United States Department of Agriculture

# Decapod Iridescent Virus (DIV1) Rapid Risk Assessment

**United States Department of Agriculture**

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### Key Points

Decapod iridescent virus (DIV1) is a recently emerged pathogen responsible for high mortality events in several farmed shrimp species, including species cultured in the United States. The current known global distribution of DIV1 includes China, Taiwan, Thailand, and Vietnam. To data there have been no DIV1 introductions into U.S. shrimp aquaculture.

The overall estimated risk of decapod iridescent virus (DIV1) introduction into the United States via importation of shrimp and shrimp products is high due to:

- Reported presence of DIV1 in some countries that export to the United States
- Lack of DIV1 surveillance and reporting in many countries
- DIV1 has a wide known-host range
- Reported virus persistence in approximately 20 percent of crustaceans surviving natural disease and experimental challenge. The ability of surviving animals to function as reservoir hosts is presumed
- Lack of Federal and State regulations (except for Florida) regarding importation of potentially infected shrimp and shrimp products in general
- Lack of Federal import regulations specific to DIV1

The most likely entry pathways include:

- Ballast water and ship fouling
- Importation of live shrimp for aquaculture purposes
- Importation of shrimp and shrimp seafood products for human consumption
- Imported bait shrimp

The overall estimated risk of DIV1 exposure occurring in domestic shrimp farms is moderate to high. The most likely exposure pathways include:

- Introduction of DIV1-infected shrimp into aquaculture facilities
- Contaminated water sources

This risk assessment is preliminary and is subject to several limitations, such as:

- Lack of quantitative data regarding the epidemiology of DIV1, including lack of data on specific entry and exposure pathways as well as susceptibility of native crustaceans
- No known methods to reliably estimate disease consequences in aquaculture systems
- No nationally representative domestic surveillance program

# Background

## History

Decapod iridescent virus (DIV1) and its associated isolates, including shrimp hemocyte iridescent virus (SHIV 20141215, SHIV) and *Cherax quadricarinatus* iridovirus (CQIV CN01, CQIV), are viruses of the genus *Decapodiridovirus,* as classified by the Executive Committee of the International Committee on Taxonomy of Viruses (ICTV).[1] SHIV was identified in 2014 as the causative agent of high mortality events in farmed *Penaeus vannamei*, *P. chinensis*, and *Macrobrachium rosenbergii* in several of China's coastal areas and provinces (Guangdong, Hebei, Zhejiang).[1] CQIV was first described in 2014 in China as the cause of high mortality disease outbreaks in *Cherax quadricarinatus* and *P. vannamei*.[2] Initially called "white head" or "white spot" disease, DIV1 was first reported in 2014 in Chinese crustacean aquaculture systems experiencing high mortality events.[1] This document will use DIV1 to refer to the virus and the two associated isolates, as recommended by the ICTV.

## Geographic Distribution

The original source of DIV1 is unknown.[3] Published reports describe occurrences of the disease in aquaculture systems in China beginning in 2014, followed by detection in 11 of 16 provinces (69 percent) in 2017 and 2018.[4] Outbreaks affecting approximately 25 percent of the shrimp-producing areas in Guangdong province were reported in 2019 and 2020. The pathogen has also been detected in waters off the coast of China.[1, 2, 4] In 2020, Taiwan reported DIV1 presence in crayfish and shrimp farms via the World Organisation for Animal Health World Animal Health Information System (WOAH-WAHIS).[5] In 2020, Thailand reported detection of DIV1 in wild *P. monodon* harvested from the northeastern Indian Ocean in 2018 and 2019.[6] In 2020, it was reported that the disease had been identified in farmed shrimp in Vietnam.[7] To date, there have been no detections of DIV-1 in the United States.

## Current Regulations

Effective January 1, 2021, the WOAH determined that DIV1 met the WOAH criteria for listing as described in *Aquatic Animal Health Code, Article 1.2.2*. [8-10] DIV1 is also listed in the WOAH /Network of Aquaculture Centres in Asia-Pacific quarterly aquatic animal disease report.[3, 5]

As of June 2022, DIV1 was included as a reportable disease on the United States National Animal Health Reporting System (NAHRS) Reportable Diseases, Infections, and Infestations List and the USDA-APHIS National Veterinary Accreditation Program (NVAP) Notifiable Diseases and Conditions website.[11-14] Currently there are no Federal regulations requiring documentation of crustacean health prior to import to the United States, and imported crustaceans are not quarantined at ports of entry prior to distribution within the United States. There is currently no national surveillance plan for DIV1.

Some States (e.g., California, Florida, and Texas) require certification of health before entry for both imported and domestic crustacean species (specific requirements for DIV1 in all states are not known or readily accessible). As of June 1, 2022, the Florida Department of Agriculture and Consumer Services (FDACS) issued a penaeid shrimp health update stating that All Florida Aquaculture Certificate of Registration holders producing penaeid shrimp much comply with applicable rules in the Florida Best Management Practices Manual, including that a) all live penaeid shrimp sold to a certified facility/operator must be accompanied by diagnostic results, including testing for DIV1, from an accredited laboratory and a signed Official Certificate of Veterinary Inspection (OCVI); b) the diagnostic results and OCVI must be provided to the FDACS, Division of Aquaculture prior to shipment.[15]

Management of ballast water discharge via ballast water treatment and exchange (BWTE) is regulated federally by the United States Environmental Protection Agency (EPA), the United States Coast Guard (USCG), and at State levels. Ballast water discharges are required to meet International Maritime Organization ballast water management convention D-2 standards for allowable concentrations of living organisms, microorganisms, and human enteric pathogens considered "*indicators problematic for ballast water*."[12-14, 16] Current regulations and standards do not list conditions for ballast water treatment, monitoring, or testing for aquatic pathogens, including DIV1. Vessels are not required to install a ballast water treatment system if they a) do not discharge ballast water, b) discharge only to shoreside facilities, or c) discharge to water that presents little threat (such as public drinking water).[12, 13, 16] Vessels operating in only one Captain of the Port (COPT) Zone are exempted from ballast water exchange reporting and recordkeeping requirements [13, 16-18]. However, COPT zones are administrative, are not established using ecological or biological bases, and may not be appropriate boundaries for addressing invasive species.[18]

Seafood processors, including those that process shrimp, are subject to Seafood Hazard Analysis Critical Control Point (HACCP) Regulation (21 CFR Part 123 and other regulation (i.e., Current Good Manufacturing Practice regulation, 21 CFR Parts 117 Subpart B). However, such regulations are designed to ensure human public health, and monitoring seafood processing for aquaculture safety is not under the purview of such regulations.[19, 20]

Domestic seafood processing operations may process or reprocess imported seafood, including imported chilled or frozen shrimp and shrimp seafoods. Processing operations produce solid waste, sludge, and wastewater.[21] Wastewater discharges are regulated under the Federal Water Pollution Control Act (Clean Water Act (CWA)) and EPA Seafood Processing Effluent Guidelines and Standards (a.k.a., Canned and Preserved Seafood Category; 40 CFR 408). Wastewater is discharged to public water treatment works, municipal storm sewer systems, municipal sanitary sewers, or natural water bodies.[22-25] In some States, a National Pollutant Discharge Elimination System (NPDES) permit may be required if effluents are discharged into municipal storm sewer systems, but such permitting may not be required if effluent is discharged into a municipal sanitary sewer system.[24, 26] Wastewater and effluents that enter public water treatment works or municipal sanitary sewer systems are treated prior to final discharge into natural water bodies; those entering storm sewer systems are not treated prior to discharge. It is required that wastewater disinfection and treatment be sufficient to prevent contamination or damage to public water works or natural water bodies; however, requirements are dependent on the size of the processing facility. For example, small processing plants, markets, restaurants, and farms may be exempt from some regulations. Processing facilities are required to monitor and sample wastewater discharges and notify the EPA and State regulatory agencies of the results. However, regular monitoring may not occur and violations have been reported and monitoring requirements do not include surveillance for aquatic animal pathogens. [24]

Some solid processing wastes are used to produce fish meal and fish oils.[27] Remaining solid and sludge wastes may be disposed of via solid waste land disposal methods (e.g., landfills and composting), anaerobic digestion, and land application (i.e., as fertilizer).[28] Municipal solid waste landfills are required to monitor groundwater for contamination during their active life, and post-closure. Small landfills receiving less than 20 tons of solid waste per day and facilities that can demonstrate no potential for migration of hazardous constituents into groundwater are exempted from this requirement (40 CRF Part 258, Subpart E – Ground Water Monitoring and Corrective Action).[29] Landfills are required to monitor groundwater for microbial contamination. Monitoring landfills for aquaculture pathogens, including DIV1, is not required.[29]

Anaerobic digestion results in production of biogas and digestate, composed of liquid and solid materials. Biogas is typically incorporated into renewable energy distribution systems, while digestate is incorporated into fertilizer, animal bedding, bio-based products (e.g., bioplastics), or solid amendments. Anaerobic digesters must meet local, State and Federal regulatory and permitting requirements, as well as permitting requirements for Concentrated Animal Feeding Operations. Monitoring of aerobic digestion by-product for presence of aquatic pathogens is not required.[30]

Fish waste disposed of via land application is typically regulated and permitted by individual States and may require documentation of total solids, pH, and nutrient content. Some States include requirements limiting application of waste near waterbodies, on saturated ground, land with greater that 12 percent slope or land that is flooded, frozen or snow covered, and other measures to limit or prevent run-off. There appear to be no requirements regarding surveillance for aquatic animal pathogens.[31-33] Composting of processing and food waste is regulated at the local and State level.[34] Waste typically must be composted using methods that meet pathogenic *Salmonella* spp., and fecal coliform bacteria reduction requirements, environmental impact (leachate, air emissions), and other requirements. There are no requirements requiring surveillance for aquatic animal pathogens.[34, 35]

Small markets (e.g., farm markets, live markets, retail stores) and restaurants are exempt from Federal inspection, but are regulated by State and local health authorities and subject to State and local requirements for operating a food business.[36-38] Solid and liquid waste disposal may not be subject to regulation; however, regulations vary by State. State regulatory requirements can be accessed at their respective websites.

The U.S. aquaculture industry is regulated by Federal, State, and local laws. Three types of permits are typically issued for aquaculture (e.g., biosecurity, discharge, siting). Siting permits are governed by Section 404 of the CWA and control the siting, number, and size of shrimp farms; establish requirements that must be met; regulate discharge of dredged or fill material into the nation's waters; and prevent the degradation of national waters and wetlands. The U.S. Army Corps of Engineers administers Section 404 under the overview of the EPA, often cooperatively with State coastal zone management programs.[39] The United States Fish and Wildlife Service investigates potential fish and wildlife impacts.[40]

The EPA is responsible for enforcing the CWA, which authorizes the NPDES permit program.[23, 26, 40] States administer the NPDES permit program, which regulates concentrated aquatic animal production (CAAP) facilities (e.g., fish farm, hatchery, production, other facilities) that discharge pollutants into Federal waters.[24, 26] Permits and requirements are structured for each farm based on the characteristics of the water body that the farm is discharging effluent to, farm production type, and levels of ammonia, dissolved oxygen, and total suspended solids present in the effluents.[40] Aquatic animal production facilities producing less than 45,359 kilograms annually are not subject to CAAP effluent guidelines but may still need NPDES permits. CAAP facilities must a) meet permit requirements for ongoing monitoring metrics; b) keep records on animal numbers and weights, quantity of feeds, and frequency of cleaning, inspections, maintenance, and repairs; c) report failures or damage to containment systems; d) report use of experimental animal drugs and drugs not used according to label requirements; e) minimize discharges of excess feed; f) prevent discharge of drugs and pesticides that have been spilled; g) regularly maintain production and wastewater treatment systems; h) minimize solid waste discharges (e.g., uneaten feed, settled solids, animal carcasses) if they are facilities with flow-through and recirculating discharge systems; i) adequately train staff to properly operate and maintain production and wastewater treatment systems and to prevent and respond to spills; and j) develop, maintain, and certify a Best Management Practice (BMP) plan.[40] A BMP describes how the aquaculture production facilities will meet the set requirements and guidelines. Some States may develop or enact State-specific BMPs.[10, 40, 41] States may conduct unannounced BMP inspections annually or as needed, and variably regulate and monitor biosecurity and disease prevention measures to prevent potential release of aquatic pathogens into approximate natural water bodies.[40]

States are mandated under the CWA to designate specific uses of water bodies and assign site-specific water quality standards.[39, 40] State aquaculture regulations are not standardized; vary by location (e.g., coastal, inland, wetland) and type of operation; and may include oversight of aquaculture facility design, control measures to prevent escape of all shrimp life stages at all water/effluent discharge points, effluent treatment and discharge, species certification relative to wildlife management and disease freedom status, and water use.[10, 40] State coastal management guidelines must follow or may be more restrictive than those described in the Coastal Zone Management Act. [42]

## Hazard Identification

Hazard identification involves identifying and describing facts pertinent to the specific pathogen of concern.

The complete epidemiology of DIV1 is not fully known.

### Transmission

The known route of transmission is ingestion of infected food, debris, and tissues.[43] There is currently no evidence of vertical transmission.[3] The rate of transmission appears high in intensive aquaculture. Currently, infected farmed and wild crustaceans are the only established reservoirs of infection. Fomites, animal vectors (e.g., birds, mammals, aquatic animals), water, pond substrates, bait, and tainted feed have been described as potential transmission routes.[3] Virus presence and/or persistence in aquaculture environments, commensal crustaceans, invertebrates, zooplankton, pond water, soils, substrates, or other organisms is largely unknown. Recurrences of disease following re-introduction of susceptible crustaceans into previously infected ponds has been documented. [1, 3] DIV1 has been detected in shrimp and crayfish at environmental temperatures ranging from 16 to 32 °C/60.8 to 89.6 °F but has not been detected at temperatures greater than 32 °C/ 89.6 °F.[1, 3, 44]

### Affected Species

DIV1 has a wide known host range that includes several economically important cultured crustacean species. Susceptible species as described by the WOAH and published literature are summarized in **Table 1**. Susceptible species cultivated in the United States include *M. rosenbergii, P. monodon, P. vannamei*, and *Procambarus clarkii.* In some regions of the United States, escaped and potentially established populations of these species have been reported.[45-48] Species of crab present in U.S. coastal waters that appear susceptible based on experimental challenge studies include *Eriocheir sinensis* and *Pachygrapsus crassipes*. The literature has not reported susceptibility of indigenous wild penaeid shrimp or other crustaceans to DIV1.

**Table 1. DIV1 susceptible crustacean species as reported in the literature and by WOAH**

| Genus, species | Common Name | Reference |
|---|---|---|
| *Exopalaemon carinicauda* [a, b] | Ridgetail white prawn | [3, 5, 49] |
| *Fenneropenaeus merguiensis* [c] | Banana shrimp | [50] |
| *Macrobrachium japonicum* [b] | | [3] |
| *Macrobrachium nipponense* [a, d] | Oriental river prawn | [1, 3, 5, 49] |
| *Macrobrachium rosenbergii* [a, b, d] | Giant freshwater prawn | [1, 3, 5, 49] |
| *Macrobrachium superbum* [a] | | [49] |
| *Penaeus chinensis* [a, d] | Fleshy prawn | [1, 5, 49] |
| *Penaeus japonicus* [a, d] | Kuruma prawn | [1, 5, 49] |
| *Penaeus monodon* [d] | Giant tiger prawn | [5] |

| | | |
|---|---|---|
| *Penaeus vannamei* [a, b, d] | Whiteleg shrimp | [1, 5, 49] |
| *Cherax quadricarinatus* [a, b, d] | Red claw crayfish | [1, 5, 49] |
| *Procambarus clarkii* [a, c, d] | Louisiana crayfish | [1, 5, 49] |
| *Eriocheir sinensis* [c] | Chinese mitten crab | [5] |
| *Pachygrapsus crassipes* [c] | Striped shore crab | [5] |

a) Literature reported
b) Experimental challenge meeting WOAH criteria for natural infection
c) Experimental challenge did not meet WOAH criteria for natural infection
d) Detected in farmed species

## Clinical Signs and Pathogenicity

Susceptibility is variable among different species. *Macrobrachium rosenbergii* and *M. nipponense* are reported as highly susceptible, and *P. vannamei* has been reported to be more susceptible compared to *C. quadricarinatus* and *Pr. clarkii*.[1] Clinical signs are non-specific, develop rapidly (approximately three days to first observation in experimental challenge studies), and include abnormal appearing antenna, anorexia, empty gastrointestinal tract, lethargy, loss of coloration around the hepatopancreas, reddish discoloration of the body, soft shell, and whitish to yellowish discoloration of the head. Moribund animals lose ability to swim and sink to the bottom of the enclosure. A white triangle may be seen at the base of the rostrum in *M. rosenbergii*. Mortality may occur within three days of onset of clinical signs. Daily mortalities ranging from 14 to 16 percent and cumulative mortalities of 80 to 100 percent are reported in some species (e.g., *P. vannamei*, *M. rosenbergii*).[1, 3, 4, 43, 49] Virus persistence in approximately 20 percent of crustaceans surviving natural disease and experimental challenge has been reported. The ability of surviving animals to function as reservoir hosts is unclear but presumed.[43]

## Diagnostic Testing

DIV1 virus has been identified in shrimp and crayfish at all life stages, with highest levels of detection in animals with a body length of four to seven centimeters.[1, 3, 4] Virus is detectable in antennal flagellum, cuticle, gills, hematopoietic tissues, hemocytes, hepatopancreas, lymphoid organs, muscle, pleopods, rostrum, and uropods.[3, 4] Currently available validated diagnostic assays include a nested PCR [4] and two TaqMan probe based real-time PCR (TaqMan qPCR) assays.[44] The PCR primers and TaqMan probes are DIV1-specific and have a low detection limit (four copies per reaction) and high sensitivity and specificity (95.3 and 99.2 percent, respectively).[3, 5] Additional diagnostic methods include histopathology, *in situ* digoxigenin (DIG)-labelling-loop-mediated DNA amplification, *in situ* hybridization assay (ISH), and transmission electron microscopy (TEM).[1, 44] Infection with DIV1 is considered confirmed if two or more of the following criteria are met: a) gross clinical signs are present; b) histopathological findings are consistent with DIV1 infection; c) ISH assay on target tissues is positive; d) PCR is positive (followed by confirmation via sequencing); e) nested-PCR is positive (followed by confirmation via sequencing); and f) TaqMan probe based real-time PCR is positive.[3] Viral DNA has been detected in dried, desiccated shrimp using the TaqMan qPCR; however, this only confirmed persistence of DNA in tissue, not persistence of intact infectious virus.[1, 4] Currently there are no tests for detection of DIV1 in the environment.

## Treatment

There are no treatments or vaccines available.

### Control Measures

Prevention and control of DIV1 introduction and spread requires appropriate biosecurity measures. Generic on-farm biosecurity measures, such as cleaning and disinfection, are recommended to minimize fomite spread via equipment, vehicles, and staff. Filtering and treatment of influent and effluent water is recommended. Enhanced biosecurity measures include quarantine and surveillance testing of introduced animals, broodstock, post-larvae, and moribund or sick crustaceans; restricted movement of live crustaceans onto, off, or within the farm; and protocols regarding removal and disposal of moribund or dead crustaceans. Polyculture should be avoided. Live or frozen raw crustaceans, crustacean byproducts, and polychaetes (marine annelid worms) should not be used as feed ingredients.[1, 3, 44]

### Public Health

DIV1 is not a zoonotic disease.

## Entry Assessment

An entry assessment describes the pathway(s) from points of origin to points of entry that might allow introduction of the hazard into a particular environment and estimates the probability of that happening.

The overall likelihood that DIV1 will enter the United States is *high*, with a *low to moderate* degree of uncertainty This assessment is based on:

- Lack of Federal regulation and regulation in most States regarding imports of live crustaceans or bait shrimp
- Historical introductions of shrimp pathogens via live shrimp for imported aquaculture purposes, bait shrimp, and chilled or frozen shrimp and seafood for human consumption
- Knowledge and data gaps associated with all identified entry pathways

Potential entry pathways of introduction include:

1. Ballast water and Ship Fouling
2. Live shrimp imported for aquaculture purposes
3. Imported fresh or chilled shrimp and shrimp seafoods for human consumption
4. Imported bait shrimp
5. Imported shrimp by-product

### Entry via Ballast Water and Ship Fouling

The likelihood that DIV1 could enter the United States via ballast water or ship fouling is *high* with a *moderate* degree of uncertainty. Ballast water and ship fouling have not been definitively associated with DIV1 introduction; however both are confirmed sources of invasive animal (e.g., crustaceans, echinoderms, fish, mollusks, plankton), microorganism (e.g., bacteria, viruses), and plant species introductions in coastal and freshwater systems nationally and internationally.[17, 18, 51-53] Crustacean species, including shrimp, can compose up to 50 percent of taxa fouling commercial and recreational ships and boats in fresh and marine water.[53] Discharged ballast water may contain crustacean species, and free virus or virus attached to organic matter and plankton, which may be distributed to susceptible crustacean populations (wild or cultivated) via water currents.[54, 55]

Ballast water is to be treated and exchanged in accordance with International, Federal and State regulations and standards. Some ships are exempt from BWTE and recordkeeping requirements, or are allowed to discharge ballast water in COPT zones. However, COPT zones are administrative and do not consider ecological or biological factors that may permit movement of invasive microorganisms, organisms, or plants out of the zone. BWTE efficacy is estimated to range from 50 to 90 percent and reduces but does not eliminate living organisms and microorganisms from ballast water and biofilms or sediments in ballast tanks.[17, 18, 51] In general, data are lacking on the efficacy of BWTE on viruses. Published literature suggests that a) viral testing may not occur; and b) BWTE may decrease the concentration of viruses present in ballast water below the detection limits of assays currently used to evaluate treatment methods.[17, 18, 51] Current regulations and standards do not list conditions for ballast water treatment, monitoring, or testing for aquatic pathogens, including DIV1. Despite International, Federal and State regulation and standards, regulatory non-compliance does occur and is reported in the literature.[56-58]

The literature did not identify any reports definitively linking ballast water or ship fouling to introduction of DIV1 at a port of entry, coastal waterway, or aquaculture facility. However, this lack of data or reporting does not preclude the potential for ballast water or ship fouling to function as transboundary pathways of DIV1 introduction. The likelihood that this pathway will occur is dependent upon specific conditions (e.g., location of ballast water discharge relative to the location of susceptible populations, dispersal of ballast water discharges in water currents, environmental conditions, concentration of plankton or organic matter in the water, survivability of virus in water).[54, 55] Additional knowledge and data gaps affecting the assessment of this entry pathway include, but are not limited to, lack of a) surveillance data or studies monitoring ballast water or ship fouling for DIV1 presence/absence; b) data on the efficacy of ballast water treatment on viruses; c) the length of time that DIV1 remains viable in water and the infectious dose required to elicit disease; and d) information regarding proximity of ports to susceptible crustacean (wild or cultivated) populations.

### Entry via Imports of Live Shrimp Imported for Aquaculture Purposes

The likelihood that DIV1 could enter the United States via imports of live shrimp imported for use in aquaculture is *high* with a *low* degree of uncertainty. Imported nauplii, juvenile and broodstock shrimp are identified in the literature as potential and known sources of pathogen introduction in shrimp aquaculture globally.[59] Live shrimp from foreign hatcheries are imported to the United States for aquaculture purposes, and have historically served as entry pathways for shrimp foreign animal disease (FAD) introductions.[60] The use of air freight to import live shrimp may result in importation of asymptomatic, healthy appearing, DIV1-infected animals during the incubation period, or animals that have survived clinical disease and remain infected. There are currently no Federal import regulations pertaining to DIV1, and there is lack of capability to quarantine live shrimp or other crustaceans at U.S. ports of entry prior to release. There is lack of consistency among States regarding disease surveillance requirements for imported shrimp and other crustaceans. There is lack of data tracking sources, volumes, and movements of shrimp and nauplii prior to and post import, including from areas in the world where DIV1 is known to be present.

## Entry via Imported Chilled and Frozen Shrimp and Shrimp Seafood for Human Consumption

The likelihood that DIV1 could enter the United States via imports of chilled and frozen shrimp and shrimp seafood for human consumption is *high* with a *moderate* degree of uncertainty. Currently there are no published reports of DIV1 detection in chilled or frozen shrimp or shrimp seafood products. However, the validity of this pathway has been demonstrated via documented detections of other pathogenic shrimp viruses (Taura syndrome virus, TSV; white spot syndrome virus, WSSV; yellowhead virus, YHV) in imported frozen commodity shrimp.[61, 62] High concentrations of DIV1 virus have been detected in a variety of shrimp tissues, including edible tissues (muscle) [3, 4], but data regarding virus viability in chilled tissues or after freeze/thaw cycles and stability studies in seafood are lacking.

The United States imports chilled and frozen shrimp and shrimp seafood commodities from countries with reported presence of DIV1 in cultured and/or wild shrimp populations (China, Thailand, Taiwan, Vietnam)(**Appendix, Table 1**).[63] Imported chilled and frozen shrimp and shrimp seafood are required to be prepared in facilities regulated and inspected by the government of the country of origin and must meet USDA and Food and Drug Administration (FDA) processing requirements (e.g., Seafood Hazard Analysis Critical Control Point Plan; HACCP). Only shrimp that appear healthy are to be processed. However, DIV1-infected shrimp may appear healthy, and in some countries, outbreak control measures can include harvest of infected shrimp for human consumption pathways.[59, 62, 64] Inspection rates by U.S. regulatory agencies or contracted third-party inspectors are typically low at foreign processing facilities compared to the number of facilities that produce seafood. In addition, country-of-origin government oversight may be unknown to U.S. regulatory agencies. The FDA does not require or conduct surveillance testing of processing facilities or product for aquatic animal disease pathogens.[61]

## Entry via Imported Bait Shrimp

The likelihood that DIV1 could enter the United States via imports of bait shrimp is *high* with a *high* degree of uncertainty. Imported bait shrimp has been described in the literature as a potential source of aquatic pathogen introduction globally, and studies have demonstrated the existence of this pathway in the United States via identification of TSV and WSSV in imported frozen bait shrimp purchased at bait and grocery stores.[61, 64-66] DIV1 was not detected in these studies, and a literature search did not identify other studies performing surveillance for DIV1 in imported bait shrimp; however, high concentrations of DIV1 virus may be detected in a variety of shrimp tissues.[3]

The United States imports bait shrimp for use in inland freshwater and marine sport fishing [61], including from countries that have reported DIV1 presence in wild and farmed shrimp (e.g., China, Taiwan, Thailand, Vietnam). The total volume of bait shrimp imported and the volumes imported from individual countries annually is not known because bait shrimp are imported under the Harmonized Tariff Schedule of the United States, subheading 0511.91.0090 *Products* *of Fish or Crustacean, Molluscs, or Other Aquatic Invertebrates; Dead Animals of Chapter 3, Unfit for Human Consumption, NESOI*"(**Appendix, Table 2**)[63] Importation of these products is generally unregulated and does not include testing for foreign aquatic animal disease pathogens, including DIV1. Additional knowledge and data gaps affecting assessment of this pathway include a) lack of research or surveillance for DIV1 in imported bait shrimp; and b) lack of information regarding the final disposition pathways of imported bait shrimp relative to wild and farmed susceptible shrimp populations.

### Entry via Imported Shrimp Byproduct or Other Feed Materials

The likelihood that DIV1 may enter the United States in shipments of imported shrimp byproduct or other feed materials is *moderate* with a *high* degree of uncertainty. Unknown quantities of imported shrimp meal, flours and pelleted product, and other materials (e.g., polychaete worms, other crustacean byproducts) are imported to the United States for use as ingredients in shrimp (and other) aquaculture feeds. DIV1 virus may be found in many shrimp tissues, including cuticle and other tissues that may be incorporated into shrimp byproduct or feed materials.

The volume of such products imported to the United States is unknown because these materials are collectively imported as "*Flours, Meals, and Pellets of Fish or of Crustaceans, Molluscs or Other Aquatic Invertebrates, NESOI, Unfit For Human Consumption.*"[63] The United States does import some of these products from countries with documented presence of DIV1 (e.g., China, Taiwan, Thailand, Vietnam)(**Appendix, Table 3**).[63] Information regarding the manufacturing and inspection processes used by all importing countries are not readily accessible; however, the high temperatures typically used to prepare meal-type byproduct (500 °C/932 °F) and pelleted and extruded feeds (71 to 84.6 °C/160 to 300 °F) are likely sufficient to inactivate DIV1 given published thermal inactivation recommendations for this pathogen (56 °C/ 132.8 °F for at least 30 minutes).[67-69] It is not known if all imported products are thermally processed prior to import or if some materials are imported raw. The stability of DIV1 in unprocessed shrimp meals, flours or other feed materials is not published. There are no Federal or State regulations requiring testing of imported shrimp meals, flours or pelleted products, or other feed materials intended for aquaculture, for presence of DIV1. Currently, there have been no documented introductions or outbreaks of DIV1 definitively associated with use of shrimp byproduct in aquaculture feeds. Feeding of polychaete worms imported from China has been implicated in introduction of DIV1 to Vietnam.[7] Knowledge and data gaps affecting assessment of this pathway include, but are not limited to a) lack of studies or field reports describing DIV1 exposure occurring via feeding of imported shrimp meal, flours or pelleted products or other feed ingredients; b) definitive sources and volumes of imported shrimp byproduct and other feed materials are not known; c) the disposition pathways of such imported products are not known; d) processing steps applied to such products prior- or post-import are not standardized or published; e) lack of regulations requiring testing of aquaculture feed ingredients for aquatic pathogens; f) lack of published studies or reports of DIV1 detection in shrimp feeds or feed ingredients; and g) DIV1 introduction via this pathway has been implied but not proven.

## Exposure Assessment

An exposure assessment describes the pathway(s) from the port of entry that might allow exposure of vulnerable animal or human populations to a hazard and estimates the probability of that happening.

The overall likelihood that domestically farmed shrimp will be exposed to DIV1 is *moderate to high*, with a *moderate to high* degree of uncertainty. This assessment is based on:

- Documented exposures of farmed shrimp to FADs via live shrimp
- Documented exposures of farmed and wild shrimp to FADs via imported shrimp seafoods and bait
- The potential for exposure to occur via water
- Knowledge and data gaps associated with all identified exposure pathways

Potential entry pathways of exposure may include:

1. Introduction of DIV1-infected shrimp into aquaculture facilitates
2. Chilled and frozen shrimp and shrimp seafood imported for human consumption
3. Imported bait shrimp
4. Shrimp feed materials
5. Contaminated water sources
6. Accidental, intentional, or malicious release

### Exposure via Introduction of DIV1-Infected Shrimp into Aquaculture Facilities

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via introductions of infected live shrimp is *high* with a *low* degree of uncertainty. Movement and introduction of live aquatic animals that are commensal carriers of or are subclinically infected with aquatic animal pathogens is described in the literature as the most likely pathway of disease introduction into aquaculture farms.[70, 71] As stated in the Entry Assessment, shrimp from foreign hatcheries are imported to the United States for aquaculture purposes. Previous shrimp FAD introductions (e.g., IHHNV, TSV, WSSV) into domestic shrimp aquaculture demonstrate the validity of this exposure pathway.[59, 60, 72-74] Aquatic pathogen introductions can also occur via movement of domestically reared aquatic animals.[70, 71] Within country movement of live shrimp has been described as a source of DIV1 spread among shrimp farms in countries where this pathogen is endemic.[75, 76] In the United States, domestically produced nauplii, post-larvae, and broodstock shrimp are transferred between shrimp farms for breeding and grow-out purposes, and can be ordered by various means, including internet sales. These animals are often shipped to destination locations within one to three days of order placement. The incubation period for DIV1 is approximately three days; therefore, it is plausible that DIV1 infected shrimp could be appear clinically healthy when transiting from a source farm to a destination. Transport water is described in the literature as a potential route of aquatic pathogen introduction.[3] DIV1 could plausibly be introduced into a shrimp farm if the transport water was transferred directly into shrimp aquaculture structures. Environmental contamination leading to exposure of susceptible indigenous wild shrimp populations is also plausible if transport water is not treated prior to disposal (e.g., on farm, or via wastewater treatment).

To date, there have been no reports of DIV1 introduction into U.S. shrimp aquaculture via this exposure pathway. However, given the history of shrimp FAD introduction in the United States, it is probable that introduction may occur despite availability of a) selectively bred specific pathogen-free (SPF) shrimp; b) regulations and permitting guidelines for non-native shrimp culture in some States (e.g., California, Florida, Texas); and c) WOAH Aquatic Animal Health Code guidelines and standards for importation and transit of aquatic animals and disease control and prevention.[59, 73, 74, 77, 78] There is currently no national surveillance plan for DIV1, and currently only Florida requires diagnostic testing for DIV1. [15] Therefore, the potential for this exposure pathway to occur in the United States depends upon the biosecurity, quarantine, and disease surveillance protocols used by shrimp farms supplying or receiving imported or domestically reared live shrimp. Knowledge and data gaps affecting assessment of this pathway include a) lack of reporting on the sources and volumes of live shrimp imported for use in shrimp aquaculture; b) lack of data regarding the sources and volumes of shrimp transported among States and aquaculture facilities for use in shrimp aquaculture; c) lack of Federal regulations requiring pre-import documentation of crustacean health and testing for DIV1 freedom; d) lack of a national surveillance plan for DIV1; e) lack of surveillance requirements by some shrimp-producing States; and f) lack of information regarding the biosecurity, quarantine, disease surveillance, and disease reporting practices at domestic aquaculture facilities.

### Exposure via Imported Chilled and Frozen Shrimp or Shrimp Seafood

The overall likelihood that susceptible farmed shrimp will be exposed to DIV1 via imported chilled and frozen shrimp or shrimp seafood intended for human consumption of infected live shrimp is *moderate* with a *high* degree of uncertainty. The validity of this exposure pathway has been documented. For example, imported prawns were epidemiologically linked to introduction of a WOAH-listed shrimp pathogen (WSSV) in Australia, and feeding of imported shrimp seafood resulted in introduction of WSSV into a population of susceptible animals (freshwater crayfish) at the National Zoo in the United States.[62, 63, 66, 79-81] In the United States, primary exposure of farmed shrimp is unlikely because chilled and frozen shrimp or shrimp seafood are not fed directly to farmed shrimp. Exposure would most likely occur secondarily via contamination of water by the routes described below.

#### Processing plant waste streams

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via processing plant solid and liquid waste streams is *moderate* with a *high* degree of uncertainty. An unknown volume of imported chilled and frozen shrimp and shrimp seafood products are processed or reprocessed in domestic plants, markets (retail, live, farmgate, farmers markets, and restaurants) throughout the United States, including those on coastal bays and estuaries where native shrimp populations may be present.[62] Proximity between processing plants and susceptible wild or farmed shrimp populations increases the risk of disease introduction, with on-farm processing presenting the greatest level of risk to farmed species, especially if the plant or market processes shrimp from outside sources.[71, 81-83]

Potential routes of pathogen release are associated with inadequate disinfection, discharge, storage, or disposal of solid and liquid wastes.[83] Processing plants are required to disinfect and monitor waste streams to prevent inadvertent release of contaminants; however, a) disinfection requirements are dependent upon the size of the processing facility (small processing plants, markets, restaurants and farms may be exempt from regulation); b) the level of oversight at plants is unknown, c) violations have been reported; d) there are no regulations requiring surveillance of processing waste for aquatic pathogens; and e) the efficacy wastewater and solid waste treatments at processing plants on inactivation of aquatic pathogens, including DIV1, is not known.[22, 24, 26, 84-86] Wastewater entering public water treatment works or municipal sanitary sewer systems is treated prior to final discharge into natural water bodies. The efficacy of the treatments on the inactivation of aquatic animal pathogens, including DIV1, is not published, and wastewater treatment facilities are not required to perform surveillance for aquatic animal pathogen presence. Treatment of wastewater entering storm sewer systems is not required. Discharge of wastewater containing DIV1 into sewer systems, or coastal or inland waterways, could provide a plausible pathway of shrimp aquaculture source water contamination and could result in exposure of susceptible wild shrimp populations.[84] Solid processing wastes may be disposed of by solid waste streams (e.g., landfills, compost, burying), anaerobic digestion, or land application (i.e., fertilizer). There is regulatory oversight associated with each of these disposition methods; however, despite such regulation, microbial contamination of water bodies and groundwater via each of these disposition routes has been reported in the literature [29, 87-91]. Regulatory oversights do not require monitoring for presence of aquaculture pathogens. It is possible that wildlife and birds foraging on landfills, or composted and buried waste, could serve as fomites or transmission vectors of microbial pathogens, including DIV1. It is therefore plausible that solid processing disposal routes could provide secondary pathways of shrimp aquaculture source water contamination.

Data and knowledge gaps affecting assessment of this exposure route include lack of a) data regarding the volume and sources of imported chilled and frozen shrimp or shrimp seafood that is processed or reprocessed in domestic plants; b) data on the number and proximity of shrimp farms or susceptible wild shrimp populations to processing plants; c) published information reporting on the volume of seafood processing waste produced by processing plants; d) published reports describing detection of DIV1 in shrimp processing waste streams; g) data on the aquatic pathogen transmission vector capability of wildlife and birds that forage on landfills or composted or buried waste.

### Disposal of Imported Fresh and Chilled Shrimp or Shrimp Seafood Consumer Waste

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via disposal of imported chilled and frozen shrimp and shrimp food consumer waste is *moderate* with a *high* degree of uncertainty. Approximately 40 percent of commercial seafood is discarded as waste.[92] Landfill disposal is the most common waste disposal pathway. As previously stated, landfill operators are required to monitor groundwater for microbial contamination. Regulatory exemptions do occur, and there are no monitoring requirements relative to aquatic animal pathogens such as DIV1. Additional seafood waste disposal pathways may include composting or burial, and consumers may discard shrimp heads and other tissues (e.g., cuticle, uneaten tissues) directly into natural waterbodies.[74] Disposal of imported chilled and frozen shrimp and shrimp seafood consumer waste may provide a pathway of exposure given that a) the U.S. imports chilled and frozen shrimp and shrimp seafood from countries where DIV1 is present; b) DIV1 is present in many shrimp tissues; c) there is potential for water contamination associated with landfill, composted, buried or discarded shrimp seafood wastes.[88-90] Knowledge and data gaps affecting assessment of this exposure pathway include those described for processing wastes. There is also lack of information regarding a) the sources and total volume of imported chilled and frozen shrimp and shrimp seafood discarded as waste; b) proportions of such product that enter landfills or is composted, buried, or disposed of via other methods; and c) published data providing evidence that exposure of farmed shrimp to DIV1 has occurred via this exposure pathway.

### Use of Imported Chilled and Frozen Shrimp or Shrimp Seafood for Bait

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via use of imported chilled and frozen shrimp or shrimp seafood for bait is *moderate* with a *low to moderate* degree of uncertainty. Imported chilled and frozen shrimp seafood used as bait has previously been associated with the introduction of aquatic FADs. For example, use of imported frozen uncooked shrimp for bait by recreational fishermen was considered the most likely pathway of WSSV introduction into Moreton Bay, South East Queensland, Australia in 1992.[93, 94] The frequency of use and volume of imported chilled and frozen shrimp, or shrimp seafoods, for bait in the United States is not known. However, it is reasonable to assume that this activity occurs and that the volume of such products used for this purpose may be large. For example, a 2019 Australian survey reported that approximately 27 percent of recreational fishermen purchased raw imported shrimp from supermarkets for use as bait and that hundreds of tons of shrimp seafood were entering Australian waterways annually due to this activity.[93, 94] Similar data is not available for the United States. An internet search identified several United States recreational fishing sites and chat boards recommending use of frozen shrimp purchased from grocery stores for bait, with some sites describing frozen shrimp as "*superior to commercial bait shrimp.*" Some states, such as Texas, have regulations prohibiting use of imported shrimp products for bait [41]; however, rates of compliance or enforcement are not known. Additional knowledge and data gaps affecting assessment of this exposure pathway include lack of data reporting on the volume of and locations in which imported chilled and frozen shrimp or shrimp seafood are used as bait. There is also a lack of published reports of surveillance for or detection of DIV1 in imported shrimp seafood products.

### Use of Imported Chilled and Frozen Shrimp or Shrimp Seafood as Aquatic Animal Food

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via use of imported chilled and frozen shrimp or shrimp seafood as food for aquatic animals is *low* with a *moderate* degree of uncertainty. Imported chilled or frozen shrimp seafood is often incorporated into the diets of captive aquatic animals (cephalopods, crustaceans, fish, aquatic mammals) kept as pets, or housed in aquariums, zoos and other such institutions.[62, 95-97] An internet search identified multiple websites that a) recommend feeding of chilled or frozen shrimp to a variety of aquatic pets; and b) advertise imported pet foods containing or composed of krill and/or freeze-dried or frozen fresh- and salt-water shrimp products for sale. The validity of this exposure pathway was documented in the 1990s when feeding of imported shrimp resulted in introduction of WSSV into a freshwater crayfish population housed at the National Zoo.[62, 98] Knowledge and data gaps affecting assessment of this pathway include a) the sources and volumes of imported chilled and frozen shrimp or shrimp seafood fed to aquatic animals; b) the location and numbers of aquatic animals fed imported chilled and frozen shrimp or shrimp seafood relative to shrimp aquaculture facilities; c) the waste disposition and water treatment pathways associated with the institutions that use chilled or frozen shrimp or shrimp seafood in animal diets are not known.

### Exposure via Imported Bait Shrimp

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via imported bait shrimp is *moderate* with a *moderate* degree of uncertainty. Direct exposure of farmed shrimp via this exposure pathway is unlikely because bait shrimp are not fed to farmed shrimp or incorporated into shrimp feeds. This pathway would most likely lead to DIV1 introduction via contamination of water sources. Shrimp pathogens (WSSV,TSV) have been detected in imported bait shrimp, and the commercial and recreational use of bait shrimp has been implicated in the introduction of aquatic FADs.[61, 65] The volume and distribution of imported bait shrimp used in the United States by the commercial fishing industry and for recreational sport fishing is not published [61]; however, an internet search shows that imported bait shrimp may be purchased online and in bait shops throughout the United States. Given the accessibility of such product and recommendations for use on various internet sites, it appears that bait shrimp may be regularly used for recreational fishing. There are currently no Federal regulations requiring surveillance of imported bait shrimp for FADs of concern to shrimp aquaculture. Some States, such as Texas, do have regulations in place regarding use of any type of imported shrimp (e.g., live, dead, whole, or in pieces) from a non-Gulf of Mexico State or different countries as bait, but levels of compliance and enforcement are not known.[41] Review of the literature did not identify reports describing detection of or exposure to DIV1 occurring via this pathway. This lack of data does not preclude the potential for exposure of susceptible wild or farmed shrimp to occur. Additional knowledge and data gaps that affected the assessment of this exposure pathway include lack of a) data reporting on the volume and distribution of imported bait shrimp used in commercial and recreational fishing; b) research or surveillance for presence of aquatic pathogens, including DIV1 in imported bait shrimp.

### Exposure via Imported Shrimp Byproduct or Other Feed Materials

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via imported shrimp byproduct or other feed materials is *low* with a *moderate* degree of uncertainty. Unknown quantities of imported shrimp meal, cuticle meal, byproducts, and other materials (e.g., polychaete worms, byproduct of other crustaceans) are used as ingredients in shrimp (and other) aquaculture feeds. The high temperatures used to prepare meal-type byproduct (dryer temperature, 500 $^{o}$C/932 $^{o}$F; internal product temperature, 100 $^{o}$C/212 $^{o}$F), and pelleted and extruded feeds (71 to 84.6 $^{o}$C/160 to 184 $^{o}$F; and 87.7 to 149 $^{o}$C/190 to 300 $^{o}$F respectively) are likely sufficient to inactivate DIV1, given the recommended thermal inactivation temperature for this pathogen (56 $^{o}$C/132.8 $^{o}$F for at least 30 minutes).[67-69] Polychaete worms may be used as shrimp feed or feed ingredients and the feeding of polychaete worms imported from China was implicated in introduction of DIV1 to Vietnam.[7] Data describing the sources, volume, product-type or use of polychaete worms as feed ingredients by the U.S. shrimp farming industry is generally unavailable. Additional knowledge and data gaps that affect the assessment of this pathway include a) the sources and volumes of shrimp byproduct, cuticle meal, shrimp meal, and other feed materials imported by the U.S. are not known;

b) the processing steps applied to such products prior- or post-import are not standardized or known; c) there are no regulations requiring testing of aquaculture feed ingredients for aquatic pathogens; d) there are no published studies or reports of DIV1 detection in shrimp feeds or feed ingredients; and e) DIV1 introduction via this pathway has been implied, but not definitively proven.

### Exposure via Water Used by Shrimp Aquaculture Facilities

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via water used for shrimp aquaculture is *moderate* with a *moderate* degree of uncertainty. Influent water contaminated with infected hosts or pathogens suspended in or attached to organic materials (e.g., debris, plankton, and algae) present in water is described in the literature as a disease exposure pathway for all farmed aquatic species, and pathogen introductions into wild aquatic animal populations via aquaculture effluent water releases have been reported. [99-103] For example, introduction of WSSV into shrimp farms from local WSSV-infected wild shrimp populations has been documented, and genetic analysis suggests that IHHNV was introduced into wild shrimp populations in the Gulf of California via intensive penaeid shrimp aquaculture.[99, 100, 102-104] This pathway has not been definitively established for DIV1. However, transfer of DIV1 between ponds on affected farms via water has been implicated in disease outbreaks, and shrimp farm effluent water discharges have been suggested as sources of infection in wild shrimp populations in coastal waters along China and in the Indian Ocean.[1, 43]

In general, shrimp aquaculture operations minimize use of influent water and effluent discharges per production cycle.[105] The volume of water used and discharged is variably dependent upon the shrimp species reared, the type of production system, and the management and biosecurity methods used.[105] Influent water may be sourced from ocean or freshwater systems such as aquifers, wells, rivers, streams, and municipal water sources. Influent water biosecurity measures often include use of deep-sea water wells or underground aquifers as water sources, influent water treatments (including filtration, ozonation, and ultraviolet irradiation), covering ponds/tanks, drying of ponds overwinter, disinfection of tanks and equipment, and use of low exchange or recirculating water systems.[106, 107] Contamination of influent water may occur via several routes. Examples include but are not limited to a) ballast water and ship fouling; b) processing and seafood waste streams; c) use of bait shrimp for commercial and recreational fishing; d) release of inappropriately treated transport and effluent water from shrimp farms; e) accidental water releases; and f) presence of wild DIV1-infected shrimp populations in source waters. [55, 106, 108, 109] Aquaculture effluent discharges are subject to Federal and State effluent regulations specific to water quality (e.g., levels of ammonia, dissolved oxygen, total suspended solids), but do not mandate testing for presence of aquatic pathogens.[25] Some State aquaculture BMPs and aquaculture facility biosecurity measures do include effluent water treatment guidelines designed to prevent aquaculture pathogen releases.[10, 40, 41] Despite these fail safes, unexpected water management failures (e.g., biosecurity lapses, effluent water treatment failures, accidental releases, weather events, overtopping of ponds, flooding) may lead to exposure of farmed or wild shrimp populations to aquatic disease pathogens such as DIV1.

Inland farms with good influent water biosecurity measures are less likely to incur disease introduction via this pathway. Farms are more prone to disease introduction if they are not highly biosecure; are located on coastlines; have open ponds; use open water sources; or are in close proximity to other shrimp-rearing facilities, shrimp processing plants, shipping ports, and wild shrimp populations.[19, 81, 82, 106, 108, 109] Other factors impacting the potential for exposure to pathogens (including DIV1) via this pathway include the a) source of the contaminated water; b) presence of DIV1 infection in locally proximate farmed and/or wild shrimp populations; c) pathogen concentration in the contaminated water; d) infectious dose required to elicit infection in susceptible hosts; e) proximity of aquaculture farms to contaminated water sources; f) volume of water used by individual shrimp farms; g) biosecurity and monitoring protocols utilized by farms regarding the treatment of influent water; and h) treatment and disposition routes of effluent water discharges.[19, 81, 106, 108]

Knowledge and data gaps affecting assessment of this pathway include but are not limited to a) transmission via this pathway is anecdotally reported but has not been confirmed; b) the length of time that DIV1 may remain viable in water and the infectious dose required to elicit disease are not known; c) there are currently no diagnostic tests validated for environmental testing; therefore, environmental surveillance data is lacking; d) influent and effluent water biosecurity and treatment measures are not standardized or generally available for review; e) the efficacy of individual farm protocols are unknown, and g) information on the proximity of shrimp farms to sources of potentially contaminated water are lacking.

### Exposure via Accidental, Intentional or Malicious Release

The likelihood that susceptible farmed shrimp will be exposed to DIV1 via accidental, intentional, or malicious release of infected shrimp is *low to moderate*, with a *moderate* degree of uncertainty. The literature describes accidental introduction of wild shrimp and other crustaceans into aquaculture facilities as mechanisms of aquatic pathogen introduction (e.g., IHHNV, WSSV, YHV, TSV).[45, 46, 48, 110, 111] Accidental introductions are mostly likely to occur via water as described above. Additional accidental introduction pathways include migration of infected crustaceans into or out of aquaculture structures (typically ponds); escape or accidental release of farmed shrimp; wildlife vectors; and fomites.[45, 46, 48, 110, 111] Most shrimp species cannot walk on land (*M. dienbienphuense* is an exception); however, migration of other crustaceans such as crabs, crayfish into or among shrimp ponds has been documented.[1] For example, the red crayfish (*Pr. clarkii*) is indigenous to the United States, is susceptible to DIV1, is highly invasive, can migrate overland (up to 3.2 kilometers/ 2 miles), and could plausibly enter shrimp farm ponds if farm biosecurity is not sufficient.[48, 112, 113] Escapes and accidental releases of cultured non-native shrimp *(P. vannamei, P. monodon, M. rosenbergii)* have resulted in successful population establishment in some coastal waters of the continental United States, Puerto Rico, and Hawaii, and have been implicated in the introduction of pathogens (e.g., IHHNV, TSV, WSSV, YHV) into wild shrimp populations.[45-47, 110, 111] Introductions of aquatic pathogens of concern into aquaculture facilities and natural water bodies via wildlife (e.g., fish, amphibians, reptiles, mammals) and birds (piscivorous birds, waterfowl) that function as fomites or transmission vectors have been described in the literature.[114-118] Contaminated fomites may result in accidental exposure of farmed shrimp to DIV1 or other aquatic pathogens. Potential fomites include people (farm staff, staff shared with other farms, visitors); contaminated shoes, clothing or personal protective equipment (PPE); and contaminated vehicles and farm equipment entering farms or shrimp rearing structures.[83, 119] Intentional introductions of pet animal aquatic species into natural waterbodies and aquaculture ponds have been documented, demonstrating the plausibility of aquatic pathogen introduction occurring via this route.[120-121] Malicious introduction would include acts of sabotage or agricultural terrorism.[122, 123]

Review of the literature did not identify reports of DIV1 introduction into farmed or wild shrimp populations definitively linked to the accidental, intentional or malicious exposure routes; however, lack of data does not preclude the potential for this to occur. Factors affecting the potential for exposure to occur via these routes include the geographic location of shrimp farms (farms that are near other farms, natural water bodies, wildlife habitat, or near urban areas or roadways may be more susceptible) and the biosecurity measures used by farms to minimize the potential for pathogen introduction via the described routes. Knowledge and data gaps that affected assessment of this pathway included lack of research and surveillance data for DIV1 associated with each of the described routes of exposure, and information regarding the biosecurity measures used by farms to address potential accidental, intentional, or malicious introductions.

## Consequence Assessment

A consequence assessment describes the relationship between the exposures to a pathogen and the various consequences of such exposures. Consequences may be evaluated at the local, regional, or national level, and may include such things as:

- Direct consequences, such as production losses or public health impacts
- Indirect consequences, such as prevention and control costs or trade losses

The United States is the second largest consumer of shrimp globally, with shrimp accounting for approximately 25 to 30 percent of the entire U.S. seafood market. [124] The United States' share of the global shrimp market is small; however, it is economically impactful domestically and locally. Shrimp aquaculture occurs in multiple States including Alabama, Arkansas, California, Florida, Georgia, Hawaii, Illinois, Indiana, Kentucky, Louisiana, Mississippi, Ohio, South Carolina, Tennessee, and Texas.[125] Most domestic shrimp production (over 70 percent) occurs in Texas.[126] In 2017, Texas produced approximately 1.45 million kg of shrimp, followed by Alabama (138,138 kg). In Louisiana, the crayfish industry is an integral part of the State economy, with approximately 49,999 hectares/123,550 acres devoted to cultivation and total industry profits exceeding $150 million USD annually.[40, 127] In 2018, the USDA National Agricultural Statistics Service reported 2018 sales of saltwater shrimp, freshwater prawn, and crayfish for reared domestically for food totaling $50.85 million USD, $1.08 million, and $45.63 million, respectively. [128] The volume of shrimp seafood exported by the United States from 2012 to 2021 ranged from approximately 4.5 million to 7.7 million kg of product.[63] Countries receiving the greatest volume of product, in order of aggregate volume, included Canada, India, China, Vietnam, Denmark, Hong Kong, Thailand, Jamacia, Indonesia, Germany, Sweden and Guatemala (**Appendix, Table 4**).[63]

From 2012 to 2021, the United States imported approximately 581 million to 1.1 billion kg of chilled and frozen shrimp and shrimp seafood products from over seventy countries, including countries with reported presence of DIV1 (China, Taiwan, Thailand, Vietnam) (**Appendix, Table 1**). Top importing countries in order of aggregate volume included India, Indonesia, Ecuador, Vietnam, Thailand, Mexico, Argentina, Guyana, Peru and China.[63] During the same period, the United States imported approximately 23.3 million to 56 million kg of "*Products of Fish or Crustacean, Molluscs, or Other Aquatic Invertebrates; Dead Animals of Chapter 3, Unfit for*

*Human Consumption, NESOI*" which likely includes shrimp imported for use as bait (**Appendix, Table 2**).[63] Top importing counties in order of aggregate volume, included Canada, Iceland, Denmark, Taiwan, Mexico, Germany, South Korea, Ecuador, China and Norway. Product was imported from two countries (China, Taiwan) with reported presence of DIV1. The United States also imported approximately 38.9 to 65 metric tons of "*Flours, Meals, and Pellets of Fish or of Crustaceans, Molluscs or Other Aquatic Invertebrates, Unfit For Human Consumption, NESOI*." Top importing countries, in order of aggregate volume imported, included Mexico, Norway, France, Denmark, Peru, Japan, Spain, Ecuador, Morocco and Germany (**Appendix, Table 3**). [63] It is plausible that some volume of this material included shrimp-based meals, flours or pellets intended for use in aquaculture (including shrimp) feeds or feed materials.

Given that DIV1 is now a reportable disease, it is likely that domestic and international regulatory actions may be enacted following detection of DIV1 in the U.S.

Given the level of outbreak control associated with recent shrimp FAD introductions (e.g., IHHNV), it appears likely that immediate short-term impacts would occur and would be primarily associated with disease control in the affected facilities and State(s) in which the detection(s) occurred. Such impacts may include movement restrictions, outbreak control measures, restocking of farms, and local economic effects. Given that DIV1 is now a WOAH reportable disease, it is plausible that there could be significant long-term local and national economic and export trade consequences should DIV1 introduction occur. It is highly plausible that countries may develop pre-import requirements for DIV1 testing or disease freedom statements for live animals, commodity products or bait, and that international trade restrictions would be implemented should a DIV1 outbreak occurred in individual aquaculture facilities.[129]

A summary of the consequences following DIV1 introduction into native wild shrimp and *Pr. clarkii* populatons (farmed, indigenous, or invasive) was not within the scope of this assessment. However, these species are susceptible and environmental conditions favorable to sustaining an outbreak, local and regional consequences could be impactful. Direct and indirect environmental consequences could affect local food webs and the overall ecology in an affected area. Local fisheries that harvest wild shrimp would likely be economically impacted.[130, 131]

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A summary of the consequences following DIV1 introduction into native wild shrimp and *Pr. clarkii* populatons (farmed, indigenous, or invasive) was not within the scope of this assessment. However, these species are susceptible and environmental conditions favorable to sustaining an outbreak, local and regional consequences could be impactful. Direct and indirect environmental consequences could affect local food webs and the overall ecology in an affected area. Local fisheries that harvest wild shrimp would likely be economically impacted.[130,131]

## Risk Estimation

A risk estimation is defined as the combination of the liklihood and uncertainty of the entry and/or exposure pathways and the consequences of exposure. Capability to estimate overall risk associated with emerging diseases such as DIV1 is affected by the quality and quantity of available data and published information. In general, most of the data currently availble on DIV1 are qualitative; quantitative data are generally lacking.

The overall estimated risk of DIV1 exposure, based upon evaluation of the described potential entry and exposure pathways and the associated consequences, is *moderate*. However, the risk associated with individual pathways ranges from *high* to *low*. The overall risk is sufficient to suggest that prevention or mitigation measures should be recommended. Currently, it does not appear that farmed shrimp in the United States have been exposed to DIV1.

The summarized estimated risk of DIV1 entering into the United States via one or more of the identified entry pathways is *high* based upon the the levels of likelihood and uncertainty assigned to each of the identified entry pathways (**Table 2**). Entry pathways associated with a high likelihood of DIV1 introduction include ballast water, ship fouling, live shrimp imported for aquacutlure purposes, imports of chilled and frozen shrimp and shrimp seafoods for human consumption, and imported bait shrimp. The assigned uncertainties for these pathways range from *low to high* dependant upon whether or not reported disease entry has occurred via these pathways and the quantity (or lack of), quality, and sources of literature and data associated with each pathway.

**Table ENTRY RISK:** Summary of the plausibility of DIV1 introduction via entry pathways

| Pathway | Likelihood | Uncertainty |
|---|---|---|
| Ballast water and ship fouling | High | Moderate |
| Live shrimp imported for aquaculture purposes | High | Low |
| Imported chilled and frozen shrimp and shrimp seafood for human consumption | High | Moderate |
| Imported bait shrimp | High | High |
| Imported shrimp by-product or other feed materials | Moderate | High |

The summarized risk of DIV1 exposure occurring in domestic shrimp farms via one or more of the identified exposure pathways is *moderate to high* (**Table 3**). The *high* level of risk is associated with high likelihood that DIV1 exposure will occur via introduction of imported infected live shrimp into aquacuture facilities. The remaining pathways are associated with *moderate* likelihoods, which combined with the potential uncertainties and consequences, present moderate levels of risk.

**Table 3:** Summary of the plausibility of DIV1 introduction via exposure pathways

| Pathway | Likelihood | Uncertainty |
|---|---|---|
| Introduction of imported DIV1infected shrimp into aquaculture facilities | High | Low |
| Imported chilled and frozen shrimp, and shrimp seafood for human consumption | Moderate | High |
| Imported bait shrimp | Moderate | Moderate |
| Imported shrimp by-product or other feed materials | Low | Moderate |
| Water used by shrimp aquaculture facilities | Moderate | Moderate |
| Accidental, intentional, or malicious release | Low to Moderate | Moderate |

## Limitations

In this assessment, primary pathways of entry and exposure were identified, and associated levels of likelihood, uncertainty and risk were estimated using available data and literature relative to DIV1 epidemiology, current import, export and production practices, and existing biosecurity measures. To more accurately characterize the risk, additional information is needed. Some of these needs include, but are not limited to:

1. Virus characteristics: As noted by WOAH, many of characteristics of DIV1 that are relevant to risk analysis are unknown, such as survival outside the host, survival in water or other environmental substrates, and movement patterns in water.
2. Susceptible species: The total number of species susceptible to DIV1 is not definitively known.
3. Global distribution: Global surveillance data and reporting on the distribution of DIV1 in farmed and wild shrimp populations (for both WOAH Member and non-Member countries) are currently lacking.
4. Characteristics of the shrimp industry: The volumes, types, movement patterns, and interactions with imported and domestically reared shrimp, and other characteristics of the industry are not readily available for review. These are needed to accurately estimate the full extent of the consequences and risks that DIV1 introduction poses to domestic shrimp aquaculture, and to determine the potential impacts an DIV1 outbreak may have in this sector.
5. Regulatory authority with respect to DIV1: The USDA is the Competent Authority for aquatic animal health, including the regulation of aquatic animal diseases of concern. Currently, USDA has no regulations regarding imports of shrimp or shrimp products with respect to DIV1. Presently, Florida has implemented DIV1-specific regulation regarding importation or movement of shrimp following WOAH listing of DIV1. Requirements for DIV1 surveillance by other States are generally not known.
6. Surveillance testing and disease freedom status in the United States: There is currently no national surveillance plan in the United States, and there are insufficient data to determine DIV1 national disease freedom status. Florida has recently implemented DIV1 specific regulation that includes freedom of disease testing; however, not all States have such requirements, and there is currently an insufficient volume of collected data available for review relative to these requirements. There is also a lack of knowledge regarding presence or absence of DIV1 in indigenous wild crustacean populations. There are currently no national disease spread or consequence models published for DIV1.
7. Presence of DIV1 in indigenous wild crustaceans: This risk assessment did not include the effect that DIV1 introduction might have on indigenous wild shrimp or other crustacean populations. However, there are domestic fisheries that would likely be impacted if these animal populations were susceptible to DIV1, and DIV1 introduction occurred. This represents an area for future assessment given that harvest of wild shrimp and other crustaceans is economically important and because there is potential for infected populations of these animals to serve as sources of pathogen exposure to cultured shrimp via water.

## Rapid Risk Assessment Definition

A rapid risk assessment is designed to provide a quick and approximate estimate of the risk (likelihood of entry and exposure, combined with the consequences, given that a risk event occurs) for a pathogen of interest. The objectives of a rapid risk assessment include 1) determining the likelihood and impact of emerging or evolving animal health threats, and 2) identifying data gaps.

These assessments often have the following characteristics:

- Are performed with limited resources compared to risk assessments or analyses
- Guide additional data collection or more in-depth risk assessments and analyses
- May have limited information on the pathogen
- Discuss the most likely pathways of entry; may not list or evaluate all potential pathways
- Are qualitative in nature and consider the impact of total uncertainty on likelihood and risk ratings
- Do not evaluate potential consequences in detail
- Do not discuss potential impact of future mitigations

## Likelihood, Consequence, Uncertainty, and Risk Categories

For this assessment, we have assigned qualitative likelihoods for expressing likelihood, uncertainty, consequence, and risk. Terms and definitions for provided in the following tables.

**Table 1. Definition of likelihood categories for risk assessment**

| Term | Definition |
|---|---|
| Negligible | This event would almost certainly never occur |
| Low | This event would be unlikely to occur |
| Moderate | This event would be nearly as likely to occur as to not occur |
| High | This event would be likely to occur |
| Very High | This event is almost certain to occur |

**Table 2. Definition of uncertainty levels [132]**

| Term | Definition |
|---|---|
| Low | Available data is well supported, reliable, complete, and accessible from multiple sources or published references, and in general agreement. |
| Moderate | Data available, but with high interpretability issues, potential biases, reliability issues, and/or underreporting. |
| High | Some data available but may be incomplete, unreliable, from a small number of published sources, and/or demonstrates conflicting evidence. Includes the combination of anecdotal evidence, personal communications, and expert opinion with available published data, if all sources are in general agreement. |

**Table 3. Definition of risk levels**

| Term | Definition |
|---|---|
| Negligible | Suggests that the risk is low enough that it need not be considered, and no further mitigations are necessary. |
| Low | Suggests resources to further evaluate or mitigate this risk should be considered. A low risk is greater than a negligible risk due to a potential likelihood of occurrence, associated consequences, or a combination of both. |
| Moderate | Suggests that the risk is of a sufficient magnitude that measures to prevent or mitigate the risk should be considered. A moderate risk is greater than a low risk due to a greater likelihood of occurrence, greater consequences, or a combination of both. |
| High | Suggests that the risk is of sufficient magnitude that measures to prevent or mitigate the risk are necessary and the consequences will have significant impact at the regional or national level. A high risk is greater than a moderate risk due to a greater likelihood of occurrence, greater consequences, or a combination of both. |

# Appendix

**Table 1:** Volume (kilograms) of chilled and frozen shrimp and shrimp seafood products imported by the United States from 2012 to 2021. Countries are listed in order of aggregate volume.[63]

| Country | Year 2012 | Year 2013 | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Year 2019 | Year 2020 | Year 2021 | Aggregate Volume |
|---|---|---|---|---|---|---|---|---|---|---|---|
| India | 91,494,042 | 127,271,137 | 151,031,223 | 194,936,153 | 232,503,628 | 326,641,606 | 384,326,038 | 459,703,336 | 392,476,260 | 534,150,446 | 2,894,533,869 |
| Indonesia | 100,199,381 | 107,457,210 | 138,398,340 | 146,764,276 | 147,200,838 | 145,653,730 | 157,031,066 | 148,580,210 | 159,636,069 | 167,420,387 | 1,418,341,507 |
| Ecuador | 94,674,101 | 93,868,252 | 119,672,696 | 111,438,917 | 94,971,863 | 93,543,736 | 98,302,670 | 109,868,647 | 165,106,953 | 251,681,658 | 1,233,129,493 |
| Vietnam[a] | 52,833,568 | 65,857,986 | 87,450,592 | 63,498,063 | 61,838,126 | 45,478,540 | 39,377,745 | 21,686,645 | 37,523,051 | 65,016,146 | 540,560,462 |
| Thailand[a] | 128,139,050 | 73,166,160 | 49,292,332 | 53,774,052 | 69,008,927 | 59,992,244 | 34,939,182 | 27,602,696 | 23,580,130 | 19,968,694 | 539,463,467 |
| Mexico | 10,278,896 | 13,482,167 | 20,480,258 | 27,697,203 | 25,076,182 | 27,197,561 | 24,620,935 | 29,561,562 | 25,711,114 | 20,449,649 | 224,555,527 |
| Argentina | 949,883 | 2,530,272 | 6,164,061 | 6,980,046 | 12,341,032 | 18,928,541 | 17,349,874 | 19,239,929 | 26,010,345 | 27,057,757 | 137,551,740 |
| Guyana | 17,754,918 | 17,205,693 | 13,350,246 | 14,466,647 | 16,771,399 | 18,450,911 | 13,991,594 | 9,467,108 | 5,942,636 | 4,180,637 | 131,581,789 |
| Peru | 11,513,735 | 12,540,913 | 16,393,532 | 15,027,679 | 13,313,705 | 13,489,532 | 15,272,468 | 10,413,472 | 10,771,769 | 9,010,150 | 127,746,955 |
| China[a] | 19,257,227 | 15,994,851 | 13,342,214 | 9,717,296 | 14,496,269 | 24,898,205 | 24,983,424 | 1,353,634 | 748,311 | 508,900 | 125,300,331 |
| Malaysia | 31,454,820 | 16,844,519 | 30,454,723 | 15,716,551 | 321,804 | 293,973 | 437,073 | 877,885 | 350,515 | 115,509 | 96,867,372 |
| Honduras | 9,864,225 | 9,183,236 | 9,410,054 | 5,246,409 | 3,928,362 | 6,155,010 | 10,023,285 | 4,846,892 | 1,818,424 | 1,536,751 | 62,012,648 |
| Venezuela | 2,221,396 | 1,814,347 | 2,908,492 | 2,197,474 | 3,239,757 | 2,727,500 | 5,179,345 | 6,878,851 | 2,926,433 | 1,960,137 | 32,053,732 |
| Panama | 3,343,107 | 5,374,876 | 4,614,875 | 3,641,248 | 3,427,736 | 2,925,816 | 2,749,350 | 1,235,812 | 618,572 | 819,912 | 28,751,304 |
| Bangladesh | 3,379,629 | 4,659,094 | 2,102,996 | 2,560,144 | 4,741,184 | 1,481,373 | 1,758,843 | 1,217,355 | 2,137,979 | 3,574,670 | 27,613,267 |
| Nicaragua | 4,802,403 | 3,470,947 | 3,032,243 | 2,698,860 | 2,920,440 | 2,029,941 | 2,845,682 | 2,037,498 | 1,778,199 | 1,030,691 | 26,646,904 |
| Guatemala | 2,492,450 | 2,681,668 | 1,673,575 | 2,312,047 | 2,601,319 | 2,554,250 | 935,809 | 560,327 | 1,059,965 | 608,404 | 17,479,814 |
| Philippines | 491,698 | 2,374,932 | 2,863,979 | 2,050,671 | 1,822,262 | 2,402,204 | 956,096 | 704,693 | 150,527 | 472,446 | 14,289,508 |
| Saudi Arabia | 333,954 | 0 | 0 | 355,332 | 1,029,883 | 0 | 0 | 1,103,900 | 3,446,747 | 2,114,442 | 8,384,258 |
| Suriname | 1,323,804 | 1,871,984 | 1,605,846 | 737,785 | 948,840 | 757,336 | 526,710 | 59,330 | 0 | 3,204 | 7,834,839 |
| Canada | 152,723 | 68,177 | 85,666 | 2,970,472 | 281,446 | 163,899 | 135,002 | 176,619 | 397,407 | 169,423 | 4,600,834 |
| Burma | 0 | 598,456 | 1,196,730 | 614,465 | 207,400 | 364,818 | 478,244 | 204,120 | 182,773 | 498,348 | 4,345,354 |
| Belize | 461,235 | 900,869 | 924,630 | 845,659 | 329,634 | 149,249 | 82,929 | 9,072 | 28,461 | 0 | 3,731,738 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sri Lanka | 143,187 | 344,895 | 623,467 | 111,436 | 199,276 | 210,418 | 363,328 | 118,645 | 131,275 | 1,368,785 | 3,614,712 |
| South Korea | 173,048 | 181,140 | 124,608 | 149,016 | 157,968 | 128,430 | 126,061 | 173,713 | 178,471 | 288,369 | 1,680,824 |
| Nigeria | 110,510 | 175,406 | 181,018 | 178,318 | 125,130 | 130,296 | 244,519 | 125,889 | 107,136 | 65,580 | 1,443,802 |
| Colombia | 595,663 | 40,198 | 32,350 | 208,136 | 88,728 | 148,749 | 66,706 | 43,404 | 93,979 | 53,993 | 1,371,906 |
| Taiwan[a] | 128,877 | 151,472 | 145,961 | 169,732 | 168,668 | 109,530 | 175,646 | 38,708 | 89,620 | 113,286 | 1,291,500 |
| Hong Kong | 43,878 | 100,228 | 164,052 | 127,760 | 58,032 | 109,752 | 186,772 | 108,497 | 54,486 | 227,734 | 1,181,191 |
| Costa Rica | 157,909 | 218,260 | 105,998 | 168,302 | 78,044 | 171,241 | 88,119 | 76,213 | 23,308 | 29,826 | 1,117,220 |
| Spain | 848 | 6,723 | 14,028 | 81,445 | 97,078 | 85,576 | 128,534 | 213,063 | 336,590 | 130,842 | 1,094,727 |
| United Arab Emirates | 21,612 | 345,704 | 35,200 | 54,472 | 88,926 | 293,234 | 72,174 | 0 | 0 | 0 | 911,322 |
| El Salvador | 92,018 | 245,892 | 93,587 | 95,276 | 43,685 | 86,000 | 23,039 | 39,745 | 0 | 21,147 | 740,389 |
| Chile | 36,290 | 56,914 | 58,658 | 63,311 | 184,666 | 76,590 | 138,334 | 17,306 | 0 | 0 | 632,069 |
| Australia | 0 | 8,010 | 1,975 | 3,490 | 37,925 | 72,002 | 42,976 | 122,695 | 102,884 | 131,989 | 523,946 |
| New Caledonia | 36,400 | 32,880 | 25,056 | 16,704 | 24,282 | 22,284 | 32,938 | 63,256 | 98,504 | 0 | 352,304 |
| Pakistan | 119,052 | 132,774 | 0 | 0 | 66,144 | 0 | 0 | 0 | 0 | 0 | 317,970 |
| Brunei | 0 | 121,406 | 112,455 | 24,780 | 44,177 | 1,816 | 0 | 11,378 | 0 | 0 | 316,012 |
| Singapore | 14,152 | 66,950 | 0 | 298 | 1,538 | 890 | 0 | 10,000 | 63,476 | 110,400 | 267,704 |
| Madagascar | 38,957 | 9,761 | 0 | 0 | 28,384 | 0 | 84,276 | 39,056 | 7,752 | 8,569 | 216,755 |
| Norway | 29,486 | 0 | 0 | 0 | 16,129 | 24,426 | 0 | 0 | 83,488 | 0 | 153,529 |
| Senegal | 0 | 0 | 5,904 | 30,060 | 25,974 | 10,608 | 28,672 | 1,680 | 19,168 | 28,584 | 150,650 |
| Denmark | 16,906 | 30,614 | 0 | 0 | 2,304 | 11,228 | 33,336 | 20,736 | 13,824 | 19,264 | 148,212 |
| Brazil | 0 | 0 | 0 | 1,106 | 0 | 0 | 0 | 22,380 | 0 | 91,544 | 115,030 |
| Gambia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 56,131 | 56,444 | 112,575 |
| Iceland | 0 | 0 | 0 | 0 | 0 | 70,470 | 0 | 0 | 0 | 29,030 | 99,500 |
| Cyprus | 0 | 0 | 0 | 38,152 | 38,102 | 50 | 0 | 0 | 0 | 0 | 76,304 |
| Ghana | 0 | 0 | 0 | 0 | 332 | 10,447 | 25,909 | 17,693 | 15,169 | 1,982 | 71,532 |
| Japan | 9,342 | 370 | 1,150 | 10,842 | 2,867 | 2,160 | 442 | 16,172 | 12,349 | 7,114 | 62,808 |
| Greenland | 7,398 | 0 | 0 | 0 | 0 | 0 | 6,745 | 18,630 | 18,630 | 0 | 51,403 |
| Guinea | 0 | 0 | 0 | 0 | 0 | 0 | 108 | 0 | 9,282 | 40,066 | 49,456 |
| Portugal | 0 | 1,000 | 9,301 | 8,179 | 5,408 | 5,386 | 4,583 | 5,679 | 0 | 6,246 | 45,782 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| New Zealand | 0 | 0 | 0 | 0 | 15,569 | 0 | 0 | 0 | 25,124 | 0 | 40,693 |
| Turks & Caicos | 37,540 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37,540 |
| Bulgaria | 0 | 0 | 17,019 | 0 | 0 | 0 | 0 | 0 | 0 | 20,344 | 37,363 |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32,658 | 4,590 | 0 | 37,248 |
| Morocco | 0 | 0 | 286 | 2,636 | 399 | 0 | 0 | 0 | 27,258 | 2,208 | 32,787 |
| Turkey | 0 | 0 | 0 | 0 | 0 | 0 | 25,698 | 0 | 0 | 0 | 25,698 |
| Netherlands | 0 | 17,626 | 0 | 0 | 0 | 985 | 0 | 0 | 1,126 | 2,765 | 22,502 |
| Dominican Rep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15,872 | 15,872 |
| Antigua Barbuda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15,436 | 0 | 15,436 |
| Seychelles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,152 | 0 | 14,152 |
| Monaco | 14,086 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,086 |
| Tunisia | 13,608 | 0 | 0 | 240 | 0 | 0 | 0 | 0 | 0 | 0 | 13,848 |
| Greece | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 53 | 7,550 | 7,703 |
| Mozambique | 2,304 | 2,856 | 180 | 0 | 0 | 0 | 0 | 0 | 998 | 0 | 6,338 |
| Cote d`Ivoire | 0 | 0 | 670 | 2,400 | 588 | 0 | 0 | 2,294 | 0 | 0 | 5,952 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,608 | 0 | 0 | 4,608 |
| Oman | 0 | 0 | 0 | 0 | 0 | 2,774 | 0 | 0 | 0 | 0 | 2,774 |
| France | 0 | 0 | 0 | 0 | 0 | 0 | 840 | 1,260 | 0 | 0 | 2,100 |
| United Kingdom | 1,344 | 0 | 0 | 450 | 0 | 0 | 0 | 0 | 0 | 0 | 1,794 |
| Trinidad & Tobago | 1,211 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,211 |
| Italy | 0 | 312 | 252 | 0 | 418 | 0 | 150 | 0 | 0 | 0 | 1,132 |
| Jamaica | 0 | 0 | 0 | 0 | 950 | 0 | 0 | 0 | 0 | 109 | 1,059 |
| Haiti | 0 | 0 | 0 | 402 | 538 | 0 | 0 | 0 | 0 | 0 | 940 |
| Belgium | 0 | 0 | 0 | 0 | 0 | 0 | 784 | 0 | 0 | 0 | 784 |
| Russia | 272 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 272 |
| Annual Volume | 589,262,143 | 581,509,137 | 678,202,578 | 687,794,392 | 714,924,265 | 798,065,317 | 838,204,053 | 858,734,951 | 864,006,899 | 1,115,228,003 | |

[a]Country with reported presence of DIV1

**Table 2:** Volume (kilograms) of products of fish or crustacean, molluscs, or other aquatic invertebrates; dead animals of Chapter 3, unfit for human consumption, NESOI imported by the United States from 2012 to 2021. Countries are listed in order of aggregate volume.[63]

| Country | Year 2012 | Year 2013 | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Year 2019 | Year 2020 | Year 2021 | Aggregate volume |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 14,597,472 | 17,467,378 | 17,117,979 | 21,884,638 | 29,292,010 | 25,675,820 | 21,935,780 | 25,590,269 | 23,899,694 | 31,306,739 | 228,767,779 |
| Iceland | 339,212 | 936,163 | 4,110,401 | 5,541,758 | 5,588,358 | 6,778,688 | 7,253,606 | 5,299,432 | 5,964,093 | 9,353,599 | 51,165,310 |
| Denmark | 0 | 0 | 0 | 2,122,295 | 432,885 | 2,827,493 | 5,945,403 | 4,665,649 | 6,015,192 | 6,677,166 | 28,686,083 |
| Taiwan[a] | 1,633,004 | 1,724,961 | 1,826,216 | 3,793,596 | 5,039,558 | 4,311,278 | 2,845,744 | 3,196,029 | 2,569,509 | 1,161,165 | 28,101,060 |
| Mexico | 2,584,987 | 1,356,704 | 3,063,251 | 2,819,638 | 4,564,419 | 7,566,060 | 1,262,462 | 922,646 | 1,759,161 | 1,996,857 | 27,896,185 |
| Germany | 307,858 | 377,304 | 1,237,531 | 1,069,844 | 810,405 | 1,806,319 | 2,110,435 | 2,680,306 | 2,606,687 | 2,579,814 | 15,586,503 |
| South Korea | 2,981,304 | 1,116,226 | 1,593,066 | 3,190,465 | 2,712,228 | 2,148,987 | 1,184,937 | 147,000 | 78,821 | 207,848 | 15,360,882 |
| Ecuador | 488,550 | 1,468,610 | 1,885,540 | 1,291,990 | 1,171,168 | 1,462,261 | 2,051,905 | 46,860 | 1,065,870 | 615,819 | 11,548,573 |
| China[a] | 298,512 | 504,698 | 879,485 | 991,318 | 2,766,675 | 1,843,875 | 923,431 | 736,411 | 1,122,299 | 788,198 | 10,854,902 |
| Norway | 146,754 | 2,340,760 | 1,011,303 | 911,487 | 267,399 | 346,227 | 413,616 | 1,795,627 | 1,780,827 | 1,329,478 | 10,343,478 |
| Annual Total | 23,377,653 | 27,292,804 | 32,724,772 | 43,617,029 | 52,645,105 | 54,767,008 | 45,927,319 | 45,080,229 | 46,862,153 | 56,016,683 | |

[a]Country with reported presence of DIV1

**Table 3:** Volume (metric tons) of flours, meals, and pellets of fish or of crustaceans, molluscs or other aquatic invertebrates, NESOI, unfit for human consumption imported by the United States from 2012 to 2021. Countries are listed in order of aggregate volume.[63]

| Country | Year 2012 | Year 2013 | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Year 2019 | Year 2020 | Year 2021 | Aggregate Volume |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mexico | 46,776 | 56,862 | 40,563 | 22,227 | 16,380 | 25,764 | 23,238 | 22,023 | 25,272 | 19,989 | 299,094 |
| Norway | 75 | 123 | 2,682 | 5,133 | 11,169 | 14,760 | 11,409 | 16,992 | 13,131 | 17,742 | 93,216 |
| France | 2,154 | 3,231 | 2,997 | 3,501 | 6,087 | 6,642 | 12,189 | 4,923 | 4,215 | 6,549 | 52,488 |
| Denmark | 3,294 | 2,304 | 663 | 2,748 | 6,252 | 2,595 | 1,668 | 1,917 | 1,164 | 1,311 | 23,916 |
| Peru | 819 | 3,282 | 2,988 | 3,246 | 3,246 | 5,232 | 888 | 645 | 825 | 1,767 | 22,938 |
| Japan | 2,325 | 4,446 | 1,503 | 1,485 | 1,413 | 1,593 | 1,149 | 1,422 | 1,062 | 1,755 | 18,153 |
| Spain | 0 | 0 | 0 | 0 | 1,104 | 2,847 | 11,220 | 2,160 | 291 | 432 | 18,054 |
| Ecuador | 1,698 | 930 | 549 | 615 | 3,945 | 2,424 | 111 | 240 | 303 | 825 | 11,640 |
| Morocco | 0 | 0 | 0 | 0 | 561 | 1,020 | 1,140 | 1,779 | 3,183 | 2,457 | 10,140 |
| Germany | 0 | 135 | 0 | 0 | 852 | 1,614 | 2,064 | 2,160 | 1,242 | 198 | 8,265 |
| Annual volume | 57,141 | 71,313 | 51,945 | 38,955 | 51,009 | 64,491 | 65,076 | 54,261 | 50,688 | 53,025 | |

**Table 4:** Top countries by aggregate volume (kilograms) receiving United States exports of chilled and frozen shrimp and shrimp seafood products to from 2012 to 2021.[63]

| Country | Year 2012 | Year 2013 | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Year 2019 | Year 2020 | Year 2021 | Aggregate Volume |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 776,430 | 860,472 | 1,140,223 | 1,677,221 | 960,216 | 1,208,134 | 881,228 | 783,983 | 563,023 | 637,420 | 9,488,350 |
| India | 421,777 | 487,221 | 932,132 | 872,954 | 634,689 | 650,521 | 529,990 | 856,357 | 1,222,300 | 1,785,800 | 8,393,741 |
| China | 185,182 | 747,641 | 108,350 | 311,425 | 323,295 | 608,791 | 1,516,869 | 685,325 | 626,818 | 530,484 | 5,644,180 |
| Vietnam | 149,006 | 108,011 | 151,021 | 939,860 | 1,560,396 | 283,913 | 301,360 | 427,423 | 337,023 | 319,263 | 4,577,276 |
| Denmark | 460,856 | 764,490 | 704,214 | 513,034 | 216,085 | 110,465 | 668,561 | 8,586 | 0 | 121,512 | 3,567,803 |
| Hong Kong | 292,512 | 257,712 | 241,724 | 377,590 | 386,451 | 220,270 | 390,537 | 443,578 | 464,652 | 167,308 | 3,242,334 |
| Thailand | 639,086 | 200,709 | 23,268 | 213,045 | 790,929 | 45,979 | 187,171 | 108,497 | 122,720 | 128,946 | 2,460,350 |
| Jamaica | 107,058 | 108,048 | 200,412 | 134,706 | 328,644 | 360,975 | 168,260 | 230,282 | 60,474 | 236,700 | 1,935,559 |
| Indonesia | 184,179 | 76,492 | 35,593 | 97,922 | 66,938 | 227,786 | 324,303 | 255,640 | 220,862 | 236,467 | 1,726,182 |
| Germany | 559,526 | 55,595 | 131,747 | 383,976 | 19,084 | 21,812 | 29,778 | 18,772 | 54,810 | 28,120 | 1,303,220 |
| Sweden | 531,370 | 241,930 | 0 | 416,456 | 44,344 | 0 | 1,089 | 920 | 0 | 0 | 1,236,109 |
| Guatemala | 3,846 | 177,625 | 46,244 | 72,635 | 28,940 | 560,152 | 72,048 | 0 | 5,071 | 57,015 | |

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