Interpretive Summary:

Quantitative Risk Assessment on the Public Health Impact of Pathogenic *Vibrio parahaemolyticus* In Raw Oysters

Center for Food Safety and Applied Nutrition
Food and Drug Administration
U.S. Department of Health and Human Services

July 2005

FDA
C F S A N

Quantitative Risk Assessment on the Public Health Impact of Pathogenic *Vibrio parahaemolyticus* in Raw Oysters

PREFACE

This Interpretive Summary provides an overview of the 2004 Food and Drug Administration (FDA) *Vibrio parahaemolyticus* risk assessment. Its purpose is to briefly describe, in non-technical language, the material covered in the complete risk assessment. This includes background information on *Vibrio parahaemolyticus*, the techniques and data used to develop the risk assessment, the results of the risk assessment, and the interpretation, implications and limitations of those findings. A full understanding of the risk assessment requires the reader to consider the complete risk assessment. The complete risk assessment may be obtained on the Internet at www.cfsan.fda.gov. A printed copy will be provided upon request. Requests may be faxed to the CFSAN Outreach and Information Center at 1-877-366-3322.

INTRODUCTION

Vibrio parahaemolyticus is a bacterium that occurs naturally in coastal marine waters and estuaries (where rivers flow into the sea). It is recognized world-wide as a significant cause of bacterial seafood-borne illness. The United States Centers for Disease Control and Prevention (CDC) estimates that of the approximately 7,880 *Vibrio* illnesses each year in the United States, approximately 2,800 are estimated to be associated with *Vibrio parahaemolyticus* and raw oyster consumption. *Vibrio parahaemolyticus* is normally present in many types of raw seafood, including fish, crustaceans, and molluscan shellfish. It multiplies and colonizes in the gut of filter-feeding shellfish such as oysters, clams, and mussels. Not all strains of *Vibrio parahaemolyticus* cause illness; on the contrary, pathogenic strains represent a small percentage of the total *Vibrio parahaemolyticus* present in the environment or seafood.

FDA conducted this “product pathway” risk assessment to characterize the factors influencing the public health impact associated with the consumption of raw oysters containing pathogenic *Vibrio parahaemolyticus.* This is referred to as a “product pathway” risk assessment because the factors that influence the risk associated with *Vibrio parahaemolyticus* in oysters are examined from harvest through post-harvest handling to consumption. The risk assessment was conducted in response to outbreaks in 1997 and 1998 in the United States involving more than 700 cases of *Vibrio parahaemolyticus* illness. These outbreaks renewed concern for this pathogen as a serious foodborne threat to public health and raised concerns about the effectiveness of the risk management guidance available at that time.

SCOPE AND GENERAL APPROACH

This risk assessment was initiated in January 1999 and a draft risk assessment was made available for public comment in 2001. The draft risk assessment has been modified to take into account public comments, to incorporate additional scientific data and knowledge that has become available since 2001, and to take advantage of improvements in modeling techniques. Modifications made to the draft risk assessment are provided in Summary Table 1.

Summary Table 1. Modifications Made to the 2001 Draft *Vibrio parahaemolyticus* Risk Assessment

Topic	Modifications
Assumptions	Additional information was obtained that further support the following assumptions: • Growth rates for pathogenic and non-pathogenic *Vibrio parahaemolyticus* are similar; • Time required for refrigerated oysters to cool down to temperatures that do not support the growth of *Vibrio parahaemolyticus* is variable and may range from 1 to 10 hours.
Additional Data/ Information	• Prevalence of total and pathogenic *Vibrio parahaemolyticus* at harvest for Pacific Northwest (PNW) and Gulf Coast regions; • Relationship between water temperature and *Vibrio parahaemolyticus* levels in oysters; • Time-to-refrigeration after harvest for the PNW region.
Model/ Modeling Techniques	• Included intertidal harvesting in the PNW as an additional harvest region; • Evaluated mitigation effect of specific reduction levels of *Vibrio parahaemolyticus* in addition to types of interventions; • Included regression-based sensitivity analysis; • Added two additional uncertainty parameters (total *Vibrio parahaemolyticus* in oysters based on water temperature and dose-response relationship) to the examination of factors that influence risk predictions; • Oyster meat weights at retail were used rather than those at harvest; • Comparison of the model-predicted number of illnesses using both retail survey and epidemiological data.

This risk assessment is based on a quantitative simulation model. The focus is on raw oysters, because that is the food in the United States predominately linked to outbreaks of illness associated with this pathogen since 1997. The risk assessment examines events occurring from oyster harvest to consumption that influence the levels of *Vibrio parahaemolyticus* likely to be present in raw oysters at the time of consumption. The levels of *Vibrio parahaemolyticus* in oysters at the time of consumption are influenced by the harvest methods and environmental conditions, as well as the handling of oysters after harvest. These practices and conditions vary considerably among different geographic areas and at different times of the year. Therefore, the model was constructed to predict illnesses for each harvest region and season in the United States. The likelihood and severity of illness following exposure to pathogenic *Vibrio parahaemolyticus* from consumption of raw oysters was estimated. Once developed, the baseline model was used to develop “what-if” scenarios to evaluate the likely impact of potential intervention strategies on the exposure to pathogenic *Vibrio parahaemolyticus* from consumption of raw oysters.

The risk assessment had two main objectives:

- determine the factors that contribute to the risk of becoming ill from the consumption of pathogenic *Vibrio parahaemolyticus* in raw oysters
- evaluate the likely public health impact of different control measures, including the effectiveness of current and alternative microbiological standards

RISK ASSESSMENT FRAMEWORK

Microbial risk assessments generally include four components: Hazard Identification, Hazard Characterization, Exposure Assessment, and Risk Characterization. These components are defined and discussed in detail below.

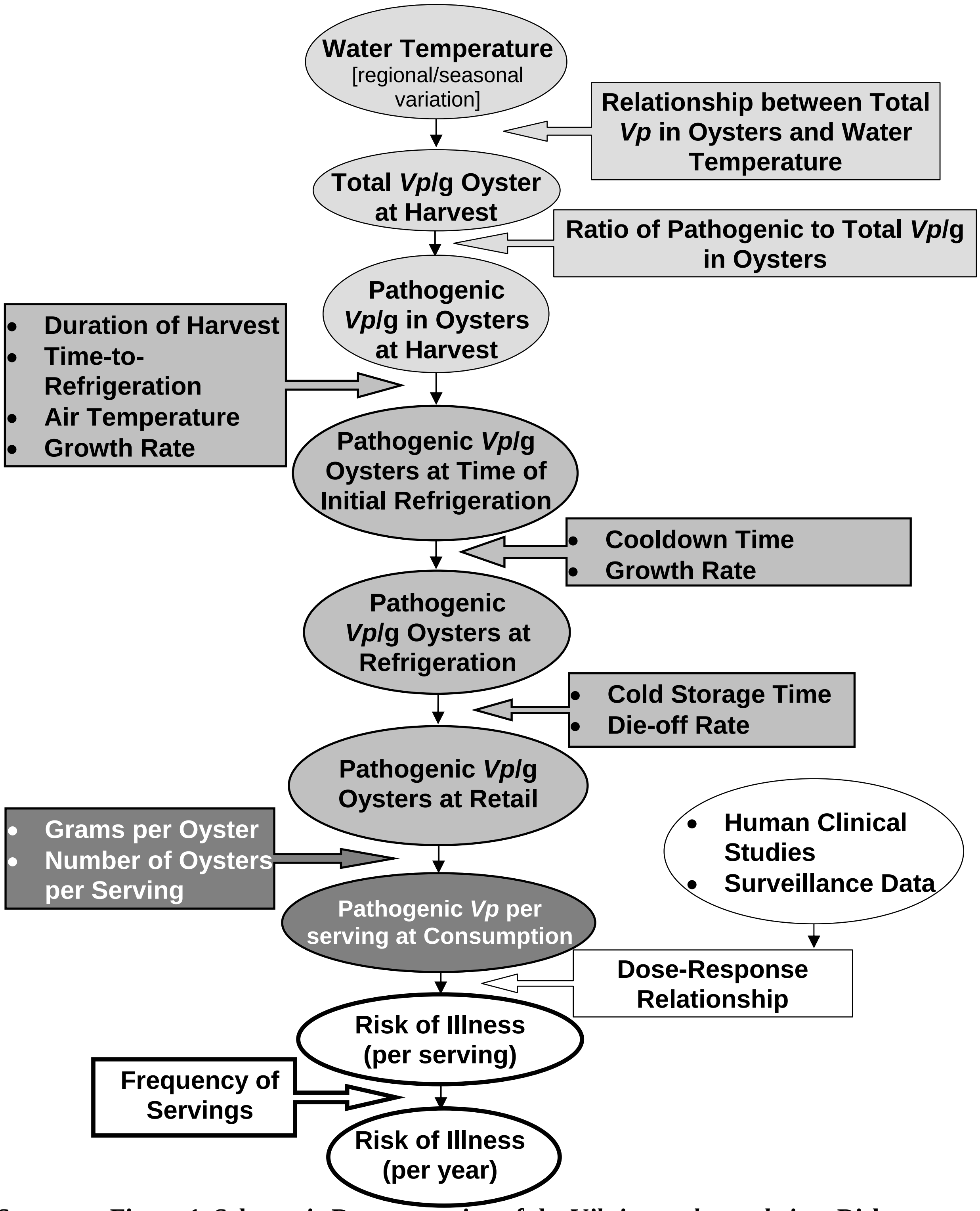
- <u>Hazard Identification</u>: Identifies the pathogenic microorganism (i.e., the hazard) that may be present in a particular food or group of foods that is capable of causing adverse health effects. The hazard on which this risk assessment is focused is pathogenic *Vibrio parahaemolyticus* in raw oysters. The adverse health effects are the primary illnesses caused by oral ingestion of *Vibrio parahaemolyticus*: gastroenteritis alone or gastroenteritis followed by septicemia.
- <u>Hazard Characterization/Dose-Response/Severity Assessment</u>: Characterizes the relationship between the level of exposure to a pathogen (dose) and the likelihood of an adverse health effect for individuals within a population (response). For this risk assessment, a quantitative relationship was developed to predict the number and severity of illnesses resulting from ingestion of different amounts of pathogenic *Vibrio parahaemolyticus*. The risk assessment considered two subpopulations, “healthy” individuals, and individuals with impaired immune systems, in evaluating the likelihood of septicemia.
- <u>Exposure Assessment</u>: Defines the frequency and likely level of exposure to *Vibrio parahaemolyticus* from consumption of raw oysters containing these microorganisms.

- Risk Characterization: Integrates Dose-Response and Exposure Assessment to predict the probability of potential adverse outcomes for individuals within a population or a specified subpopulation. For this risk assessment the likelihood and severity of illness from the consumption of raw oysters containing pathogenic *Vibrio parahaemolyticus* were predicted. An important part of this step is determining the uncertainties associated with these predicted risk estimates distinguishing, to the extent possible, uncertainty from the inherent variation that occurs in any biological and environmental system.

Summary Figure 1 depicts a schematic representation of the components of the *Vibrio parahaemolyticus* risk assessment model. The Exposure Assessment model was separated into three modules: harvest, post-harvest, and consumption. The model outputs from the Exposure Assessment were then combined with the Dose-Response model to relate these exposures to public health outcomes. The model inputs are expressed as distributions instead of single point estimates (such as a mean). Using a distribution allows a range of values, each with a specific frequency of occurrence, to be included in the model. Distributions are commonly used in simulation modeling to account for the inherent biological variability in nature and our uncertainty of the “true” values, resulting in a more accurate prediction of the risk.

Data for this risk assessment were obtained from many sources including published and unpublished scientific literature and reports produced by various organizations such as State shellfish control authorities, the CDC, the shellfish industry, the Interstate Shellfish Sanitation Conference (ISSC), and state health departments. In some instances, the conduct of the risk assessment required that assumptions be made when data were incomplete for the purposes of modeling. To the extent possible, research undertaken to address the data gaps identified in the 2001 draft risk assessment have been incorporated into the model. The criteria used to select data for the risk assessment modeling are described in detail in the complete risk assessment.

For the risk assessment, 6 harvest regions and 4 seasons (winter, spring, summer, and fall) were considered separately in the model for a total of 24 region/season combinations (i.e., there were predictions of illnesses for 24 regions/seasons). The oyster harvest regions included: Gulf Coast (Louisiana), Gulf Coast (non-Louisiana), Mid-Atlantic, Northeast Atlantic, Pacific Northwest (Dredged), and Pacific Northwest (Intertidal). In the Gulf Coast, the harvest duration (i.e., time between removal of the oysters from the water to unloading them at the dock) for Louisiana is longer than for other states in that region (Florida, Mississippi, Texas, and Alabama). Since harvest duration can affect the levels of *Vibrio parahaemolyticus* in raw oysters, the Gulf Coast was divided into these two distinct regions. The Pacific Northwest was also divided into two regions, but in this case it was based on harvest methods, intertidal versus dredged. Oysters harvested in intertidal areas are typically exposed to higher temperatures before refrigeration than those harvested using dredging, leading to the need to define two harvest practice-based regions within the Pacific Northwest.



Summary Figure 1. Schematic Representation of the V*ibrio parahaemolyticus* Risk Assessment Model [The light grey boxes with black lettering show the Harvest Module, the gray boxes with black lettering show the Post-Harvest Module, the dark grey boxes with white lettering show the Consumption Module, the white boxes with black lettering show the Dose-Response model, and the white boxes with dark black outline show the Risk Characterization. Vp= *Vibrio parahaemolyticus*]

HAZARD IDENTIFICATION

Vibrio parahaemolyticus is a salt tolerant bacterium and a normal inhabitant of the marine environment. This bacterium is found in many types of seafood, including fish, crustaceans, and molluscan shellfish. It was first isolated in 1950 and implicated in an outbreak of food poisoning in Japan. In the United States, the first confirmed outbreak of *Vibrio parahaemolyticus* illness occurred in Maryland in 1971. Since 1997, several large outbreaks, associated with the consumption of raw oysters, have been reported in the United States. These outbreaks are shown in Summary Table 2.

Summary Table 2. Outbreaks of Illnesses from *Vibrio parahaemolyticus* Associated with Consumption of Raw Oysters in the United States

Year	Location	Number of Cases
1997	Pacific Northwest[a]	209
1998	Pacific Northwest[a]	48
1998	Texas	416[b]
1998	Northeast Atlantic	10
2002	New York	7
2002	New Jersey	11
2004	Alaska	46

[a] The Pacific Northwest includes California, Oregon, Washington State, and British Columbia.
[b] 296 cases in Texas and 120 cases in other states that were traced back to oysters harvested from Texas.

Human illnesses from ingestion of *Vibrio parahaemolyticus* have been well documented. Any exposed individual can become infected with *Vibrio parahaemolyticus* and develop illness. The most common clinical manifestation of *Vibrio parahaemolyticus* infection is gastroenteritis, an inflammation of the gastrointestinal tract. Gastroenteritis is usually an illness of short duration and moderate severity that is characterized by diarrhea, vomiting, and abdominal cramps. *Vibrio parahaemolyticus* infections can also lead to septicemia, a severe, life-threatening disease caused by the multiplication of pathogenic microorganisms and/or the presence and persistence of their toxins in circulating blood. Individuals with underlying chronic medical conditions (such as diabetes, alcoholic liver disease, hepatitis, and those receiving immunosuppressive treatments for cancer or AIDS) do not appear to be at a higher risk of acquiring the initial infection than otherwise healthy people. However, individuals with underlying chronic conditions do appear to have a higher risk of the initial infection developing into septicemia.

The CDC estimates that of the total *Vibrio* illnesses in the United States (average 7,880 per year), there are approximately 4,500 *Vibrio parahaemolyticus* illnesses and of those approximately 2,800 are estimated to be associated with raw oyster consumption. There have been reports of *Vibrio parahaemolyticus* illness associated with various types of cooked and raw seafood including crayfish, lobster, shrimp, crab, oysters, and clams. *Vibrio* illnesses associated with cooked seafood are likely due to inadequate heating or recontamination after cooking. Although thorough cooking destroys *Vibrio*, oysters are often eaten raw, which may explain why it is the most common seafood associated with

Vibrio infection in the United States. Epidemiological data indicate that consumers of raw oysters are 2.8 times more likely to experience *Vibrio parahaemolyticus* illness compared to non-raw oyster eaters. Food intake surveys indicate that raw shellfish is not a commonly consumed food in the United States: only 10 to 20% of the population consumes raw shellfish at least once a year. Among oyster consumers, raw oysters are typically eaten approximately once every 6 weeks and the typical serving size ranges from 6 to 24 oysters, with 12 being the most frequent.

Not all strains of *Vibrio parahaemolyticus* cause illness; on the contrary, pathogenic strains generally represent a small percentage of the total *Vibrio parahaemolyticus* present in the environment or seafood. Pathogenic *Vibrio parahaemolyticus* strains are more likely to produce symptomatic infections and have one or more distinctive traits that are generally absent in non-pathogenic strains. Two important virulence indicators are the ability to produce thermostable direct hemolysin (TDH) and the ability to produce a related toxin, thermostable related hemolysin (TRH). Hemolysin is an enzyme that breaks down red blood cells on a blood agar plate, which is referred to as the Kanagawa phenomenon. The vast majority of *Vibrio parahaemolyticus* strains isolated from the stools of patients with *Vibrio parahaemolyticus* gastroenteritis are TDH-positive (TDH^+). The role of traits other than TDH has not yet been determined. Therefore, for the purposes of this risk assessment, pathogenic *Vibrio parahaemolyticus* is defined as strains that are TDH^+.

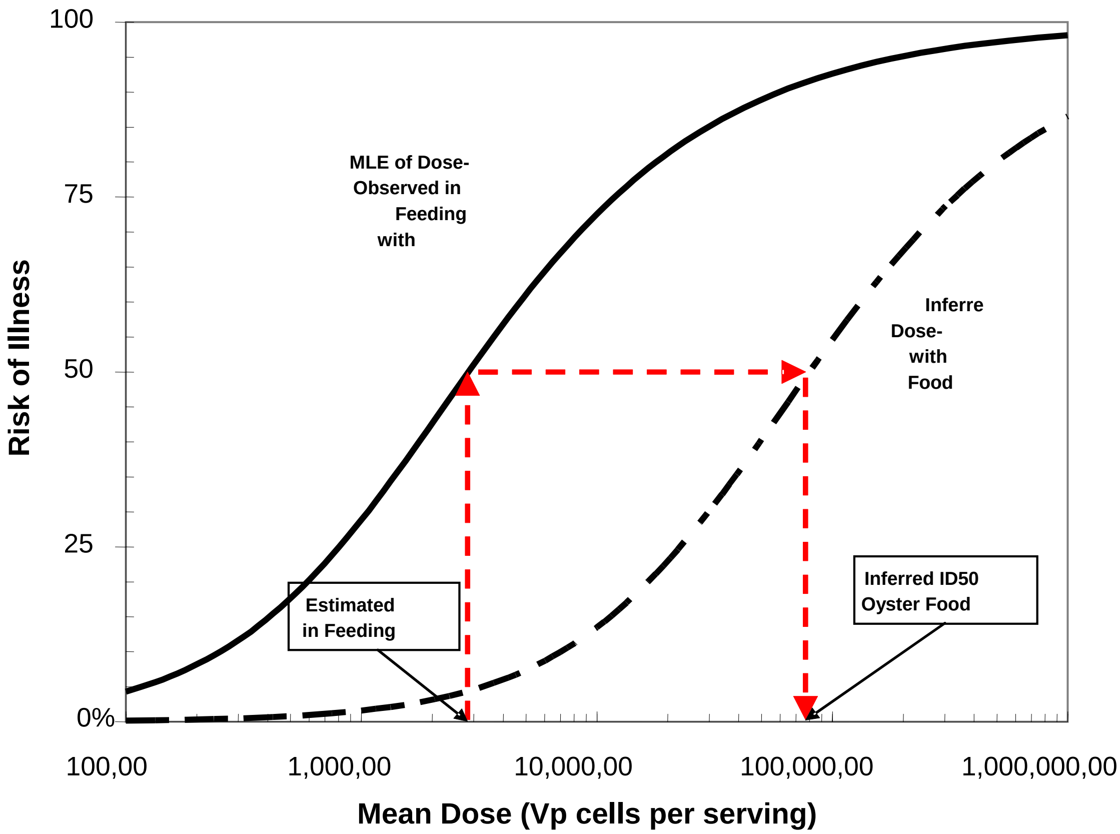
Vibrio parahaemolyticus infections occur throughout the year, peaking in spring and summer. Cases are most often associated with the regions of the country within close proximity to marine environments. The geographical distribution of cases attributed to oysters from specific harvest areas likely reflects the propensity for individuals in close proximity to coastal areas to consume raw shellfish. Likewise, the volume of oysters harvested in the U.S. each year varies by season. Approximately 66% of the annual oyster harvest occurs in the winter and fall with the remainder in spring and summer. There are also regional differences in the oyster harvest volume; the Gulf Coast accounts for approximately one-half of the oyster harvest, the Pacific Northwest about a fourth, and less than a tenth from the Mid-Altantic region. In addition, regional climatic differences (e.g., water temperatures) and post-harvest handling practices influence the levels of *Vibrio parahaemolyticus* in shellfish and consequently the potential for illness.

HAZARD CHARACTERIZATION

In a quantitative risk assessment, the Hazard Characterization typically entails the determination of a dose-response relationship for a specified population, relating the incidence of an identified adverse effect with the level of exposure to a particular microorganism (or substance). This dose-response relationship is often expressed as a relation between different levels of exposure and the likelihood (or probabilities) that such exposures will result in illness. For this risk assessment, a quantitative relationship was developed to predict the number and severity of illnesses resulting from ingestion of pathogenic *Vibrio parahaemolyticus*.

A quantitative dose-response model for *Vibrio parahaemolyticus* was developed based on human clinical feeding studies. The model extrapolates the observed illness rates from the studies to doses and illness rates that are more likely to be encountered with contaminated oysters. Next, the dose-response curve was adjusted to account for the estimates of the annual illness burden (2,800 cases per year) as determined by CDC. This approach is typically referred to as “anchoring” to epidemiological data. There is uncertainty in the dose-response relationship because of the limited data from the clinical studies. This uncertainty was accounted for in the model by multiple curve-fitting of the data.

Summary Figure 2 shows the dose-response model. Using the most likely estimate of the dose-response curve (i.e., the dashed line), the probability of illness is approximately 0.5 (50%) for a dose of approximately 100 million (i.e., $1x10^8$) *Vibrio parahaemolyticus* cells/serving. This means for every 100 individuals eating a serving of oysters that contains $1x10^8$ cells of pathogenic *Vibrio parahaemolyticus*, approximately 50 individuals will become ill. At lower exposure levels ($1x10^3$ or $1x10^4$), the probability of illness is much lower (<0.001). Using the risk assessment results and available epidemiological data, the likelihood that a *Vibrio parahaemolyticus* illness (gastroenteritis) will lead to septicemia was determined for healthy and immunocompromised individuals. (See section entitled, Risk Characterization, for the results of the assessment.)



Summary Figure 2. The Dose-Response Model for *Vibrio parahaemolyticus (Vp)*
[The solid line is the best estimate of the model fit to pooled human feeding studies. The dashed line shows the shift adjustment so that the model predictions agree with epidemiological surveillance data. MLE denotes the maximum likelihood estimate. ID_{50} is the dose corresponding to a 50% probability of gastroenteritis.]

EXPOSURE ASSESSMENT

The purpose of the Exposure Assessment is to determine the likelihood of ingesting pathogenic *Vibrio parahaemolyticus* from consumption of raw oysters, and the likely level of exposure. Insufficient data are available on the levels of pathogenic *Vibrio parahaemolyticus* in raw oysters at the moment of consumption. Therefore, the model predicts these levels using available data on the factors that influence the levels of the pathogen present in oysters at harvest. These factors include the environmental conditions that contribute to the likely presence of *Vibrio parahaemolyticus* in oysters at harvest and the impact of post-harvest handling and processing practices on the growth or decline of *Vibrio parahaemolyticus* in oysters prior to consumption. In addition, the frequency of oyster meals and the amount of oysters consumed per serving were considered.

The Exposure Assessment was divided into three modules that reflect the chain of events from oyster harvest to consumption: Harvest, Post-Harvest, and Consumption. The levels of total and pathogenic *Vibrio parahaemolyticus* in oysters were estimated for each handling or processing event. The predicted levels of *Vibrio parahaemolyticus* from each module were used as inputs for the subsequent module (e.g., results from the Harvest module served as the input to the Post-Harvest module). Because *Vibrio parahaemolyticus* levels may be affected by climate and region-specific oyster harvesting practices, modeling was conducted separately for each of the 24 harvest region/season combinations described in the "Risk Assessment Framework" section above.

Harvest Module. In the Harvest Module of the Exposure Assessment model, factors identified as potentially influencing the variation of levels of *Vibrio parahaemolyticus* at the time of harvest were evaluated and the effects of those factors that could be suitably quantified were incorporated into the quantitative simulation model.

The available data suggest that a number of factors can affect the presence and growth of *Vibrio parahaemolyticus* in oysters at the time of harvest. Once present in the environment, *Vibrio parahaemolyticus* levels are affected primarily by water temperatures and to a lesser extent by salinity levels. Such factors as the amount of zooplankton in the shellfish growing area, the rate of tidal flushing, levels of dissolved oxygen in the water, and the presence of pollutants have less certain effects on *Vibrio parahaemolyticus* levels. Oyster-specific factors, such as the physiology and health of the oyster also contribute to the ability of *Vibrio parahaemolyticus* to colonize and grow in the oysters. Bacteriophages, toxins, or other proteins produced by bacterial strains that infect or colonize oysters at the same time as *Vibrio parahaemolyticus* may affect the survival of the *Vibrio parahaemolyticus*. In addition, the percentage of the total *Vibrio parahaemolyticus* that is pathogenic may vary. Several studies suggest that the average percentage of pathogenic *Vibrio parahaemolyticus* is higher on the West Coast than in other areas of the country.

Although a number of potential factors affecting *Vibrio parahaemolyticus* levels at the time of harvest were identified, there were little data available to quantify the effects of most of these factors. Furthermore, accompanying analyses indicated that in most instances water temperature is overwhelmingly the primary determinant that controls *Vibrio parahaemolyticus* levels in oysters. Water salinity was not included as a variable in the model because preliminary modeling indicated that the small variability in water salinity in the major commercial harvest regions was not a strong determinant of *Vibrio parahaemolyticus* prevalence and growth in oysters. Additionally, the impact on the model of varying water salinity was overshadowed by the impact of varying water temperatures. Levels of pathogenic *Vibrio parahaemolyticus* in oysters at-harvest were predicted using data on: 1) the relationship between total *Vibrio parahaemolyticus* in oysters and water temperature, 2) water temperature distributions, and 3) the ratio of pathogenic to total *Vibrio parahaemolyticus* in oysters.

The relationship between total *Vibrio parahaemolyticus* levels in oysters and water temperature was modeled based on the assumption that *Vibrio parahaemolyticus* may be present at levels below the sensitivity of the analytical method (e.g., less than the limit of detection) but not actually zero, even at low temperatures. The distribution of pathogenic

Vibrio parahaemolyticus in oysters at harvest was determined using the distribution of total *Vibrio parahaemolyticus* in oysters at harvest and the appropriate pathogenic percentage for each region (i.e., 2.3% for the Pacific Northwest and 0.18 % for the Gulf Coast, Mid-Atlantic, and Northeast Atlantic regions).

Summary Table 3 provides the predicted mean levels of *Vibrio parahaemolyticus* at harvest for each of the 24 region/season combinations. Across all regions, the predicted levels are much higher in the warmer months compared to the cooler months. The predicted levels for the Gulf Coast region are considerably higher than the other regions due to the warmer water temperatures. During the summer, the levels of *Vibrio parahaemolyticus* in the mid-Atlantic and Northeast Atlantic are higher than those of the Pacific Northwest (when harvest occurs by dredging). Even during the summer, air temperatures in the Pacific Northwest are cooler, on average, than in the Gulf and Atlantic regions. However, exposure to higher temperatures for longer time periods, such as occurs during intertidal harvest in some Pacific Northwest areas, allows for additional growth, resulting in an increase of total and pathogenic *Vibrio parahaemolyticus* to levels higher than that of the Northeast Atlantic region.

Summary Table 3. Predicted Mean Levels of *Vibrio parahaemolyticus* per gram in Oysters At-Harvest

Region	Level	Summer[a]	Fall[a]	Winter[a]	Spring[a]
Gulf Coast (Louisiana)[b]	Total	2,100	220	52	940
	Pathogenic	4	<1	<1	2
Gulf Coast (Non-Louisiana)[b]	Total	2,100	220	52	940
	Pathogenic	4	<1	<1	2
Mid-Atlantic	Total	780	51	3	200
	Pathogenic	1	<1	<1	<1
Northeast Atlantic	Total	230	33	4	42
	Pathogenic	<1	<1	<1	<1
Pacific Northwest (Dredged)[c]	Total	5	<1	<1	<1
	Pathogenic	<1	<1	<1	<1
Pacific Northwest (Intertidal)[d]	Total	650	2	<1	61
	Pathogenic	15	<1	<1	1

[a] Predicted mean levels of total and pathogenic *Vibrio parahaemolyticus* per gram of raw oysters. Values rounded to 2 significant digits. [b] Note: the values for Louisiana and non-Louisiana areas are the same because the water temperature is similar for these regions. Differences in the Gulf Coast states occur in the post-harvest portion of the model (See Summary Table 4). [c] Predicted mean levels when oyster reefs are submerged. [d] Predicted mean levels after intertidal exposure.

<u>Post-Harvest Module</u>. The Post-Harvest Module of the Exposure Assessment model predicts the effects of typical industry practices on *Vibrio parahaemolyticus* densities in oysters during transportation, distribution, and storage from harvest through retail. After oysters are harvested, levels of *Vibrio parahaemolyticus* can increase or decline in oysters during handling and storage before consumption. After harvesting, oysters are typically stored unrefrigerated on the oyster boat for a period of time ranging from a few hours to more than half a day. The potential growth of *Vibrio parahaemolyticus* in the oysters during this period of unrefrigerated holding is a function of the air temperature at the time of harvest and the length of time oysters are unrefrigerated. Once the oysters are placed under refrigeration (e.g., during transport or after arrival at wholesalers), the rate of growth slows until oysters reach a “no-growth” temperature (i.e., below 10˚C) for *Vibrio parahaemolyticus*. The length of time during which *Vibrio parahaemolyticus* growth occurs after the start of refrigeration and the (reduced) rate of growth during this period of time were estimated. When held at a refrigeration temperature of 45°F (7.2°C), levels of *Vibrio parahaemolyticus* decrease slowly as cells die under this storage condition; this effect was included in the Post-Harvest model. The post-harvest levels are carried forward to the Consumption Module where the dose levels of *Vibrio parahaemolyticus* consumed are modeled.

Summary Table 4 provides the predicted mean levels for total and pathogenic *Vibrio parahaemolyticus* in oysters post-harvest. These results, in comparison to those shown in Summary Table 3, are indicative of the effects of current post-harvest handling and processing practices on *Vibrio parahaemolyticus* levels. The predicted total and pathogenic *Vibrio parahaemolyticus* levels in oysters post-harvest are highest in both the Louisiana and non-Louisiana Gulf Coast regions because the levels at-harvest were the highest and ambient temperature is much higher in this region than in the other regions, allowing for more growth. Predicted levels in the Gulf Coast (Louisiana) are higher than those in the Gulf Coast (non-Louisiana), reflecting a longer time from harvest to refrigeration. The type of harvesting also has an impact on the levels of *Vibrio parahaemolyticus*. In the Pacific Northwest, the typically longer exposure to warmer air temperatures during intertidal harvesting can elevate oyster temperatures, allowing for additional growth of *Vibrio parahaemolyticus* during intertidal harvesting.

Summary Table 4. Predicted Mean Levels of Total and Pathogenic *Vibrio parahaemolyticus* per gram in Oysters Post-Harvest

Region	Level	Summer[a]	Fall[a]	Winter[a]	Spring[a]
Gulf Coast (Louisiana)	Total	60,000	5,700	290	23,000
	Pathogenic	100	10	<1	39
Gulf Coast (Non-Louisiana)	Total	42,000	2,500	135	16,000
	Pathogenic	73	4	<1	28
Mid-Atlantic	Total	12,000	310	1	4,200
	Pathogenic	21	<1	<1	7
Northeast Atlantic	Total	2,500	52	1	510
	Pathogenic	4	<1	<1	<1
Pacific Northwest (Dredged)[b]	Total	100	<1	<1	9
	Pathogenic	2	<1	<1	<1
Pacific Northwest (Intertidal)[c]	Total	1,700	4	<1	150
	Pathogenic	38	<1	<1	4

[a] Predicted mean levels of total and pathogenic *Vibrio parahaemolyticus* per gram of raw oysters. Values rounded to 2 significant digits. [b] Predicted mean levels when oyster reefs are submerged. [c] Predicted mean levels after intertidal exposure.

Consumption Module. The Consumption Module of the Exposure Assessment model estimates the levels of total and pathogenic *Vibrio parahaemolyticus* in a single serving of an oyster meal. The number of oyster meals or servings eaten, the quantity of oysters consumed per serving, and the pathogenic *Vibrio parahaemolyticus*/g oyster at consumption are included in this module. The number of servings eaten refers to the oysters harvested from a specific region. As such, the risk assessment model predicts illness associated with oysters harvested from specific regions but does not predict illness associated with the location (region) where the oysters were consumed or illness reported. Summary Table 5 provides the mean predicted levels of total and pathogenic *Vibrio parahaemolyticus* at consumption.

Summary Table 5. Predicted Mean Levels of Total and Pathogenic *Vibrio parahaemolyticus* per Serving of Oysters at Consumption

Region	Level	Summer[a]	Fall[a]	Winter[a]	Spring[a]
Gulf Coast (Louisiana)	Total	12,000,000	1,200,000	58,000	4,600,000
	Pathogenic	21,000	2,000	98	7,900
Gulf Coast (Non-Louisiana)	Total	8,500,000	500,000	27,000	3,200,000
	Pathogenic	15,000	880	47	5,600
Mid-Atlantic	Total	2,500,000	62,000	280	850,000
	Pathogenic	4,300	110	<1	1,500
Northeast Atlantic	Total	500,000	11,000	300	100,000
	Pathogenic	860	17	<1	180
Pacific Northwest	Total	21,000	46	2	1,900
(Dredged) [b]	Pathogenic	460	1	<1	43
Pacific Northwest (Intertidal)	Total	330,000	800	3	30,000
[c]	Pathogenic	7,500	17	<1	740

[a] Predicted mean levels of total and pathogenic *Vibrio parahaemolyticus* per serving of raw oysters. Values rounded to 2 significant digits. [b] Predicted mean levels when oyster reefs are submerged. [c] Predicted mean levels after intertidal exposure.

RISK CHARACTERIZATION

The Risk Characterization combines the results of the Exposure Assessment model with the Dose-Response model to predict the number of illnesses and the severity of illness associated with different regions and seasons. Estimates of the uncertainty associated with these predictions of risk and illness burden (i.e., upper and lower bounds) are also determined. For simplicity, the results of these regional and seasonal predictions of illness are presented below as the mean of the distribution (i.e., the mean number of predicted illnesses). A detailed description of the uncertainty distributions can be found in the complete risk assessment. Sensitivity analyses were conducted to evaluate the importance of the various input factors on the model results. The model was validated by comparing the results to a retail study and epidemiological data.

Predicted Illness Burden

Risk per Serving. The "risk per serving" is the risk of an individual becoming ill (gastroenteritis alone or gastroenteritis followed by septicemia) when he or she consumes a single serving of oysters. As shown in Summary Table 6, the predicted risk per serving is highest for the Gulf Coast (Louisiana) region and lowest for Pacific Northwest (Dredged) region. Within a region, the risk per serving is highest for the warmer months and lowest for the cooler months. For example, for the Northeast Atlantic, the risk per serving in the winter is on the order of $1x10^{-8}$, meaning only one illness in every 100 million servings. For this same region, the risk per serving in the summer is approximately 3 orders of magnitude higher (one illness in every 100,000 servings). For the Pacific Northwest region during the summer and spring, the risk per serving is higher for oysters harvested by intertidal compared with dredged methods.

Summary Table 6. Predicted Mean Risk per Serving Associated with the Consumption of Pathogenic *Vibrio parahaemolyticus* in Raw Oysters

Region	Mean Risk Per Serving[a]				
	Summer	Fall	Winter	Spring	Total
Gulf Coast (Louisiana)	4.4×10^{-4}	4.3×10^{-5}	2.1×10^{-6}	1.7×10^{-4}	6.6×10^{-4}
Gulf Coast (Non-Louisiana)[b]	3.1×10^{-4}	1.9×10^{-5}	1.1×10^{-6}	1.2×10^{-4}	4.5×10^{-4}
Mid-Atlantic	9.2×10^{-5}	2.2×10^{-6}	1.1×10^{-8}	3.1×10^{-5}	1.3×10^{-4}
Northeast Atlantic	1.8×10^{-5}	4.0×10^{-7}	1.1×10^{-8}	3.6×10^{-6}	2.2×10^{-5}
Pacific Northwest (Dredged)	1.0×10^{-5}	2.6×10^{-8}	8.1×10^{-10}	8.7×10^{-7}	1.1×10^{-5}
Pacific Northwest (Intertidal)[c]	1.4×10^{-4}	3.9×10^{-7}	1.7×10^{-9}	1.3×10^{-5}	1.5×10^{-4}

[a] Risk per serving refers to the predicted risk of an individual becoming ill (gastroenteritis alone or gastroenteritis followed by septicemia) when he or she consumes a single serving of raw oysters.
[b]Includes oysters harvested from Florida, Mississippi, Texas, and Alabama. The time from harvest to refrigeration in these states is typically shorter than for Louisiana.
[c]Oysters harvested using intertidal methods are typically exposed to higher temperature for longer times before refrigeration compared with dredged methods.

Risk per Annum. The "risk per annum" is the predicted number of illnesses (gastroenteritis alone or gastroenteritis followed by septicemia) in the United States each year. As shown in Summary Table 7, for each region, the highest number of predicted cases of illnesses is associated with oysters harvested in the summer and spring and the lowest in the winter and fall. Of the total annual predicted *Vibrio parahaemolyticus* illnesses, approximately 92% are attributed to oysters harvested from the Gulf Coast (Louisiana and non-Louisiana states) region in the spring, summer and fall and from the Pacific Northwest (intertidal) region in the summer. The lower numbers of illnesses predicted for the Northeast Atlantic and Mid-Atlantic oyster harvests are attributable both to the colder water temperatures and the smaller harvest from these regions. The harvesting practice also has an impact on the illness rate. Intertidal harvesting in the Pacific Northwest poses a much greater risk than dredging in this region (192 vs. 4 illnesses per year). This is likely attributable to elevation of oyster temperatures during intertidal exposure leading to *Vibrio parahaemolyticus* growth.

Summary Table 7. Predicted Mean Annual Number of Illnesses Associated with the Consumption of *Vibrio parahaemolyticus* in Raw Oysters

Region	Mean Annual Illnesses[a]				
	Summer	Fall	Winter	Spring	Total
Gulf Coast (Louisiana)	1,406	132	7	505	2,050
Gulf Coast (Non-Louisiana)[b]	299	51	3	193	546
Mid-Atlantic	7	4	<1	4	15
Northeast Atlantic	14	2	<1	3	19
Pacific Northwest (Dredged)	4	<1	<1	<1	4
Pacific Northwest (Intertidal)[c]	173	1	<1	18	192
TOTAL	1,903	190	10	723	2,826

[a] Mean annual illnesses refers to the predicted number of illnesses (gastroenteritis alone or gastroenteritis followed by septicemia) in the United States each year.
[b] Includes oysters harvested from Florida, Mississippi, Texas, and Alabama. The time from harvest to refrigeration in these states is typically shorter than for Louisiana. [c] Oysters harvested using intertidal methods are typically exposed to higher temperature for longer times before refrigeration compared with dredged methods.

Severity of Illness. The predicted number of cases of septicemia was determined for the total United States population as shown in Summary Table 8. The number of predicted cases of septicemia was calculated by multiplying the mean number of predicted illnesses (Summary Table 7) by the probability of gastroenteritis progressing to septicemia (0.0023). The calculation of the probability of gastroenteritis progressing to septicemia is described in the complete risk assessment. Since most of the cases of illness are predicted to be associated with the Gulf Coast (Louisiana) harvest, this is also the harvest that would be expected to be associated with the highest number of cases of septicemia.

Anyone exposed to *Vibrio parahaemolyticus* can become infected and develop gastroenteritis. However, compared to the healthy population, there is about a 40-fold higher probability of an infected individual with a concurrent underlying chronic medical condition developing septicemia. The model predicts about 7 cases of septicemia each year for the total population, of which 2 would be expected to occur in healthy individuals and 5 would be expected to occur among the immunocompromised population.

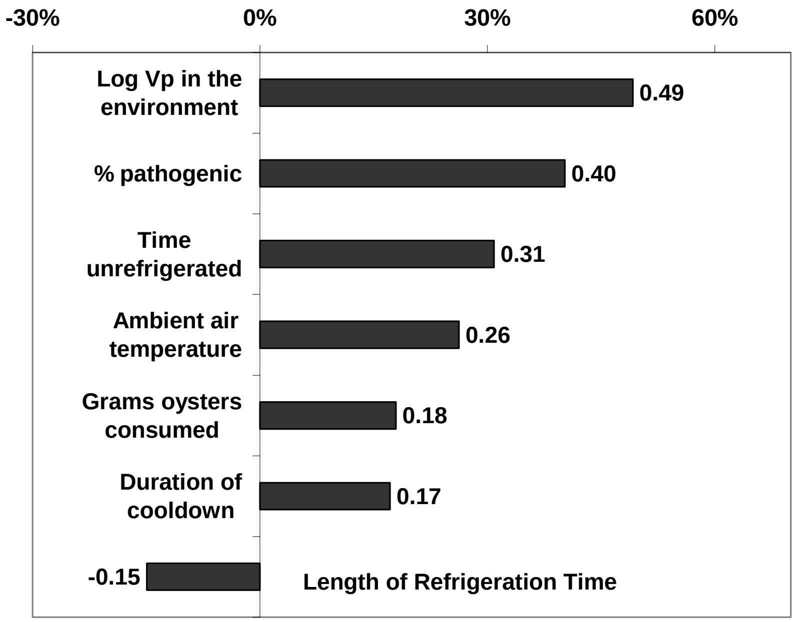
Summary Table 8. Predicted Mean Number of Cases of *Vibrio parahaemolyticus* Septicemia Associated with the Consumption of Raw Oysters

	Mean Annual Cases of Septicemia[a]				
Region	**Summer**	**Fall**	**Winter**	**Spring**	**Total**
Gulf Coast (Louisiana)	3	<1	<1	1	4
Gulf Coast (Non-Louisiana)[b]	<1	<1	<1	<1	1
Mid-Atlantic	<1	<1	<1	<1	<1
Northeast Atlantic	<1	<1	<1	<1	<1
Pacific Northwest (Dredged)	<1	<1	<1	<1	<1
Pacific Northwest (Intertidal)	<1	<1	<1	<1	<1
TOTAL	4	<1	<1	2	7

[a] Calculated by multiplying the probability of septicemia (0.0023) by the mean predicted number of illnesses (see Summary Table 7). [b] Includes oysters harvested from Florida, Mississippi, Texas, and Alabama. The typical time from harvest to refrigeration of oysters for these states is shorter than for Louisiana.

Sensitivity Analysis

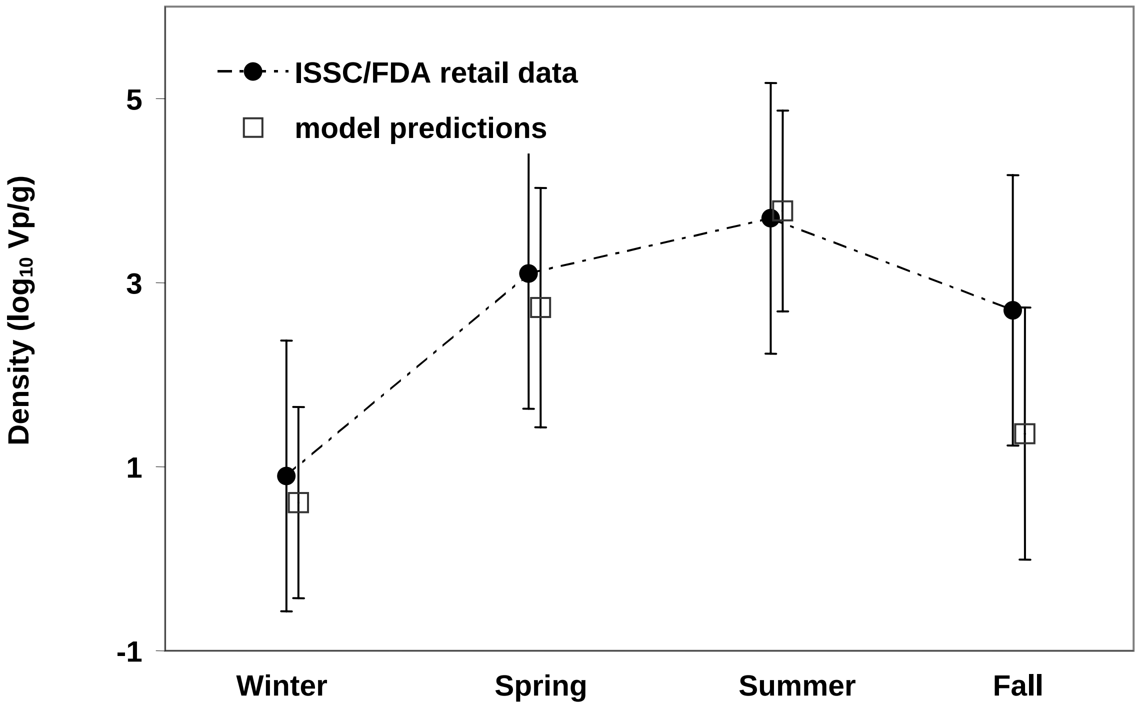
A sensitivity analysis was conducted to determine which model input factors have the strongest influence on the predicted probability of illness. A representative example of this type of evaluation is shown in Summary Figure 3. The graph (referred to as a Tornado Plot) shows the rank and magnitude of influence of factors (from highest to lowest) on the probability of illness. For example, in the Gulf Coast (Louisiana) Summer harvest, the model prediction of risk is influenced the most by the level of *Vibrio parahaemolyticus* in the environment and secondly by the percent of pathogenic *Vibrio parahaemolyticus* in oysters at the time of harvest. The length of time oysters are unrefrigerated after harvest and air temperature are also important factors. The ranking is similar for all regions, except for intertidal-harvested oysters in the Pacific Northwest. For the Pacific Northwest intertidal harvest, the second and third most influential factors are air and oyster temperatures. Thus, for this region, higher levels of risk are associated with oysters that have been collected on warm sunny days. Since the levels of *Vibrio parahaemolyticus* decrease during cold storage, the length of time the oysters are refrigerated is negatively correlated with the risk for all regions and seasons and the factor points to the left rather than to the right on the Tornado Plot.



Summary Figure 3. Tornado Plot of Influential Variability Factors of *Vibrio parahaemolyticus* (Vp) Illness per Serving of Raw Oysters in the Gulf Coast (Louisiana) Summer Harvest

Model Validation

Exposure predictions were validated by comparing predicted *Vibrio parahaemolyticus* levels in oysters at the time of consumption to data from a 1998-1999 survey of *Vibrio parahaemolyticus* levels in oysters at retail conducted collaboratively by the Interstate Shellfish Sanitation Conference (ISSC) and the FDA (Summary Figure 4). These data were not used in the development of the risk assessment model. In general, the mean *Vibrio parahaemolyticus* levels predicted by the model compared well with the mean levels from the ISSC/FDA survey, particularly for the Gulf and Mid-Atlantic summer when the risk of illness is highest. For the Pacific Northwest, the model predictions are higher than the ISSC/FDA estimates, but there is substantial uncertainty associated with the ISSC/FDA data for this region due to the relatively small number of samples. Based on the generally good agreement between model-predicted *V. parahaemolyticus* densities and observed densities at retail, the exposure assessment portion of the model is considered to be validated.



Summary Figure 4. Observed $\log_{10}$ Density of Total *Vibrio parahaemolyticus* at Retail Compared to Model Predictions for the Gulf Coast (Louisiana and non-Louisiana states) [The error bars indicate one standard deviation above and below either the model predictions (square box) or observed values (filled circle).]

The corresponding validation of the risk estimates based on a comparison of the risk assessment predictions and available epidemiological data showed a higher degree of uncertainty. The surveillance data reported to CDC are the only data available to validate the model predictions of illness for each region and season. Temporally, the model predictions and CDC data both indicate that the risk of illness is higher in the spring and summer than in the winter and fall. However, agreement between the surveillance data and the regional predictions of risk were less clear cut, though both showing similar trends (e.g., the highest number of illnesses are associated with Gulf Coast oysters followed by Pacific Northwest oysters). In part, this uncertainty reflects the fact that the surveillance data indicate where (location) the illness occurred and the model predicts illnesses attributed to where (region) oysters were harvested. It is difficult to trace the oysters that caused an illness back to the harvest region. Because of the intrinsic difference in what the two systems measure (location of illness occurrence vs. harvest region of oysters that cause illness), full validation of the regional model predictions of illness based on regional surveillance data will require additional research and targeted surveillance initiatives with more thorough traceback data.

WHAT-IF SCENARIOS

The risk assessment model can be used to estimate the likely impact of intervention strategies on the predicted number of illnesses. The impact of different harvesting methods, seasons (i.e., water and air temperatures), time until refrigeration, and length of storage before consumption were parameters considered in the baseline model. By changing one or more of the input parameters and measuring the resulting change in the model outputs, the likely impact of new or different processing procedures or regulatory actions can be evaluated. These changes to the baseline model are commonly referred to as “what-if” scenarios. The what-if scenarios evaluated include the following: reducing levels of *Vibrio parahaemolyticus* in oysters (representing various post-harvest mitigation controls); reducing time-to-refrigeration; re-submersion of intertidally harvested oysters; and sample-based control plans.

Reducing Levels of *Vibrio parahaemolyticus* in Oysters.

Post-harvest mitigation control scenarios included an evaluation of treatments that reduce levels of *Vibrio parahaemolyticus* in oysters. The reduction levels represent a range of potential mitigation controls: immediate refrigeration (i.e., cooling immediately after harvest); 2-log reduction (e.g., freezing and cold storage); and 4.5-log reduction (e.g., mild heat treatment, irradiation, or ultra high hydrostatic pressure). The effectiveness of immediate refrigeration may be expected to vary both regionally and seasonally and is typically approximately 1-log reduction.

Measures that control or reduce the levels of *Vibrio parahaemolyticus* in oysters reduced the predicted risk of illness associated with this pathogen (Summary Table 9). Treatment such as immediate refrigeration decreased the number of predicted illnesses by approximately 10-fold. The effect of immediate refrigeration is less pronounced in the cooler regions than in the warmer Gulf Coast. Treatment causing a 2-log decrease in the levels of *Vibrio parahaemolyticus* in oysters reduces the probability of illness by approximately 100-fold. Treatment causing a 4.5-log decrease in the number of *Vibrio parahaemolyticus* bacteria reduces predicted illness to an extent that makes it unlikely that illnesses would be observed.

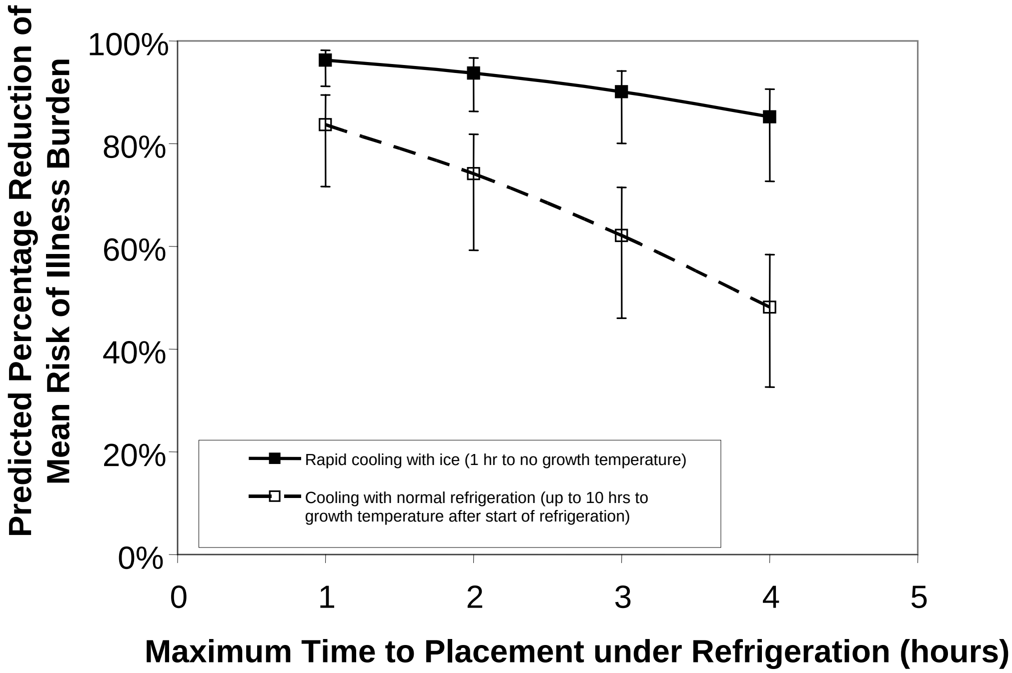
Summary Table 9. Predicted Mean Number of Illnesses per Annum from Reduction of Levels of Pathogenic *Vibrio parahaemolyticus* in Oysters

Region	Predicted Mean Number of Illnesses per Annum			
	Baseline	**Immediate Refrigeration[a]**	**2-log Reduction[b]**	**4.5-log Reduction[c]**
Gulf Coast (Louisiana)	2,050	202	22	<1
Gulf Coast (Non-Louisiana)	546	80	6	<1
Mid-Atlantic	15	2	<1	<1
Northeast Atlantic	19	3	<1	<1
Pacific Northwest (Dredged)	4	<1	<1	<1
Pacific Northwest (Intertidal)	192	106	2	<1
TOTAL	2,826	391	30	<1

[a] Represents refrigeration immediately after harvest; the effectiveness of which varies both regionally and seasonally and is typically approximately 1-log reduction.
[b] Represents any process which reduces levels of *Vibrio parahaemolyticus* in oysters 2-log, e.g., freezing.
[c] Represents any process which reduces levels of *Vibrio parahaemolyticus* in oysters 4.5-log, e.g., mild heat treatment, irradiation, or ultra high hydrostatic pressure.

Reducing the Time-to-Refrigeration

For this scenario, the impact of "rapid" cooling (i.e., using ice or an ice slurry after harvest) such that oysters would be chilled to a "no-growth" temperature (<10˚C) within 1 hour of harvest were compared to "conventional" cooling (i.e., refrigeration after harvest) such that up to 10 hours were presumed for oysters to reach the no-growth temperature. For the Gulf Coast Louisiana/ Summer harvest, the greatest reductions were predicted for shorter times to refrigeration and using cooling with ice compared to cooling under conventional refrigeration (Summary Figure 5). Predicted reduction in *Vibrio parahaemolyticus* illnesses from oysters cooled within 1 hour after harvest ranged from 86% (conventional refrigeration) to 97% (cooling with ice). The lower temperatures associated with the other regions result in predicted reductions that are less dramatic.



Summary Figure 5. Predicted Effectiveness of Two Different Methods of Cooling on *Vibrio parahaemolyticus* Risk for the Gulf Coast Region (Louisiana and non-Louisiana) Summer Harvest [Errors bars denote central 95% of uncertainty distribution about the mean % reduction.]

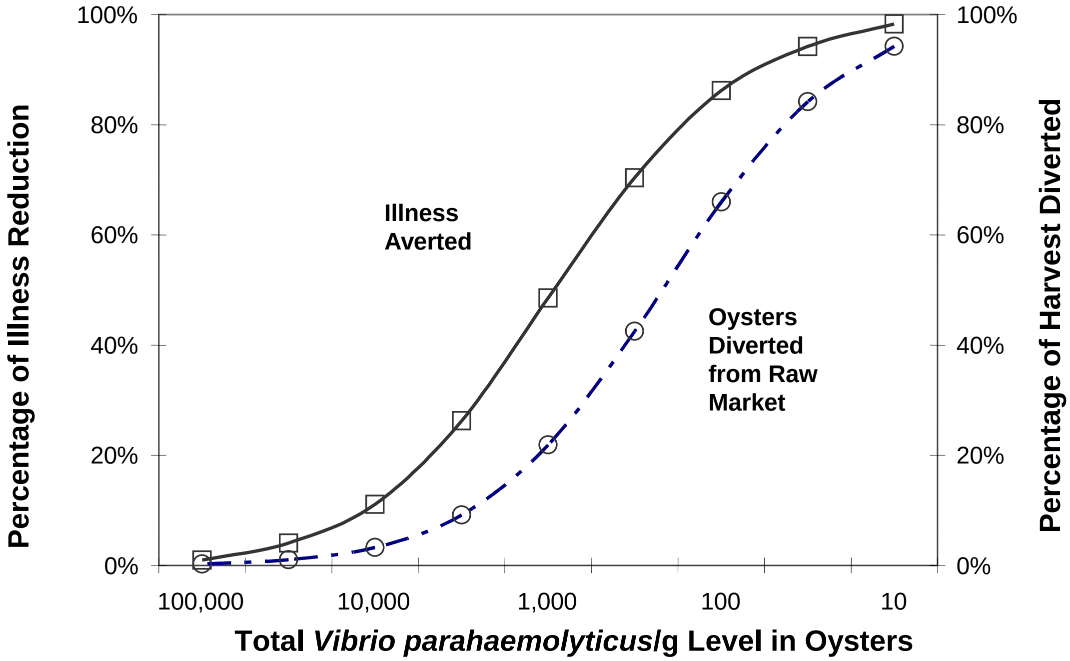
Re-submersion of Intertidally Harvested Oysters

As an example of a harvest practice scenario, the impact of overnight submersion of oysters was evaluated. The model predicts the levels of *Vibrio parahaemolyticus* in intertidally-harvested oysters, e.g., oysters are placed into baskets and removed after the tide rises, a typical practice in the Pacific Northwest. *Vibrio parahaemolyticus* levels can increase in oysters during intertidal exposure but overnight submersion of the oysters in water has been shown to reduce these levels. Delaying harvest until near the end of the tidal cycle, just before oysters are exposed again, was predicted to reduce the risk of illness by approximately 90%. Research is needed to determine whether the predicted level of reduction can be achieved when oysters are stacked in baskets.

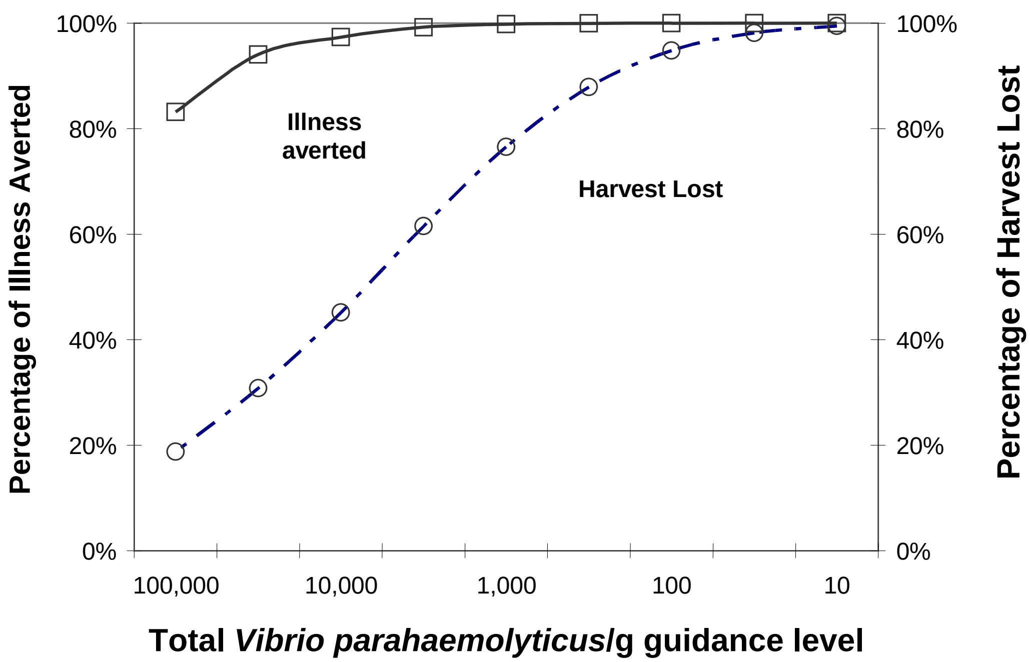
Sample-Based Control Plans

The FDA/ISSC recommends that the levels of *Vibrio parahaemolyticus* in oysters not exceed 10,000 cells/gram and the ISSC interim control plan (ICP) recommends monitoring of oyster meats for the presence of *Vibrio parahaemolyticus*. Prior to 2001, ISSC recommended that shellfish harvest waters be re-sampled for pathogenic *Vibrio parahaemolyticus* if the levels of total *Vibrio parahaemolyticus* in oyster meats at harvest exceed 10,000 cells/gram. In 2001, the ICP was revised to recommend that shellfish harvest waters be re-sampled for pathogenic *Vibrio parahaemolyticus* if the levels of total *Vibrio parahaemolyticus* in oyster meats at harvest are above 5,000 cells/gram.

The incidence of illness was evaluated assuming that it was possible to identify and exclude oysters from the raw market which contained various specified levels of *Vibrio parahaemolyticus* either at harvest or at retail. The Gulf Coast region (Louisiana)/ Summer harvest is presented here as an example. As shown in Summary Figures 6 and 7, restricting the levels of *Vibrio parahaemolyticus* in oysters either at-harvest or at-retail reduces the number of predicted illnesses, but requires diversion of oysters from the raw market (or modification of handling practices to reduce post-harvest *Vibrio parahaemolyticus* growth). For the Gulf Coast region (Louisiana) summer harvest, in the absence of subsequent post-harvest mitigation, excluding oysters containing >10,000 *Vibrio parahaemolyticus*/g at the time of harvest is predicted to prevent approximately 16% of illnesses with an impact of approximately 3% of the oyster harvest(Summary Figure 6). However, excluding oysters containing >10,000 *Vibrio parahaemolyticus* at-retail reduced predicted illness by 99% but would require approximately 43% of the oyster harvest to be diverted from the raw market consumption (or subjected to preventive controls). The impact of compliance with different "at-harvest" and "at-retail" (i.e., after refrigeration) control levels was also evaluated. As might be expected, the effectiveness of a specific (or hypothetical) control level to reduce illnesses depend was proportional to the extent of compliance with that level.



Summary Figure 6. Potential Effect of Control of Total *Vibrio parahaemolyticus* Bacterium per gram At-Harvest for the Gulf Coast Region (Louisiana) Summer Harvest



Summary Figure 7. Potential Effect of Control of Total *Vibrio parahaemolyticus* per gram At-Retail for the Gulf Coast Region (Louisiana) Summer Harvest

CONCLUSIONS

This risk assessment included an analysis of the available scientific information and data in the development of a model to predict the public health impact of pathogenic *Vibrio parahaemolyticus* in raw oysters. The assessment focuses on comparing the relative risk among different geographic regions, seasons, and harvest practices. The scientific data and the mathematical models developed during the risk assessment facilitate a systematic evaluation of strategies to reduce the public health impact of pathogenic *Vibrio parahaemolyticus* associated with the consumption of raw oysters.

Although the risk assessment modeled sporadic *Vibrio parahaemolyticus* illnesses, steps taken to reduce sporadic cases would be expected to reduce the size and frequency of outbreaks. The proportional reduction would depend on the virulence of the outbreak strain and on the survivability and growth of the strain following post-harvest treatments. Mitigation or control measures aimed at decreasing levels of *Vibrio parahaemolyticus* in oysters will also likely decrease levels of other species in the *Vibrio* genus (or family), such as *Vibrio vulnificus*.

Below are the responses to the questions that the risk assessment team was charged with answering.

What is known about the dose-response relationship between consumption of *Vibrio parahaemolyticus* and illnesses?

- Although an individual may become ill from consumption of low levels of *Vibrio parahaemolyticus*, it is much more likely that he or she will become ill if the level is high. The probability of illness is relatively low (<0.001%) for consumption of 10,000 *Vibrio parahaemolyticus* cells/serving (equivalent to about 50 cells/gram oysters). Consumption of about 100 million *Vibrio parahaemolyticus* cells/serving (500 thousand cells/gram oysters) increases the probability of illness to about 50%.
- Anyone exposed to *Vibrio parahaemolyticus* can become infected and develop gastroenteritis. However there is a greater probability of gastroenteritis developing into septicemia (and possibly death) among the subpopulation with concurrent underlying chronic medical conditions.
- The model predicts about 2,800 *Vibrio parahaemolyticus* illnesses from oyster consumption each year. Of infected individuals, approximately 7 cases of gastroenteritis will progress to septicemia each year for the total population, of which 2 individuals would be from the healthy subpopulation and 5 would be from the immunocompromised subpopulation.
- This risk assessment assumed that pathogenic strains of *Vibrio parahaemolyticus* are TDH^+ and that all strains possessing this characteristic are equally virulent. Modifications can be made to the risk assessment if data become available for new virulence determinants. For example, data from outbreaks suggest that fewer microorganisms of *Vibrio parahaemolyticus* O3:K6 are required to cause illness compared to other strains.

What is the frequency and extent of pathogenic strains of *Vibrio parahaemolyticus* in shellfish waters and in oysters?

- Levels of pathogenic *Vibrio parahaemolyticus* usually occur at low levels in shellfish waters.
- Levels of pathogenic *Vibrio parahaemolyticus* in oysters at the time of harvest are only a small fraction of the total *Vibrio parahaemolyticus* levels.

What environmental parameters (e.g., water temperature, salinity) can be used to predict the presence of *Vibrio parahaemolyticus* in oysters?

- The primary driving factor to predict the presence of *Vibrio parahaemolyticus* in oysters is water temperature. Salinity was a factor evaluated but not incorporated into the model. Salinity is not a strong determinant of *Vibrio parahaemolyticus* levels in the regions that account for essentially all the commercial harvest. Other factors such as oyster physiology and disease status may also be important but no quantifiable data were available to include these factors in the model.
- There are large differences in the predicted levels of *Vibrio parahaemolyticus* in oysters at harvest among regions and seasons. For all regions, the highest levels of *Vibrio parahaemolyticus* were predicted in the warmer months of summer and spring and the lowest levels in the fall and winter.
- Overall, the highest levels of total and pathogenic *Vibrio parahaemolyticus* were predicted for the Gulf Coast (Louisiana) and the lowest levels in the Pacific Northwest (Dredged) harvested oysters.
- After harvest, air temperature is also an important determinant of the levels of *Vibrio parahaemolyticus* in oysters. *Vibrio parahaemolyticus* can continue to grow and multiply in oysters until they are adequately chilled.
- Levels of *Vibrio parahaemolyticus* are lower in oysters after harvest in the cooler vs. warmer months. This means that reducing the time between harvest and cooling will be more important in the summer and spring than in the fall and winter.

How do levels of *Vibrio parahaemolyticus* in oysters at harvest compare to levels at consumption?

- With no mitigation treatments, levels of *Vibrio parahaemolyticus* are higher in oysters at consumption than at harvest. The difference between *Vibrio parahaemolyticus* densities at-harvest versus at-consumption is largely attributable to the extent of growth that occurs before the oysters are cooled to no-growth temperatures.
- Levels of *Vibrio parahaemolyticus* in oysters vary by region and season and are highest during the summer.
- During intertidal harvest, oysters are exposed to higher temperatures for longer times, allowing additional growth of *Vibrio parahaemolyticus* in oysters and leading to higher predicted risk of illness.
- Preventing growth of *Vibrio parahaemolyticus* in oysters after harvest (particularly in the summer) will lower the levels of *Vibrio parahaemolyticus* in oysters and, as a consequence, lower the number of illnesses associated with the consumption of raw oysters.

What is the role of post-harvest handling on the level of *Vibrio parahaemolyticus* in oysters?

- Post-harvest measures aimed at reducing the *Vibrio parahaemolyticus* levels in oysters reduced the model-predicted risk of illness associated with this pathogen.
- Reducing the time between harvest and chilling has a large impact on reducing levels of *Vibrio parahaemolyticus* in oysters and the number of illnesses. Predicted reductions were greater for shorter times to refrigeration using ice (oysters reach no-growth temperature in 1 hour) compared to cooling under conventional refrigeration (which may take up to 10 hours until oysters reach a no-growth temperature).

What reductions in risk can be anticipated with different potential intervention strategies?

- Overall. The most influential factor affecting predicted risk of illness is the level of total *Vibrio parahaemolyticus* in oysters at the time of harvest. Intervention strategies should be aimed at reducing levels of *Vibrio parahaemolyticus* and/or preventing its growth in oysters after harvest. These strategies, either at-harvest or post-harvest, may need to consider regional/seasonal differences. For example, the use of ice on harvest boats to cool oysters to the no-growth temperature of *Vibrio parahaemolyticus* will have a larger impact on reducing illnesses in the summer than in the winter when air temperatures are cooler and *Vibrio parahaemolyticus* levels are lower.
- Regional/Seasonal Differences. The risk of *Vibrio parahaemolyticus* illness is increased during the warmer months of the year, with the magnitude of this increase a function of the extent to which the growing waters (and air temperature) are at temperatures that support the growth of the pathogen (e.g., temperatures above 10˚C). For each region, the predicted numbers of illnesses are much higher for the summer compared to the winter months. Intervention measures that depend on cooling oysters to no-growth temperatures for *Vibrio parahaemolyticus* may be more important in warmer seasons and regions.

  The risk of *Vibrio parahaemolyticus* illness is substantial in the Gulf Coast region where water temperatures are warm over a large part of the year as compared to the Northeast Atlantic region where water temperatures support the growth of *Vibrio parahaemolyticus* only during a relatively small portion of the year. A difference is seen among the regions due to different harvesting methods. Within the Gulf Coast, the predicted number of illnesses is much higher in Louisiana compared to other states in this region because the harvest boats in Louisiana are typically on the water longer, i.e., leading to a longer time from harvest to refrigeration. Harvest volume is also a determining factor; in the summer, Louisiana accounts for approximately 77% of the Gulf Coast harvest. This is also seen in the Pacific Northwest by comparing intertidal versus dredged harvesting. Intertidal harvesting accounts for 75% of the Pacific Northwest harvest and exposes oysters to higher temperatures longer, allowing greater growth of *Vibrio parahaemolyticus*. Overnight submersion for a single tidal cycle, reduces levels of *Vibrio parahaemolyticus* in oysters and the risk of illness.

- Post-Harvest Treatments. Post-harvest treatments that reduce levels of *Vibrio parahaemolyticus* by 2 to 4.5-logs were found to be effective for all seasons and regions, with the most pronounced effects seen for regions and seasons with higher baseline risk. The model shows that any treatment that causes at least a 4.5-log decrease in the number of *Vibrio parahaemolyticus* bacteria reduces the probability of illness to such an extent that few illnesses would be identified by epidemiological surveillance. However, some outbreak strains (e.g., O3:K6) are more resistant to mitigations than endemic pathogenic *Vibrio parahaemolyticus* strains, and the duration or extent of treatment may need to be more stringent to achieve an equivalent degree of reduction. Studies have shown that both *Vibrio parahaemolyticus* and *Vibrio vulnificus* respond similarly to control measures such as ultra high pressure, mild heat treatment, and freezing. Therefore, mitigations aimed at decreasing levels of *Vibrio parahaemolyticus* will also likely decrease levels of *Vibrio vulnificus*.

  The model also demonstrated that if oysters are not refrigerated soon after harvest, *Vibrio parahaemolyticus* rapidly multiply resulting in higher levels. For example, the model indicates that for the Gulf Coast there is a significant reduction (~10-fold) in the probability of illness when the oysters are placed in a refrigerator immediately after harvest. Less pronounced reductions are predicted for the other regions. Predicted reduction in illness is less in colder seasons because oysters harvested in cooler weather are already at or below the temperature threshold for *Vibrio parahaemolyticus* growth and as such refrigeration has little additional impact on levels of *Vibrio parahaemolyticus*.

- At-Harvest and At-Retail Controls. Controlling the levels of *Vibrio parahaemolyticus* in oysters at-harvest or at-retail (after refrigeration and storage) drastically reduces the number of predicted illnesses but would require diversion of oysters from the raw market or modification of handling practices to reduce post-harvest *Vibrio parahaemolyticus* growth. For the Gulf Coast (Louisiana) region in the summer, excluding all oysters with at least 10,000 *Vibrio parahaemolyticus*/g at-harvest would reduce illness by approximately 16% at a loss of approximately 3% of the total harvest from the raw consumption market; and this same control level at-retail would reduce illness by about 99% with a 43% loss from the raw oyster market (or subjected to preventive controls). The effectiveness of the control level either at-harvest or at-retail to reduce illnesses depends on the extent of compliance with that control level.

  In a sample-based control strategy, a reasonable surrogate for pathogenic *Vibrio parahaemolyticus* may be total levels of this microorganism. Criteria for rejection of oysters based on the levels of this surrogate might have to vary by region. For example, an at-harvest control criterion based on total *Vibrio parahaemolyticus* levels in the Pacific Northwest might need to be more stringent than in the Gulf Coast because the incidence of pathogenic strains appears to be higher in the Pacific Northwest. However, in an outbreak, the ratio of pathogenic to total *Vibrio parahaemolyticus* may not be the same or consistent, and the model does not evaluate how well total *Vibrio parahaemolyticus* would serve as a surrogate for pathogenic *Vibrio parahaemolyticus* in an outbreak situation.

In conclusion, the risk assessment illustrates that the levels of *Vibrio parahaemolyticus* at the time of harvest play an important role in causing human illness. However, other factors that either reduce or allow growth of *Vibrio parahaemolyticus* in oysters are also important in determining the number of illnesses. For example, shortening the time-to-refrigeration of oysters in the summer controls growth of *Vibrio parahaemolyticus* in oysters and subsequently reduces illnesses associated with this microorganism.

The results of this risk assessment are influenced by the assumptions and data sets that were used to develop the Exposure Assessment and Dose-Response models. The predicted risk of illness among consumers of raw oysters could change as a result of future data obtained from continuing surveillance studies. It is anticipated that periodic updates to the model will continue to reduce the degree of uncertainty associated with the factors that influence the risk. This risk assessment provides an understanding of the relative importance of and interactions among the factors influencing risk. It can be used to facilitate the formulation of effective guidance and requirements for the industry and in the evaluations of risk mitigation strategies. This Interpretive Summary provides a brief, non-technical description of the materials covered, but a full understanding requires the reader to consider the complete risk assessment.