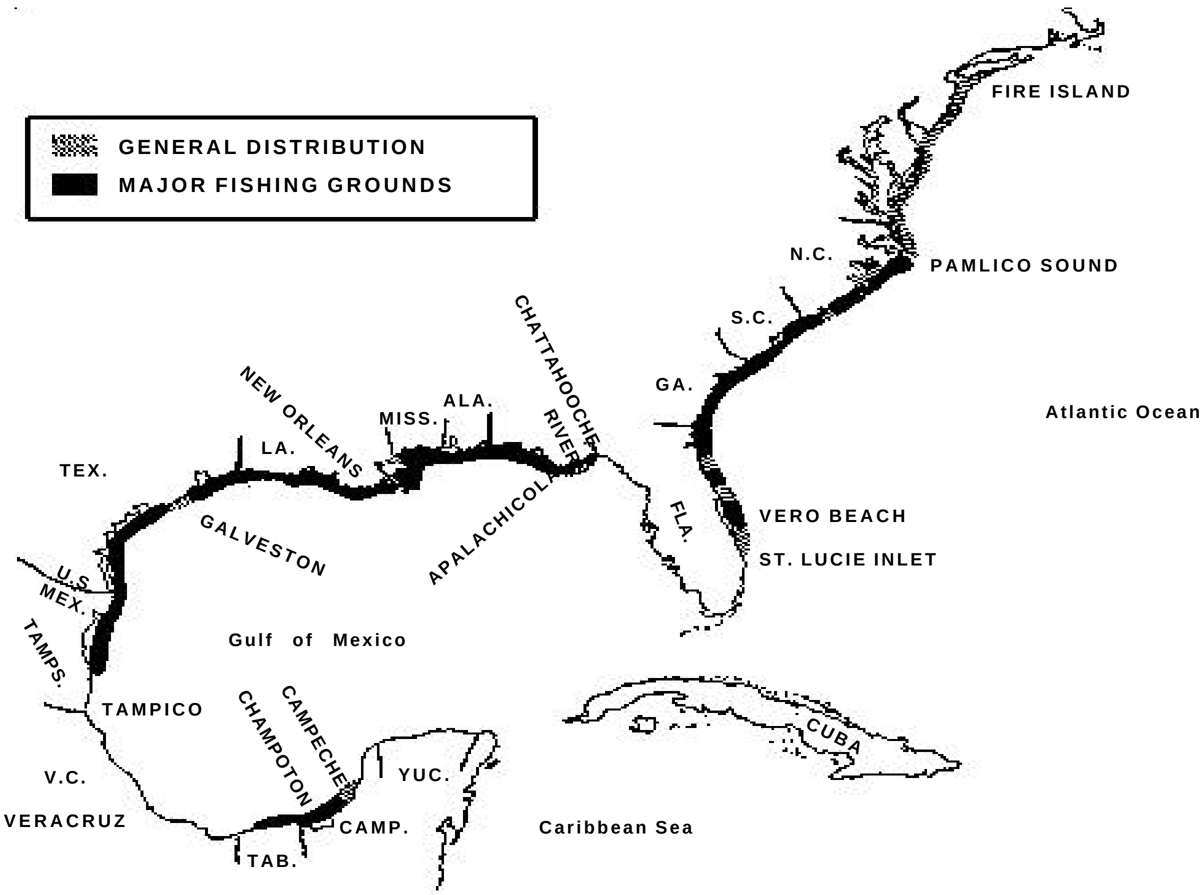

Figure 10. Distribution and major fishing areas for the white shrimp, *P. setiferus*.

The brown shrimp, the most important U.S. commercial species, occurs as far north as Martha's Vineyard, and south to Florida. It is found in the Gulf of Mexico along the panhandle of Florida, and westward as far as Campeche, Mexico (Cook and Lindner, 1970); however, major fishing areas are off the coasts of Texas and Louisiana (figure 11). Compared to the white shrimp, it is a night fishery, at distances farther offshore (up to 198 km) and at greater depths (up to 110 m) (Temple and Fischer, 1967).

Of the three species, the pink shrimp has the most limited distribution, and the smallest fishery. It is fished to some extent off North Carolina and the northeast coast of Florida, but is the major species from Sannibel along the Florida Keys (Costello and Allen, 1970). Most of the pink shrimp found in the western Gulf of Mexico range from south Texas to Campeche, Mexico (figure 12). Like brown shrimp, pink shrimp are caught at night.

The sexually mature adults of all species are present in offshore, more saline waters. Spawning, followed by hatching and completion of a complex larval development process, occurs at various distances offshore (Renfro and Brusher, 1982). All larval stages differ morphologically, and include five naupliar, three protozoeal, and three mysis stages. Depending on the season (Temple and Fisher, 1967; Brusher, Renfro and Neal, 1972), all larval stages usually occur at fairly low densities (less than 1 /m^3; Temple and Fisher, 1965) in offshore waters near their spawning grounds.

The bulk of white shrimp spawn in waters less than 27 m deep (Lindner and Anderson, 1956), brown shrimp spawn in deeper waters (up to 110 m), and pink shrimp generally spawn in waters between 15 and 48 m. The dense eggs sink to the bottom, where they hatch within hours. Pelagic development is usually rapid, but occurs at a rate dependent upon temperature.

Early postlarvae (less than 10 mm total length) are transported by currents and tidal action onto the beaches, and enter through coastal passes into estuaries and marshes. Densities at time of entry vary considerably, from day to day, within a single 24-hour period, vertically in the water mass (Baxter and Renfro, 1967; De Lancy et al., 1994; Duronsolet, et al. 1972; King, 1971; Matthews et al., 1991), and especially with season. Concentrations of entering postlarvae greatly exceed those of offshore stages. For example, during 1960 to 1963, Baxter and Renfro (1967) recovered between 50 and 100 postlarval brown shrimp/m^3 from the Galveston Bay entrance between late February and early April (i.e., period of maximum immigration for that species). Higher densities of brown shrimp have been reported; 2000 brown postlarvae/m^3 were recorded in the same area following an early spring “norther” that kept postlarvae on the ocean beach fronts rather than allowing them to enter through the passes (Matthews, Pers. Comm.). Brown shrimp postlarvae (11-13 mm total length), thought to be from late fall spawns of adult brown shrimp (Temple and Fischer, 1965) arrive earliest in the year. Depending upon water temperature and currents, brown shrimp postlarvae enter the estuaries as early as late February and early March (Baxter and Renfro, 1967), peaking in March and April. Brown postlarvae continue to enter the passes in waves throughout the spring. A second peak of somewhat smaller

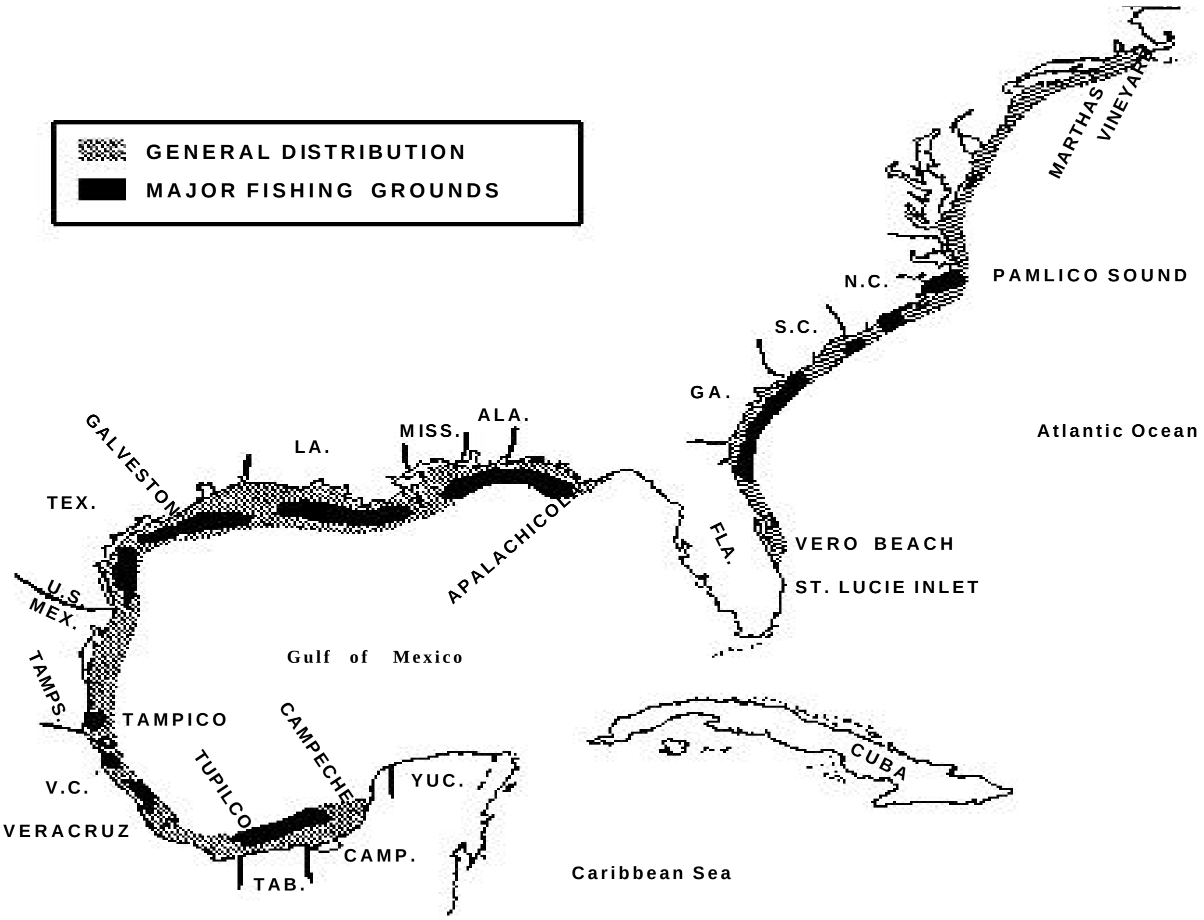

Figure 11. Distribution and major fishing areas for the brown shrimp, *P. aztecus*

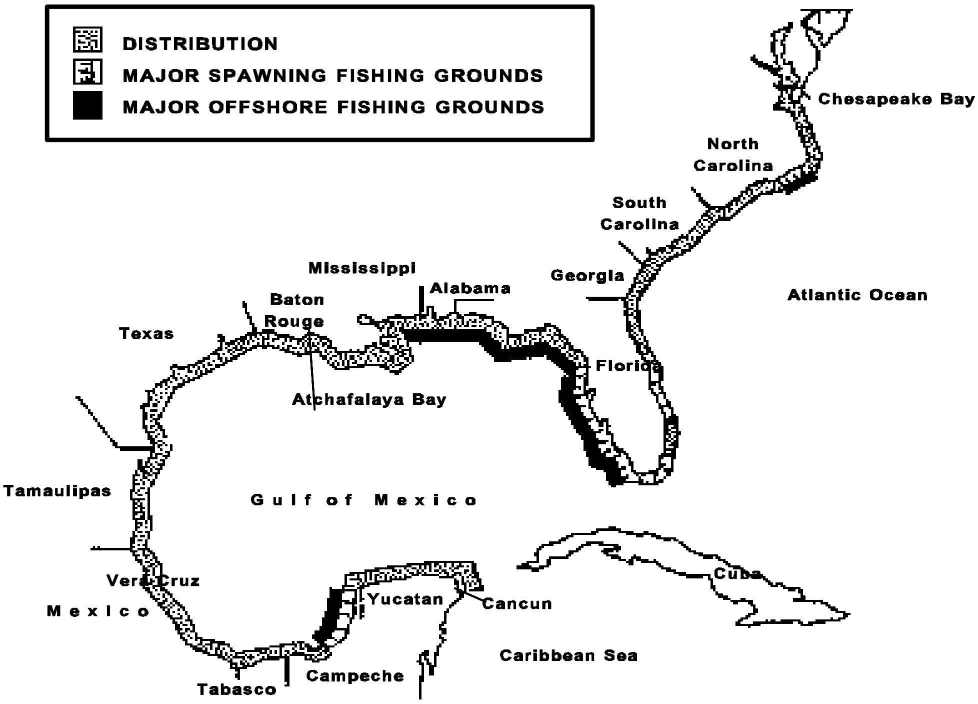

Figure 12. Distribution and major fishing areas for the pink shrimp, *P. duorarum*

(about 10 mm total length) postlarvae occurs in late summer, and rarely results in more than 10 postlarvae/m^3.

Early brown postlarvae are usually longer (10-12 mm) and heavier than those entering subsequently, and are more tolerant of low temperature, suggesting acclimation to colder offshore temperatures. Laboratory studies have shown that growth in brown shrimp postlarvae occurs at temperatures below 20^o C (from 11 to 18^o C in the laboratory; Zein-Eldin and Aldrich, 1965). In contrast, at temperatures 20^o C and above, growth can be expected among the estuarine shrimp population as a whole.

The white shrimp appear to have a shorter spawning season than the browns. Mature white females are found (May through summer) in near shore waters less than 3 m. Postlarval white shrimp do not immigrate (enter the bays) until mid-May to June and continue to enter the estuaries throughout the summer. White shrimp postlarvae were recorded in numbers greater than 100/m^3 only once in more than 400 sampling days at the Galveston Bay entrance (Baxter and Renfro, 1967). In contrast to both the brown and white shrimp, pink shrimp postlarvae enter the estuaries continuously throughout the spring, summer, and into autumn, with peaks in April through June in south Florida (Tabb et al., 1962; Allen et al., 1980) and somewhat later in North Carolina (Williams, 1959). Their numbers increase again in late fall.

Postlarvae rapidly become benthic and, as juveniles, brown shrimp are present in large numbers (densities up to 43/m^2) in the marshes from March through July (Zimmerman et al., 1984; Zimmerman and Minello, 1984). White shrimp, present later in the season, may exhibit densities as high as 115/m^2 (Zimmerman et al., 1984). The growth and development of all three species during this estuarine-marsh stage are rapid, but are affected by temperature and salinity, the presence of desired food, cover (e.g., sea grasses), substrate type, and the presence of predators (Zein-Eldin and Renaud, 1986).

Zimmerman and Minello (1984) reported that juvenile brown shrimp appeared to select for vegetation, but white shrimp present during the same summer periods showed no significant preference. In fact, during the estuarine portion of their life cycle, postlarval and juvenile white shrimp are relatively evenly distributed throughout the estuary, on both vegetated and non-vegetated bottom. Consistent with Zimmerman and Minello, various studies have shown that brown shrimp, the more carnivorous of the species, prefer marsh edges *(Spartina* sp.; Zimmerman et al, 1984), where they can graze on nematodes, amphipods and other benthic fauna (McTigue and Zimmerman, 1991; Gleason and Wellingon, 1988; Gleason and Zimmerman, 1984). The distribution of pink shrimp appears to be determined by the presence of sea grass, as well as the type of available substrate (i.e., coarse sand-shell substrate, Williams, 1960).

Juvenile shrimp emigrate out of the marshes for completion of their life cycle in open water. Factors controlling emigration are not well understood, although size and lunar stage (particularly for pink shrimp) are thought to be important (Costello and Allen, 1970). Juvenile brown shrimp (about 100 mm total length) emigrate to open waters from about mid-June through early August, perhaps under the influence of strong lunar tides. Brown shrimp are not reported in large numbers during the hot summer months, and have largely left the bays by the end of the summer. Laboratory studies have demonstrated that brown shrimp are less tolerant of temperatures above 30° C than are white shrimp (Zein-Eldin and Griffith, 1969). White shrimp remain until the first cold periods in fall and winter. Major emigration of white shrimp through the passes usually follows the onset of a "norther". Even then, some white shrimp remain in the bays where they overwinter until the following season.

<u>Data Gaps</u>:

- **Population models that adequately explain observed variability of wild populations**
- **Distribution and genetic diversity of off-shore populations**

3.7 Potential Effects of Shrimp Viruses

This section summarizes the potential effects of pathogenic viruses on wild shrimp populations. In addition, the possibility that widespread virus infection of wild shrimp populations may limit the availability of pathogen-free broodstock and seed for aquaculture is considered. Also, examples of possible viral effects on ecosystem structure and function are discussed. Finally, available information on related topics such as viral symptoms, infectivity, immunity, etc. are addressed in the section on virology (section 3.3).

3.7.1 Wild Shrimp Populations

The geographic distribution of IHHNV, TSV, WSSV, and YHV and other pathogenic viruses is likely to increase because of the extensive worldwide transport and trade of live shrimp and shrimp products. Although there are examples noted below of the occurrence of pathogenic viruses in wild shrimp populations in other parts of the world, the presence of these viruses has yet to be confirmed in wild shrimp found in U.S. coastal waters. Brock et al. (1996) noted that TSV has not been observed in any native U.S. species, nor has any impact of TSV on U.S. fishery stocks been reported recently. However, there is some unconfirmed, preliminary evidence of WSSV in wild shrimp and other organisms in South Carolina. Therefore, either the viruses are not present in U.S. wild stocks, or they may be present but undetected for the following reasons.

- <u>Virus surveillance has not been conducted</u>. The annual variability in wild shrimp harvests is well known, but until the recent virus-related problems in aquaculture there was no compelling reason to consider viral pathogens as a potential cause for these variations. Thus, there was no reason to search for viruses in wild populations.
- <u>Where surveillance has been conducted, population sampling methods may have been inadequate to detect low levels of virus occurring in wild shrimp populations</u>. Because of the rapid onset of viral diseases and the known intensity of predation pressures in wild shrimp populations, it is unlikely that wild shrimp showing frank symptoms of the disease would be found.

- Surveillance was conducted on shrimp, but viruses were not detected in infected shrimp. Viruses may not have been detected because methods for known viruses were not yet available, were insufficiently sensitive, or because shrimp were infected with previously unknown viruses. Until disease outbreaks are observed, research to detect a pathogenic virus is not initiated. Because of the rate of increase in the occurrence of previously unknown viruses, research to develop detection methods with the necessary specificity and sensitivity lags substantially behind the initial recognition of the problem.

It is also possible that viruses have been present at low levels in wild populations without causing observable disease incidents, but aquaculture conditions (e.g., crowding and physiological stress) potentiate the development and spread of disease.

There are several examples of the occurrence of pathogenic shrimp viruses in wild populations. In Asia, WSSV is reported to have spread from naturally-occurring organisms to shrimp in aquaculture (Chang, In Press a, In Press b; Wang, et al., In Press). Other evidence suggests that some wild shrimp species in Asia may either be infected or are carriers of virus (Chen, Pers. Comm.). In Mexico, blue shrimp (*P. stylirostris)* populations in the Gulf of California declined to levels which could not support commercial harvests until 1994, coincident with onset of IHHNV disease (Lightener et al., 1992, 1996a; Pantoja, 1993; Pantoja-Morales and Lightener, 1991). Beginning with the 1987-88 season, landings of blue shrimp decreased by about 1000 tons per year for four consecutive years. Stocks began to recover only after about six years. This is the best chronological association of disease and wild population effects currently known. The source of virus that caused the outbreak is not confirmed, but may have resulted from the release of infected cultured shrimp. In south and central America, TSV has been documented in wild stocks of *P. vannamei* (postlarvae and adults) collected from near-shore or off-shore fisheries in Ecuador, El Salvador, and the southern Mexican state of Chiapas (Lightner, 1996a). Finally, IHHNV appears to be endemic in wild penaeids in the Indo-Pacific, Equador, and western Panama, but it is not known whether there have been effects of IHHNV on wild shrimp populations in these areas.

Data Gaps:

- **Baseline information on presence and distribution of pathogenic viruses in U.S. wild stocks (e.g., data from summer trawls in Galveston Bay)**
- **Population models that adequately explain observed variability of wild populations**
- **Relevance of data from viral disease outbreaks in aquaculture for predicting the occurrence of disease in wild populations (e.g., effects of differences in life stage, density, water quality, survival, recovery, and carrier status of diseased shrimp, etc.)**

3.7.2 Ecological Effects

Shrimp viruses may affect penaeid shrimp populations either directly (i.e., through the combined effects of individual mortality) or through direct or indirect effects on other ecological entities. Significant indirect changes might include alterations in ecosystem structure (e.g., species composition) or function (e.g., predator/prey relationships, competition, nutrient cycling). In this section, we are concerned with the unpredictable ecological consequences that may result from alterations in shrimp populations caused by disease and with the potential consequences of viral infection of crustaceans other than shrimp.

WSSV has been identified in a number of non-penaeid shrimp and crustacean species throughout Asia, but its disease-causing potential in these species is unknown. WSSV has been experimentally induced in four Asian crustacean species: a penaeid shrimp, *Trachypenaeus curvirostris,* two non-penaeid shrimps, *Exopalaemon orientalis, Macrobrachium* sp, and the red swamp crayfish, *Procambarus clarkii* (Lan et al., 1996). WSSV has been detected at low levels in naturally-occurring Asian crab species (*Scylla serrata*, *Charybdis feriatus*, *Portunus pelagicus*, *Portunus sanguinolentus,* and *Thalamita* sp.), copepods, and shoreflies (Lightner, In Press). In the U.S., WSSV infections have been reported in crayfish (*Procambarus sp.)* in the National Zoo (Richman, unpublished data). The persistence of WSSV in native biota may increase the potential for disease transmission to susceptible organisms over time.

Potential adverse ecological effects include the transmission of virus to economically important penaeid species or the displacement or loss of ecologically or economically important species via food web interactions. For example, if WSSV infection and mass mortality occurred in wild (native) copepods, other marsh inhabitants such as juvenile shrimp and crabs that rely on copepods as a food source could also be impacted, and these species could, in turn, serve as reservoirs for infection of other species.

<u>Data Gaps</u>:

- **Distribution and effects of virus in non-shrimp organisms**
- **Ecological importance of affected non-shrimp species**

3.7.3 Aquaculture Effects

Shrimp aquaculture today depends on the availability of pathogen-free brood stocks. If wild shrimp populations become infected with pathogenic viruses, pathogen-free brood stocks may be difficult or impossible to obtain. Moreover, new pathogens, including viruses, likely will be discovered as international trade of shrimp and other fisheries products expand. If the introduction of new pathogens to wild shrimp populations is not prevented, the ability to obtain pathogen-free broodstock will be further eroded. Because the U.S. Marine Shrimp Farming Program can only address known diseases for which analytical methods are available, this program alone cannot and will not prevent the entry and spread of all shrimp diseases.

3.8 Analysis Plan

An analysis plan, usually the final stage of problem formulation (Fig. 5), is a necessary and important part of the risk assessment process, particularly in complex risk assessments like the proposed shrimp virus assessment. The analysis plan evaluates risk hypotheses and summarizes the assessment design, data needs, measures, and methods for conducting the analysis phase of the risk assessment. It may be brief or extensive, depending on the nature of the assessment.

Using the conceptual model developed during problem formulation, the analysis plan identifies the pathways most important to exposure and specifies which relationships are most critical for evaluating risks. The analysis plan also identifies measures of effects, exposure, and ecosystem characteristics that will be evaluated. Issues are identified concerning the level of confidence that can be expected from the available data relative to the level of confidence required for effective decision making. If new data are required for estimating exposures or effects, the feasibility of acquiring these data is evaluated. The risk assessment may be designed in a tiered approach to allow the collection of new data in a step wise fashion that will provide risk managers with an opportunity to make decisions on issues or data as they become available.

A good analysis plan can help ensure that managers will receive the type and extent of information required for effective decision making. Because this report is not a risk assessment, an analysis plan has not been detailed here, but will be included during the development of an actual risk assessment.

4 ANALYSIS

The analysis phase of a risk assessment (figure 5) follows problem formulation and includes two principal activities: characterization of exposure and characterization of ecological effects. Characterizing exposure for viral infections of wild populations of penaeid shrimp involves a number of considerations:

- Temporal patterns (seasonal migration, changes in life stage, frequency of viral introductions).
- Spatial patterns (distribution of shrimp relative to virus).
- Species-specificity of viruses (i.e., species differences in infectivity and virulence)
- Susceptibility of wild populations to infection.
- Ability of carriers and hosts to transmit disease.
- Ability of virus to undergo genetic change or mutation.
- Effects of shrimp processing on virulence.
- Alternative hosts for the viruses.
- Persistence of virus in different environmental media
- Minimum effective dosage; frequency and concentrations of virus in the environment.
- Mode of infection.
- Inter-/Intrapopulation transfer rates.
- Food chain transfer.
- Co-occurrence of shrimp with virus.
- Efficacy of disinfection methods.

The Analysis Phase

The characterization of exposure and characterization of ecological effects both involve evaluating available data for its scientific credibility and relevance to assessment endpoints as well as the conceptual model. In ecological effects characterization, stressor-response relationships or evidence that exposure to a stressor causes an observed response are evaluated. In exposure characterization, the source(s) of stressors, the distribution of stressors in the environment, and the contact or co-occurrence of stressors with ecological receptors are described. The process should be flexible, with interactions between evaluations of ecological effects and exposure.

The products of the analysis phase are summary profiles that describe exposure and effects (stressor-response relationships). These profiles may be written documents or may be modules of a larger process model. Alternatively, documentation may be deferred until risk characterization. In any case, the objective of the analysis plan is to ensure that the information needed for risk characterization has been collected and evaluated.

In characterizing ecological effects, direct or indirect impacts on wild shrimp populations are considered. As with characterizing exposure, there are a number of factors to consider. If infection occurs in a wild population, what level of mortality is expected and how might individual mortality be translated into population effects? Could viral effects on other susceptible species cause indirect effects on penaeid populations? Some other possible effects issues include:

- Relevance of aquaculture survival rates and clearance of virus from survivors to wild populations.
- Individual morbidity/mortality/fecundity/growth, behavior, and appearance of infected organisms.
- Potential for immunity/resistance and length of any immunity.
- Carrier status of surviving infected shrimp.
- Which species are of concern (e.g., species with critical ecological or economic importance); effects on species that may affect shrimp (e.g., food chain dynamics).
- Known outbreaks/epizootics of viruses.
- Relative sensitivity of different life stages.
- Potential for population recovery.
- Utility of analogous information from other aquatic disease examples.

5 RISK CHARACTERIZATION

Risk characterization (figure 5) is the final phase of an ecological risk assessment. During this phase, risks are estimated and interpreted. The strengths, limitations, assumptions, and major uncertainties about the risks are summarized. Risks are estimated by integrating exposure and effects profiles, using a wide range of techniques including comparisons of point estimates or distributions of exposure and effects data, process models, or empirical (e.g., field) approaches. For a shrimp virus risk assessment, the specific approach(es) for estimating risks and describing uncertainties will depend on the availability and quality of data and the resources for the assessment (e.g., time, funding, etc.).

To describe risks, risk assessors evaluate the evidence supporting or refuting the risk estimate(s) and interpret the potential for adverse effects on the assessment endpoint. Criteria for evaluating adverse effects include the nature and intensity of effects, spatial and temporal scales, and the potential for recovery. Agreement among different lines of evidence increases confidence in the conclusions of a risk assessment. Some of the possible lines of evidence that could be drawn upon to describe the risks associated with different exposure pathways include: laboratory bioassay of shrimp viruses; observations of viral outbreaks in aquaculture; observations of effects (or lack of effects) in exposed wild shrimp populations; and predicted effects based on anticipated exposure scenarios.

6 SUMMARY

This section highlights the most important uncertainties surrounding the shrimp virus issue (section 6.1) and summarizes major points identified in this report concerning exposure to and effects of shrimp viruses (section 6.2).

6.1 Data Gaps and Research Needs

This section highlights areas where additional information would be most useful in supporting the risk assessment process.

Potential Viral Effects

- Baseline information on presence and distribution of pathogenic viruses in U.S. wild stocks (e.g., data from summer trawls in Galveston Bay)
- Population models that adequately explain observed variability of wild populations
- Relevance of data from viral disease outbreaks in aquaculture for predicting the occurrence of disease in wild populations (e.g., effects of differences in life stage, density, water quality, survival, recovery, and carrier status of diseased shrimp, etc.)?
- Distribution and effects of virus in non-shrimp organisms
- Ecological importance of potentially affected non-shrimp species

Virus Information

- Temporal and spatial distributions of wild penaeid shrimp relative to the virus
- Concentrations, frequency, duration, location, and environmental medium of the virus
- Species-specificity of the viruses
- Alternative hosts of the virus
- Infectivity, transmissibility and virulence of virus
- Persistence of virus in different media
- Extent and rate of spread of the virus among wild shrimp populations
- Analogous information from other introductions of exotic diseases
- Potential for immunity/resistance and length of any immunity
- Carrier status of surviving infected shrimp
- Relationship between stress and disease susceptibility in shrimp

Virus Pathways

- Water exchange with natural waters - protocols for aquaculture operations, water treatment, etc.
- Number and size of U.S. aquaculture operations in relationship to receiving waters/habitats harboring native shrimp
- Volume, disposal patterns, and treatment for solid wastes from aquaculture

- Estimates of the extent of virus contamination of feed, broodstock/seed, vehicles, and birds/animals that could transport virus
- Volume, disposal patterns, and treatment for shrimp processing effluents and solid wastes
- Number and size of shrimp processing facilities in relationship to receiving waters/habitats harboring native shrimp
- Estimates of the extent of virus contamination of shrimp received for processing
- Extent and distribution of contaminated shrimp in retail seafood markets and disposal patterns
- Evidence of virus transfer between aquaculture and wild shrimp populations

6.2 Key Findings for Exposure to and Effects of Pathogenic Shrimp Viruses

The Shrimp Virus Work Group identified a number of important findings relative to the exposure and effects of pathogenic shrimp viruses. A summary of these findings follows.

- Shrimp viral diseases are widespread throughout the world, both in wild and cultured shrimp. IHHNV and TSV are endemic in wild populations of shrimp throughout much of Central and South America. WSSV and YHV are endemic throughout much of Asia.
- In at least one incident, viral disease has been associated with drastic reductions in wild shrimp harvests. Beginning in 1987, one viral disease (IHHNV) was associated with a decline in the Gulf of California shrimp fishery to levels that could not support commercial harvests until 1994.
- Although these viruses have not yet been positively identified in native U.S. shrimp populations, very little effort has been expended to look for them. Where investigations have been conducted, analytical methods (if available) or sampling intensities may have been inadequate to detect infection.
- Viruses have affected cultured shrimp throughout the world, often with catastrophic effects on production. For example, imports from Chinese aquaculture operations dropped substantially (1990 to 1995) due in part to viral disease. Outbreaks in 1995 and 1996 on U.S. shrimp farms caused a 50 to 95 percent loss of production at affected farms.
- Despite extensive efforts to prevent outbreaks on U.S. farms by the U.S. Marine Shrimp Farming Program, state agencies, and producers, numerous disease outbreaks have occurred in 1995, 1996, and early 1997.
- There are major economic concerns at stake. The U.S. shrimp processing industry employs over 11,000 people in 182 companies. Any new requirements that may be necessary to reduce disease risks will increase costs to producers and processors, and ultimately to consumers.
- Some foreign aquaculture operations harvest their ponds immediately upon finding disease and export the infected shrimp. This management practice, combined with tremendous increases in shrimp importation, may increase risks to U.S. natural resources. Infected shrimp are now routinely found in U.S. retail markets.
- Shrimp may become infected from many sources. Major potential exposure pathways to wild shrimp in the U.S. include shrimp processing plants wastes and wastes and

escapement from aquaculture ponds. Other potential viral sources include infected bait shrimp, ship ballast water, non-shrimp translocated animals, and natural spread of the virus. Fishing vessels and intentional introductions are also possible sources.

- Domestic shrimp are vulnerable. Specific life stages of all of the principle U.S. shrimp species are highly susceptible to infection and disease from one or more of the four subject viruses as demonstrated in laboratory tests and outbreaks at aquaculture facilities. Recently discovered Asian viruses appear to be more virulent to domestic shrimp species than those viruses thought to be endemic to South and Central America.
- Species other than shrimp may be at risk. One or more of these viruses have been found in samples of other crustaceans from around the world, including copepods, crabs, shore flies and crayfish. A number of alternate host species for the viruses have been identified.

7 ACTION ITEMS

In response to the potential risks of pathogenic shrimp viruses to wild shrimp populations, the Shrimp Virus Work Group recommends that the JSA evaluate and select among several options for conducting a risk assessment and consider endorsing the following actions: publish a scoping notice for a risk assessment in the Federal Register; sponsor stakeholder meetings to involve interested parties in the risk assessment process; coordinate an expert workshop to initiate the risk assessment; and, enhance interagency coordination to improve Federal agency responsiveness to the shrimp virus problem. Each of these actions is discussed in more detail below.

7.1 Evaluate Risk Assessment Options

The scope and focus of a risk assessment are driven by the management decisions supported by the assessment, the extent and quality of available data, and the resources (e.g., funding and time) available. In general, the lower the tolerance for uncertainty in the conclusions of the risk assessment, the greater the expenditure of resources that will be required. In this case, the principal driver for the shrimp virus assessment may be time limitations. The perceived need to complete a risk assessment may preclude waiting for the additional research that may be required for a more in-depth assessment.

To help initiate discussions, the Shrimp Virus Work Group offers three possible risk assessment options. While many approaches are possible, and a final selection cannot be made without a more thorough evaluation of available data, this discussion is intended to highlight the advantages and limitations of different approaches and to illustrate the trade-offs between the time required for the assessment and the degree of uncertainty in the results. It is important to note that while it is critical to include stakeholders in the risk assessment planning process (next section), to do so will lengthen the time required to complete a risk assessment.

- <u>Qualitative assessment</u>. This approach is illustrated by the Aquatic Nuisance Species methodology (Risk Assessment and Management Committee, 1996). An expert panel compiles available information and judges risks and uncertainties based on qualitative (e.g., low, medium, and high) categories. Usually, this type of assessment can be conducted quickly (e.g., 3-6 months after the expert workshop [section 7.4]) and for relatively little cost (e.g, $30-50K). Such a screening assessment can help identify key uncertainties and research as well as provide a basis for immediate or interim policy decisions. Nevertheless, this approach does not provide quantified risk or uncertainty estimates.
- <u>Quantitative Assessment</u>. A quantitative assessment would provide numerical estimates of the likelihood of risks to wild populations of shrimp from viral exposure from a number of sources. In this approach, uncertainties are quantified. Such an approach offers risk managers a definitive basis for making risk mitigation decisions. The availability of stressor-response information could be used to evaluate how the level of effects vary with

the level of exposure. However, the current state of scientific knowledge may not support this type of risk assessment. For example, models for shrimp populations in the Gulf of Mexico are probably inadequate for use in risk assessments. Thus, the greater time and cost requirements for a quantitative assessment (e.g., one year and $200-300K) are compounded by the need for additional research that may take months or years to complete.

- <u>Tiered Assessment</u>. Rather than an either/or choice between qualitative and quantitative assessments, it may be possible to conduct the risk assessment in a tiered approach, starting with a simple approach and advancing to a more complete assessment as the state of knowledge develops and time and resources permit. Management decisions made based on a preliminary assessment can be revisited based on additional findings from a more comprehensive risk assessment.

7.2 Publish Federal Register Scoping Notice

The Shrimp Virus Work Group proposes the following notice for publication in the Federal Register to notify interested parties of the JSA's intent to conduct a risk assessment on shrimp viruses, the availability of this report, and the dates and locations for public (stakeholder) meetings to facilitate public comments on report findings

.**DEPARTMENT OF COMMERCE**
National Oceanic and Atmospheric Administration
[I.D. 060297C]

An Evaluation of Potential Shrimp Virus Impacts on Cultured Shrimp and on Wild Shrimp Populations in the Gulf of Mexico and Southeastern U.S. Atlantic Coastal Waters

AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Commerce, on behalf of the Joint Subcommittee on Aquaculture.

ACTION: Advance notice of a proposed shrimp virus risk assessment and public meetings.

SUMMARY: The Joint Subcommittee on Aquaculture (JSA); Office of Science and Technology Policy, is releasing a report describing the potential impacts of shrimp viruses on cultured shrimp and on wild shrimp populations in the Gulf of Mexico and southeastern U.S. Atlantic coastal waters. Comments received in writing, or at public meetings, will be used to help develop plans for an ecological risk assessment on shrimp viruses.

DATES: Consideration will be given only to those comments received on or before August 11, 1997. In addition, comments may be provided at any of three public meetings. See **SUPPLEMENTARY INFORMATION** section for further details regarding these meetings.

ADDRESSES: Copies of a report prepared for the JSA entitled, “An Evaluation of Shrimp Virus Impacts on Cultured Shrimp and on Wild Shrimp Populations in the Gulf of Mexico and Southeastern U.S. Atlantic Coastal Waters” (the shrimp virus report) may be obtained by contacting NMFS Assistant Administrator's Office of Industry and Trade, at: (301) 713-2379 or by accessing the NMFS Home Page, at: http://kingfish.ssp.nmfs.gov/oit/oit.html. To ensure that written comments are considered, send an original and three copies to Mr. Jerome Erbacher, Office of Industry & Trade, Room 3675, SSMC3, NMFS, 1315 East-West Highway, Silver Spring, MD 20910, or facsimile to (301) 713-2384. To attend any of the public meetings, contact the Eastern Research Group, Inc. (ERG), Conference Registration Line,(617) 674-7374.

FOR FURTHER INFORMATION CONTACT: Dr. Thomas McIlwain, Chairperson of the JSA Shrimp Virus Work Group, NMFS, 3209 Frederick Street, Pascagoula, MS 39567, (601) 762-4591 or Dr. Thomas C. Siewicki, 219 Ft. Johnson Road, Charleston SC 29412, (803)762-8534.

SUPPLEMENTARY INFORMATION: Evidence suggests that exotic shrimp viruses may be inadvertently introduced into U.S. coastal regions. If established, these introduced viruses have the potential to infect both wild shrimp stocks and shrimp in aquaculture through a number of different pathways. Two potentially significant pathways involve the shrimp aquaculture and shrimp processing industries. Though considered less significant, examples of other potential pathways include bait shrimp, ship ballast water, research and display, translocated animals (non-shrimp), and natural spread (e.g., migratory birds, large scale currents, flooding).

In 1995, Taura Syndrome Virus (TVS) was documented in shrimp culture ponds in Texas. After the Texas outbreak, ponds were restocked with shrimp seed native to the Gulf of Mexico. However, some of the shrimp in the second stocking were later found infected with other pathogenic viruses (e.g., White Spot Syndrome Virus (WSSV) and Yellow Head virus (YHV)), only previously identified in shrimp imported from the far east. In 1996, a repeat outbreak of TSV was documented. In 1997, YHV and WSSV were identified (based on very limited data) in South Carolina. These outbreaks have raised concerns that viruses could be spread from aquaculture facilities to the wild shrimp stocks in U.S. coastal waters, with potentially serious implications.

To determine the likelihood and the potential impacts of exotic shrimp viruses on wild shrimp populations in the Gulf of Mexico and southeastern U.S. Atlantic coastal waters and on cultured shrimp in aquaculture in these areas, the JSA has decided to conduct an ecological risk assessment. (The JSA consists of representatives from several Federal organizations, including the National Marine Fisheries Service, U.S. Department of Agriculture, U.S. Fish and Wildlife Service, and the U.S. Environmental Protection Agency). In support of information exchange and education, and to determine any necessary course of action to avert the introduction of pathogenic viruses, the JSA tasked a Federal interagency work group (Shrimp Virus Work Group; SVWG) with identifying research on shrimp viruses, the mode of virus transmission, and the potential for the introduction of these viruses into the Gulf of Mexico and southeastern U.S. Atlantic coastal waters. The SVWG helped to organize and participated in a shrimp virus workshop in New Orleans, LA, in June 1996. Recently, the SVWG prepared a shrimp virus report that summarizes readily-available risk-relevant information on shrimp viruses. This report has been approved by the JSA and is available to the public for comment. Comments on the shrimp virus report received from the public (whether in writing or at the public meetings) will be used as input to a workshop that will help finalize plans for conducting a shrimp virus ecological risk assessment.

Meeting Locations and Times: July 15, in Charleston, South Carolina; July 21, in Mobile, Alabama; and July 23, in Brownsville, Texas. There is no charge for attending the public meetings listed above; however, seats are limited, so it is advisable to register as soon as possible. Participants wishing to make comments or address issues can register with ERG prior to the workshop, or on site. Each participant will be assigned a time slot on a first-come, first-served basis. Individual comments should be limited to 3 to 5 minutes; additional or lengthy comments may be submitted in writing to the address provided above.

Dated: June 10, 1997.
Rolland Schmitten,
Assistant Administrator for Fisheries,
National Marine Fisheries Service.

7.3 Sponsor Stakeholder Meetings

Given the scope and potential impact of the shrimp virus risk assessment, it would be useful to include a wide range of interested parties ("stakeholders") in the initial planning process. One way of increasing involvement (and "buy-in" to the assessment) is to hold planning meetings very early in the process. Participants could include individuals from government (Federal, state, local), industry (shrimp processing, wild fishery, and aquaculture), non-government organizations (e.g., environmental groups), and the public. The Shrimp Virus Work Group suggests two or three meetings following publication of the Scoping Notice (section 7.2). Note that while stakeholder meetings increase the time required to complete a risk assessment, even greater time may be lost if such meetings do not take place, because stakeholders are much more likely to disagree with management goals and the risk assessment process.

7.4 Coordinate Expert Workshop

The Shrimp Virus Work Group recommends the development and implementation of an "expert" workshop on the shrimp virus problem to: (1) obtain additional risk-relevant information; (2) further develop the problem formulation for a shrimp virus risk assessment; and (3) enhance integration and coordination of risk assessment efforts. Both the U.S. Environmental Protection Agency and the USDA Animal and Plant Health Protection Service have extensive experience in developing and conducting risk assessments, developing management goals, and selecting assessment endpoints and their measures. Technical and management staff from these agencies could serve as group facilitators and provide on-site technical assistance. Using this mechanism, technical experts from a diverse field of interests (e.g., crustacean virology and life history, shrimp industry, regulators (all levels), environmental groups, etc) would have the opportunity to provide needed input to the shrimp virus risk assessment during the initial planning phase. This report could serve as a resource document for review and discussion at such a workshop. An expert workshop would not only make a significant contribution to the planning of a shrimp virus risk assessment, but would also help to ensure that the results of the risk assessment are useful to risk managers and decision makers. This workshop, together with the recommended public "stakeholder" meetings, will provide needed "buy in" and support from the stakeholder community, thus contributing to the timely completion of a shrimp virus risk assessment.

7.5 Enhance Interagency Coordination

The Shrimp Virus Work Group recommends increased coordination among Federal agencies having appropriate expertise and authority to protect U.S. marine resources from pathogenic shrimp viruses. These agencies need to work collaboratively to better utilize the resources currently available and to better define roles and responsibilities of individual agencies. Existing Federal statutory authority may not be adequate to prevent further disease outbreaks, and new authorities may be necessary. However statutory authorities alone will not be sufficient to control new diseases. There is a need to implement complementary programs across the responsible Federal agencies as well as to enhance research and technology to effectively reduce the risk of disease outbreaks. The Shrimp Virus Work Group recommends that representatives of the responsible Federal agencies should work closely with the aquaculture, processing, and harvesting industries to explore a variety of opportunities to reduce the risks posed by shrimp viruses.

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