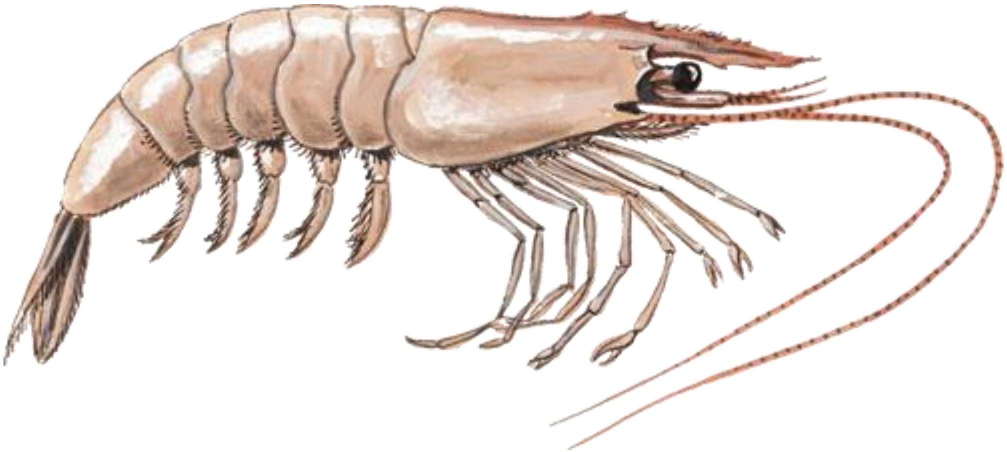
Whiteleg shrimp

Litopenaeus vannamei



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Mexico

Ponds

March 1, 2021

Seafood Watch Consulting Researcher

Final Seafood Recommendation

Pacific Whiteleg Shrimp

Litopennaeus vannamei
Mexico
Ponds

Criterion	Score	Rank	Critical?
C1 Data	5.91	Yellow	
C2 Effluent	4.00	Yellow	No
C3 Habitat	3.87	Yellow	No
C4 Chemical Use	0.00	Critical	Yes
C5 Feed	5.09	Yellow	No
C6 Escapes	2.00	Red	No
C7 Disease	2.00	Red	No
C8X Source of Stock	0.00	Green	No
C9X Wildlife mortalities	-4.00	Yellow	No
C10X Escape of secondary species	-0.40	Green	
Total	**18.47**		
Final score (0-10)	**2.64**		

OVERALL RANKING

Final Score	2.64
Initial rank	Red
Red criteria	3
Interim rank	Red
Critical Criteria?	Yes

FINAL RANK
Red

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

Pacific Whiteleg Shrimp (*Litopenaeus vannamei)* produced in ponds in Mexico have a final numerical score for 2.64 out of 10 which is in the red range, and with two Red criteria (Escapes and Disease) and one Critical criterion (Chemical Use), the final recommendation is a Red “Avoid.”

Executive Summary

Pacific whiteleg shrimp (*Litopenaeus vannamei*) are produced in semi-intensive pond culture systems across 14 of Mexico's coastal states, with the bulk (97 %) of the country's ~150,000 mt annual production (150,030 in 2017) occurring in five northwestern states bordering the Gulf of California. The industry is currently comprised of nearly 1,100 farms, with about 70,000 hectares of pond area. The United States and the European Union are major export markets for farmed Mexican shrimp, and Mexico is the 6th largest supplier of shrimp (farmed and wild-caught combined) to the U.S. market.

This Seafood Watch assessment involves a number of different criteria covering impacts associated with: effluent, habitats, wildlife interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), disease, the source stock, and general data availability. The available information indicates that Mexican shrimp farms use high water exchange rates (>15% per day) and this plays a role in the scoring of several criteria, particularly Effluent, Escapes, and Disease.

Data availability for Mexican shrimp farming is highly variable by topic. While many data sources and publications are available, the timeliness and relevance of the information to the industry as a whole is often limited. Some aspects such as effluent and habitat impacts are well-studied and are considered to give a reliable representation of the impacts, but data on feed and chemical use are very limited (despite multiple efforts to contact relevant agencies and feed companies). Overall, the quality and quantity of information on Mexican shrimp farming is moderate and scores 5.9 out of 10.

The available information indicates shrimp farms in Mexico have a high daily water exchange rate of >15 %, and there is evidence that the discharged effluent has contributed to cumulative local and regional impacts beyond the discharge area—including trophic shifts, changes in water chemistry, impacts to benthic chemistry and morphology, and possibly harmful algal blooms that affect other species; however, these observed effects were not severe (or were uncertain), and appeared to reverse quickly upon temporary cessation of production at the end of each cycle. It has previously been noted that the Mexican regulatory system, and particularly its enforcement, has been inadequate but since these observed impacts took place (primarily in studies published in 2013 and 2014), it seems clear that the Mexican government, through the "National Program for Compliance with Environmental Regulations in the Aquaculture Sector," has increased enforcement, with 71% of the total production area in Sinaloa inspected in 2017. The effects of this improved enforcement on water quality in intensive shrimp farming areas and the ongoing extent of this enforcement are currently poorly understood and increased enforcement has apparently not reached all regions. Overall, there continues to be a potentially high concern regarding effluent impacts from the Mexican shrimp industry but given the uncertain scale of the impacts and the temporary nature of the observations, the final score for Criterion 2 – Effluent is 4 out of 10.

Mexican shrimp farming grew rapidly as an industry in the 1980s and 90s, with estimates that over half of the area developed for farms was originally high value habitats bordering the coast or estuarine wetlands and salt marshes (with the exception of some conversion of tropical dry forest, the remainder is reportedly in lower value terrestrial habitats or former agricultural land--though the classification of habitat types has been questioned). Mexico implemented some protections for critical habitats such as mangroves, but the effectiveness of these measures at preserving their ecosystem health are questionable. Protections for other high-value habitats such as salt marshes have been absent, and while the loss of mangrove forests specifically has been minor, the shrimp industry has driven significant losses in salt marsh locations. Environmental regulations contain some ecological considerations in siting and an environmental impact assessment processes, though with gaps relating to consideration of cumulative impacts. There is evidence that enforcement organizations have recently made major investments in seeking industry-wide compliance, but there are still indications that existing regulation and enforcement have limitations and compliance with environmental regulations is challenged. Overall, the Criterion 3—Habitat score is 3.87 out of 10.

Data on chemical use in Mexican shrimp farms is limited. It shows that in one state (Sonora) in 2018 (the latest year of data available), approximately 24% of farms used antibiotics, of which 84% had used an antimicrobial listed as Critically-Important to human medicine by the World Health Organisation (enrofloxacin) and the remainder used either Highly-Important (oxytetracycline or florfenicol) or a mix of enrofloxacin and oxytetracycline. Regulatory restrictions are in place for the use of antimicrobials and Aquaculture Health Committees remain active in advancing animal health and biosecurity in Mexican shrimp farming, but production involves a high water exchange with the surrounding environment, and there are multiple references to acquired bacterial resistance to OTC on shrimp farms. The Sonora data indicate an increase in the number of farms using antimicrobials over time (2014 to 2018), but without more specific data to understand total overall antimicrobial usage (frequency, volumes) from Sonora and from other states, the use of Highly- and Critically-Important antimicrobials is considered significant but unknown. With the evidence of developed resistance to these antimicrobials, the final score for Criterion 4 – Chemical Use is 0 out of 10 and is a Critical conservation concern.

Without recent feed data applicable to the industry as a whole (i.e., other than isolated data points for four ASC-certified farms), assumptions based on now-dated global reference values were made for the feed composition in Mexico. Using these global values alongside the limited Mexico-specific values, the FFER value was 1.39. Although with some uncertainty, it was also assumed that Mexican forage fisheries are used in shrimp feeds which are primarily MSC-certified, and the final Wild Fish Use score is 5.68 out of 10. With an estimated feed protein content of 35.0 %, supplied predominantly by marine and crop ingredients considered suitable for human consumption, there was a net loss of edible protein of 69.3 % and a feed footprint of 10.2 ha per mt of shrimp production. Overallm the three factors combine to give a final Criterion C5 – Feed numerical score of 5.09 out of 10

It is clear that farmed shrimp are escaping from farms through unintentional losses and also possibly via intentional releases of postlarvae. Escapes may be as high as 3-6 % of total farmed shrimp, and 7-14 % of shrimp collected from “wild” Pacific populations showed signs of hatchery/farm origin. *L. vannamei* are native to the Pacific coast of Mexico, but the industry relies on hatchery production of postlarvae from selectively-bred broodstock that are genetically distinct from wild shrimp. With a high genetic diversity in wild populations, genetic impacts may be unlikely, but there is currently insufficient evidence with which to conclude this. The species has additionally been detected outside of its native range (Eastern Pacific, Mexico to Peru), in the Gulf of Mexico; this is linked to aquaculture escapes and there is potential for eventual establishment, but again, there is no evidence of establishment to date. The combination of a high risk of escape (Factor 6.1) and a moderate risk of genetic and competitive impacts (Factor 6.2) gives a final score of 2 out of 10 for Criterion 6 – Escapes.

The Mexican shrimp industry has a history of introducing and spreading exotic shrimp pathogens around the country and there is evidence that these pathogens have been transmitted to, and have significantly impacted, wild shrimp at the population level (for example wild *L. stylirostrus* shrimp populations in Mexico affected by the IHHN virus). There is ongoing uncertainty with regard to other confirmed transmissions of diseases from cultured stocks to wild ones. Despite management and regulatory improvements, the pattern of disease epidemics occurring at the farm level and the open nature of the production system suggests the likelihood of both disease amplification and transmission to wild populations is an ongoing risk. There is thus a moderate-high risk that disease linked to Mexican shrimp aquaculture will cause population-level impacts to wild shrimp or other marine organisms, and the final numerical score for Criterion 7 – Disease is 2 out of 10.

Mexican shrimp farming initially utilized wild post-larvae as the main source of stock and later still used them when hatchery-stocks were in short supply, but the industry now relies entirely on hatchery production from 34 hatcheries in the country, which produce about 10.5 billion postlarvae annually. It is therefore now considered to be completely independent of wild shrimp populations for broodstock or postlarvae, and the score for Criterion 8X – Source of Stock is a deduction of 0 out of -10.

Specific information on wildlife interactions in Mexican shrimp farms is limited, and no data are available on mortality numbers of any species. There is clearly some interaction with predatory and scavenging birds, which present nuisances in the form of product loss and biosecurity risk. The birds most likely to visit a shrimp pond are classified as Least Concern by the IUCN, although a few of these species (such as the gull-billed tern) are believed to be in population declines in part of their range, including Mexico. Farms apparently makes use of non-lethal exclusion strategies, such as human presence and scaring tactics for birds and use of nets and screens to exclude marine organisms from intakes, but there are also (dated and/or anecdotal) references to the shooting of birds, and while this is now illegal, there are no data on the enforcement. There are also suggestions that bird predation is not a significant issue for this industry and that non-lethal management is largely effective. Without more precise information, it is assumed that wildlife mortalities occur beyond exceptional cases, but that population sizes are not significantly affected. The final numerical score for Criterion 9X – Wildlife Mortalities is -4 out of -10.

The large majority of Mexican shrimp farms are in the northwest of the country and are supplied by PL from hatcheries in the same region. Although the information is not certain, a small amount of production on the Atlantic coast is considered to be supplied by the same hatcheries and therefore represent trans-waterbody movements of live animals across Mexico. The hatcheries supplying the PL are considered to have a low-moderate risk of introducing secondary, unintended organisms during the shipments, and therefore overall, there is a low risk of introducing unintended species in Mexican shrimp production. The final numerical score for Criterion 10X – Escape of secondary Species is -0.4 out of -10.

The final score for Pacific white shrimp farmed in ponds in Mexico is 2.64 out of 10 and with two red criteria (Escapes and Disease) and one Critical criterion (Chemical Use), the final recommendation is a red "Avoid."

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species
Pacific whiteleg shrimp (*Litopenaeus vannamei,* Boone, 1931).

Geographic Coverage
Mexico.

Production Method(s)
Ponds.

Species Overview

Litopenaeus vannamei is native to tropical eastern Pacific marine waters ranging from Sonora, Mexico southward to Tumbes in northern Peru (Briggs 2006). The life history of whiteleg shrimp is similar to some other members of the family Penaeidae, in which adults spawn offshore, pelagic larvae move toward the coast and develop in coastal waterbodies before again moving offshore as adults.

Production system
In Mexico, modern whiteleg shrimp production relies on domestic hatchery production of post-larvae (juvenile shrimp), using hatchery-raised (domesticated) broodstock. Larvae are reared for about 21 days prior to shipment as postlarvae to growers for transfer to nurseries or aerated ponds for growout (Briggs, 2006; Holtschmit and Garmendia, 2009; Ruiz-Velazco *et al.*, 2010; Olachea, 2011; SEMARNAT, 2012a).

Most growout (93 %) occurs via semi-intensive (vs. 7 % intensive) pond culture (COSAES 2014), where shrimp are fed artificial diets to supplement naturally-occurring forage within ponds (which is itself supported by the additional of fertilizers)(SEMARNAT, 2012a; ASC, 2017). Ponds are often earthen but may also be lined. Previously, Briggs (2006) stated individual ponds are typically 0.1-5 hectares (ha) with a depth of >1.5m, and farms typically range in total area from 4-1200 ha (INAPESCA, 2018). Mexican whiteleg shrimp farms are located proximal to the coastline and to estuarine systems (Figure 1), which facilitates pumped water exchange. A small segment of the industry has been exploring intensive culture designs with greater environmental control to combat disease issues like EMS (Shrimpnews.com, 2014) and designed in ways to reduce environmental impacts (such as by siting inland or on abandoned agriculture sites; Dr. Rick Brusca, Arizona-Sonora Desert Museum, pers. comm. 2019).

Figure 1. Aerial photo of typical Mexican shrimp farm design. Google Earth (2017).

Post-larval (PL) growth rates vary with water temperature, habitat availability, and feed type, but generally Mexican shrimp farmers will pursue one to two production cycles per year. In northern Mexico where cooler winter temperatures inhibit year-round cultivation, farmers are restricted to one longer cycle where shrimp spend 8 – 9 months in growout ponds (SEMARNAT, 2012a). Partial harvesting occurs throughout this cycle; farmers remove a portion of the biomass in the ponds to make space for the remaining shrimp to continue growing (Cesareo Cabrera, pers. comm., 2015), with these “pre-harvest” shrimp sold on the national market (Lorayne Meltzer, Prescott College, pers. comm. 2020). The last harvest of shrimp contains individuals weighing an average of 30 grams (Ibid.; Newman, pers. comm., 2014). In Nayarit, the climate allows shrimp farmers to pursue a biannual stocking regime during which PL spend 3 – 4 months in growout ponds and weigh between 8 – 16 grams at harvest (Berlanga-Robles *et al.*, 2011a; C. Cabrera pers. comm. 2015).

At harvest, ponds are drained to the surrounding environment to allow efficient collection of shrimp with seine, cast, or dips nets, or perforated buckets. Production yields are typically 500-2,000 kg/ha/crop, with 2 crops annually (or 3-4 partial harvests/year)(Briggs, 2006; Holtschmit and Garmendia, 2009; SEMARNAT, 2012a).

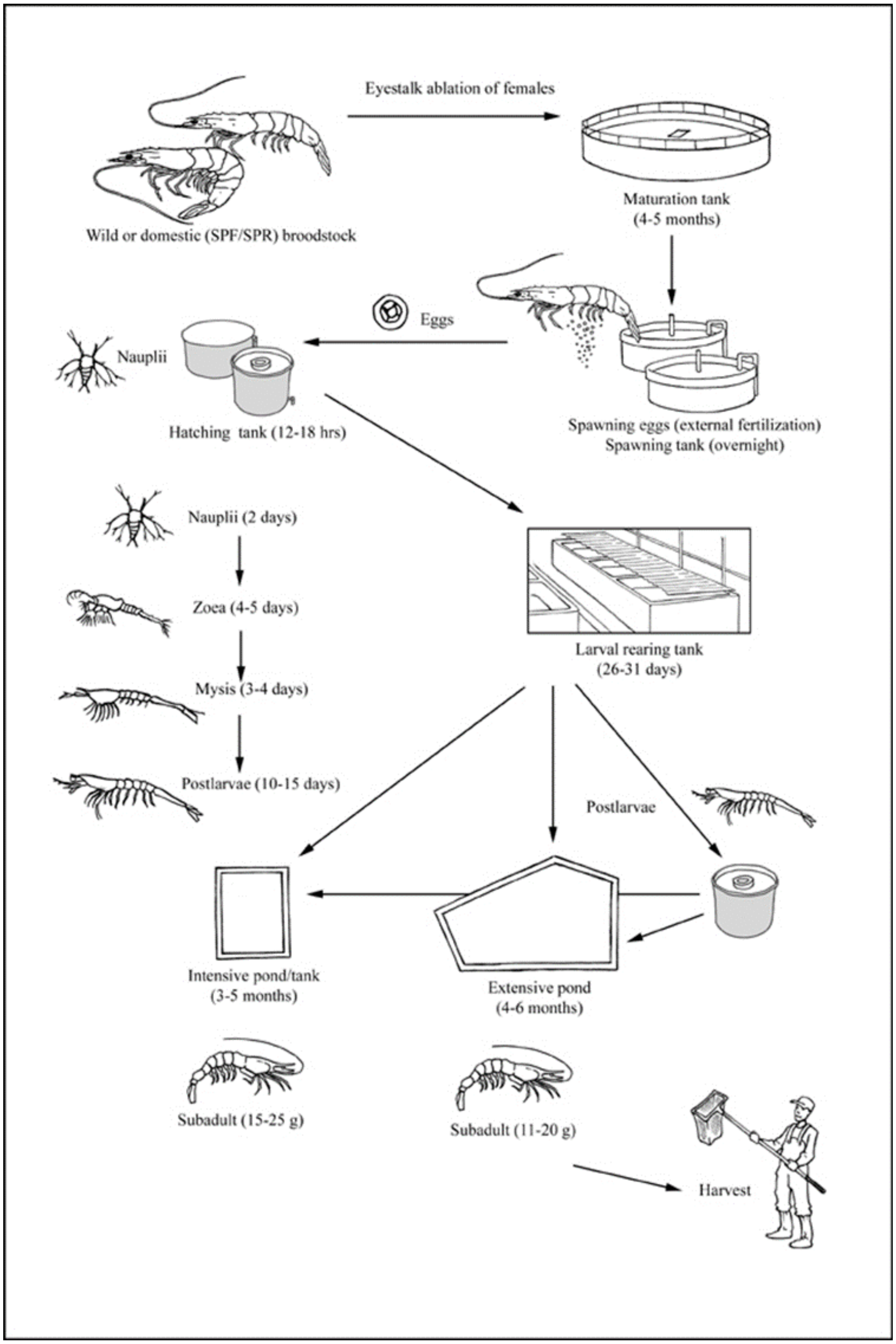

Figure 2. General depiction of whiteleg shrimp production cycle. FAO 2017.

Production Statistics

Mexico is a major producer of shrimp on a global scale, exceeding 157,000 mt of production in 2018 (Table 1) (FAO, 2019). The industry is currently comprised of nearly 1,100 farms, with about 70,000 hectares (ha; up from 53,000 ha in 2002) of water surface (INAPESCA, 2018; Casillas-Hernandez *et al.*, 2006). Production is focused across five of Mexico's 31 states in the northwestern region of the country—Sonora, Sinaloa, Nayarit, Baja California, and Baja California Sur (Barraza-Guardado *et al.*, 2013; Hernandez-Llamas *et al.*, 2014). These five states account for 97 % of national production and lesser volumes are also being produced in 9 other states—including southern Gulf of Mexico states like Tabasco's Machona Lagoon (Wakida-Kusunoki *et al.*, 2011; Mendoza-Cano *et al.*, 2016). The total area (including ponds and other farm infrastructure) in use by Mexico's shrimp farming industry is currently uncertain, but was estimated at about 86,438 ha in 2013 (López-Téllez *et al.*, 2019).

The dominant states (Sonora, Sinaloa, Nayarit, Baja California, Baja California Sur), which account for 97 % of national production, are the primary focus of this assessment and are assumed to be representative of national production as a whole, though limited references to production in other regions is cited occasionally for commentary into the effectiveness of national regulations as needed.

Most postlarvae (PL) are produced in Sonora, which is also the leading producer of shrimp for market; Sinaloa is also an important producer of PL and Mexico's second leading producer of farmed shrimp. Together, these are the country's most important production states (Barraza-Guardado *et al.*, 2013; Hernandez-Llamas *et al.*, 2014; Aquaculture Magazine, 2017). White Spot Syndrome Virus, Early Mortality Syndrome, and other disease issues resulted in sharp declines in production from 2012 to 2013, but Table 1 shows that production has since rebounded.

Table 1. Mexico and global whiteleg shrimp production 2014-18 (FAO, 2020).

	2014	2015	2016	2017	2018	Growth, 2014-17
Mexico production						
Volume (mt)	86,973	130,361	127,814	150,030	157,934	82%
Value (USD, millions)	419.28	503.08	577.28	639.59	607.46	45%
% of global production (volume)	2.42	3.43	3.10	3.17	3.18	0.76%
% of global production (value)	1.84	2.25	2.36	2.28	2.01	0.17%
Global production						
Volume (million mt)	3.60	3.80	4.13	4.73	4.97	38%
Value (USD, millions)	22,724	22,392	24,543	28,105	30,222	33%

Import and Export Sources and Statistics

Primary markets for Mexican shrimp include domestic consumption, the United States, and the European Union. The economic value of shrimp trade far outweighs that of any other single species exported from Mexico to the United States (both farmed and wild-caught); accounting for half of the total value of marine products traded annually between the two countries (FAO, 2012). In 2016, Mexican farmed shrimp exports to the United States were substantial at 25,313 mt, valued at $294.8 million, though this represents a decline from nearly 28,000t and over $320 million in 2015 (NMFS, 2017; USDA, 2017). Mexico is the 6th largest supplier of shrimp consumed by the U.S. market (Anderson *et al.*, 2016).

Common and Market Names

Scientific Name	***Litopenaeus vannamei***
Common Name	Whiteleg shrimp, white shrimp, Pacific white shrimp
Spanish	Camarón patiblanco
French	Crevette pattes blanches
Japanese	蛯 (ebi)

Product forms

Mexican shrimp are available in a variety of product forms including frozen, previously frozen, cooked and raw, head-on, head-off, peeled, and peeled and de-veined. They may also be present in value-added goods like breaded shrimp or ready meals, meeting a growing demand (Briggs, 2006; Anderson *et al.*, 2016).

Analysis

Scoring guide

- With the exception of the exceptional criteria (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rating. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the three exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Standard that the following scores relate to are available on the Seafood Watch website. http://www.seafoodwatch.org/-/m/sfw/pdf/standard %20revision %20reference/mba_seafoodwatch_aquaculture %20criteria_finaldraft_tomsg.pdf?la=en

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Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.
- Sustainability unit: the ability to make a robust sustainability assessment
- Principle: having robust and up-to-date information on production practices and their impacts publicly available.

Criterion 1 Summary

Data Category	**Data Quality**	**Score (0-10)**
Industry or production statistics	7.5	7.5
Management	5	5
Effluent	7.5	7.5
Habitat	7.5	7.5
Chemical use	2.5	2.5
Feed	2.5	2.5
Escapes	5	5
Disease	5	5
Source of stock	10	10
Predators and wildlife	5	5
Introduced species	7.5	7.5
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		**65.0**

C1 Data Final Score (0-10)	**5.9**	**Yellow**

Brief Summary

Data availability for Mexican shrimp farming is highly variable by topic. While many data sources and publications are available, the timeliness and relevance of the information to the industry as a whole is often limited. Some aspects such as effluent and habitat impacts are well-studied and are considered to give a reliable representation of the impacts, but data on feed and chemical use are very limited (despite multiple efforts to contact relevant agencies or feed companies). Overall, the quality and quantity of information on Mexican shrimp farming is moderate and scores 5.9 out of 10.

Justification of Rating

L. vannamei is a globally important aquaculture species and there is a large amount of general literature, but for Mexican production specifically, the quality and availability is variable depending on the subject. Key sources of information include federal and state governments, and state-level Aquaculture Health Committees, peer-reviewed publications, and student theses. Some of the challenges faced by development of this industry—including those related to disease, effluent, and habitat considerations have received particular attention, resulting in a compliment of presentations, white papers, magazine articles, and other gray literature. Nevertheless, some unexplained inconsistences exist, and for this assessment, some assumptions (as discussed in relevant sections) were unavoidable. As discussed throughout this report, there is a general lack of recent data and/or publications to give high confidence that the current production practices and their impacts are robustly understood.

Industry and production statistics

Production statistics are available from the United Nations Food and Agriculture Organization (FAO)(through 2018), the Mexican federal government (through 2017), some state governments and aquaculture health committees, and published literature (though there are inconsistencies depending on source). Information on production systems including typical farm sizes are available from the same sources. State organizations, such as aquaculture health committees, and the federal government have information on individual growers—such as locations, contact information, and products offered, though with some gaps in time. Publicly available Environmental Impact Assessments reviewed for this assessment provide additional specifics, as does some information gleaned from several 3rd-party (Aquaculture Stewardship Council) environmental audits and interviews with individuals familiar with the industry. The information gives a reliable presentation of the industry's production, but with some gaps in time, the data score is 7.5 out of 10.

Management and Regulations

Regulatory information is available via government websites and in the published literature. Website links to many of the aquaculture health committees offer specifics on their work, though the information available is not always up to date (e.g. Sinaloa's extends only to 2014) and the extent of information available varies widely among states; Additional information is available via social media platforms (state Aquaculture Health Committees, for example) and through a number of best practices guides published by various entities—from aquaculture health committees to federal agencies. Government websites also provide some useful information and data on enforcement and compliance, though coarse and limited in temporal coverage, and attempts to contact regulators at multiple agencies were mostly unsuccessful. Environmental Impact Assessments are publicly available and include information on regulation (though the usefulness and integrity of these has been questioned) and there are a number of peer-reviewed publications offering evaluation of Mexico's regulatory effectiveness. Third-party audits provide some insight into on-farm practices and a number of manuals and guides on shrimp farming practices are available. Despite these sources, substantial uncertainty remains about the content and enforcement of the various regulations and management practices in Mexican shrimp farms. As such, the data score for management and regulations is 5 out of 10.

Effluent

Mexico-specific studies on effluent impacts, including in the county's most important growing regions are available; for example, Barraza-Guardado *et al* (2014, 2015), Páez-Osuna *et al.*, 2003; Holtschmit and Garmendia, 2009; Miranda *et al.*, 2009; Barraza-Guardado *et al.*, 2013; Lithgow et al 2017; and more. While important recent information on the impacts of effluent discharges and on regulatory compliance and enforcement is limited, commentary on the effectiveness of effluent management and regulation is also available in recent published literature, and the available data are considered to give a reliable representation of the likely impacts. The data score for Effluent is 7.5 out of 10.

Habitat

There are numerous studies into landscape changes and impacts associated with shrimp aquaculture development in Mexico—including several investigations on impacts to mangrove forests and coastal wetlands. Details and quantities on habitat conversion are available, as well as trends for nearly the entire duration of the industry's development in Mexico—though there is some disagreement on conclusions in the literature. Farm size, location, regional maps, and images are also readily available—including historical imagery dating to 1984 via Google Earth Pro. Insights into some of the ecosystem services provided by the habitats in which shrimp farms are located (and also lost to their development) are available in the literature, including recent publications. Publicly available Environmental Impact Assessments provide a large amount of detailed information. Regulations aimed at habitat protection are available via government websites and the scientific literature additionally offers commentary on regulations and their effectiveness. There are some publicly available data and other information on enforcement, but this is often coarse and with some gaps that limit full confidence in understanding its effectiveness. Data for Habitat scores 7.5 out of 10.

Chemical Use

There are some data available on chemical usage from one aquaculture health committee for Sonora (Comité de Sanidad Acuícola en Sonora; COSAES), though information on dosage and frequency of use is limited, and the most recent data year is 2018. No robust data are available from other states. The academic literature contains several references to developed antimicrobial resistance and recent detection of antimicrobial residues in exported product. There is additional information in similar production systems from other countries that provides some supplementary information, but the relevance to Mexico is uncertain. Several attempts to contact COSAES, the Comité Estatal de Sanidad Acuicola de Sinaloa (CESASIN), the Comité de Sanidad Acuícola de Baja California Sur (CSABCS), and the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA) for more information for this assessment were unsuccessful. Data for Chemical Use scores 2.5 out of 10.

Feed

Several attempts to acquire information on shrimp feeds directly from four Mexican feed companies were unsuccessful. As shrimp aquaculture is significant at the global scale, published literature on feeds is available, though specific on detail readily applicable to Mexican shrimp production is limited to the audit reports of four farms certified to the Aquaculture Stewardship Council (ASC). Specific to Mexico, there are publications detailing local reduction fisheries and fishmeal/oil processing industries, and websites of feed companies provide some useful information. Research on shrimp feeds is extensive, so protein contents, and other useful values for this criterion are available, but again, no specific values for Mexico were available other than the four certified farms. Data for Feed scores 2.5 out of 10.

Escapes

No specific data are available on the frequency or scale of accidental escapes from shrimp ponds in Mexico, but a recent academic paper (Perez-Enriquez et al., 2018) reports surplus postlarvae are deliberately released from hatcheries. Other academic papers confirm that escapes do occur, and that farm-origin shrimp are present in the wild. Interviews with individuals familiar with the industry have challenged the description of deliberate releases and offered additional insights. As interest and investment in hatchery production of postlarvae has grown robustly since the 1990s, published research on hatchery breeding and genetic makeup of domesticated stocks is robust. Wild stock fisheries for *L. vannamei* have long been important and as shrimp aquaculture has become controversial in Mexico, investigations into the occurrence and risk of escapes of farm stocks has produced a number of peer-reviewed publications (including recently) useful to this assessment. While these publications indicate that a potential for genetic impacts exist, very little is known about the scale of the impact. Data for Escapes scores 5 out of 10.

Disease

The disease issues experienced by the Mexican shrimp farming industry have been well-documented. Some data on disease monitoring are available through state government publications and organizations (such as some, but not all aquaculture health committees), but this is limited both geographically and temporally (e.g. the most recent shrimp health data from Sonora, which offers the most detail, is from 2018). The academic literature is rich in peer-reviewed studies on occurrence, prevalence, and effects of disease issues with this industry. For this assessment, information on the impacts of disease transmission from farmed stocks to wild ones is incomplete—though examples of such transmission are well-documented. Much of these data, however, are of varying degrees of temporal relevance, and there are fewer examples of recent publications and impacts. On biosecurity and management, information is available from government websites and publications (federal agencies and state-level aquaculture health committees) and in the scientific literature. Overall, there is disease data available but more recent and more geographically representative data on prevalence and on the effects to surrounding ecosystems are needed. Data for Disease scores 5 out of 10.

Source of Stock

The transformation of the Mexican shrimp industry from collection of wild PL and broodstock to a modern industry reliant upon hatcheries is well-documented. There is ample information on hatchery production and practices and even location, contact, and product information available to understand source of stock. Data for Source of Stock scores 10 out of 10.

Wildlife and Predator Mortalities

No specific data are available on the interactions and mortalities of birds or other types of wildlife on Mexican shrimp farms, though information on typical wildlife-farm interaction is described in government manuals and best practices publications (for example). The species of birds most likely to be encountered on Mexican shrimp farms are available in general literature, and from sources such as the International Union for Nature Conservation (IUCN). Some evidence of wildlife interactions, including mortalities of aquatic species, are available. Interviews with individuals familiar with this industry provided some insights on wildlife interactions and management. Available specifics on wildlife management practices are limited, though there are some indications on deterrent methods and other best management practices being used in at least some production. There is some additional useful information on expected wildlife interactions and deterrent strategies within publicly available Environmental Impact Assessments. The literature on shrimp farming in other regions of the world offers some additional useful information. Data for Wildlife and Predator Mortalities scores 5 out of 10.

Escape of secondary species

For most of the Mexican shrimp industry, information on the locations and production numbers of hatcheries combined with the locations of the main farming regions clearly informs the likely movements of live shrimp. For the small percentage of production on the Atlantic coast, there is no detailed information of the hatchery sources of postlarvae, but one reference (Mendoza-Cano *et al.*, 2016) and interviews with knowledgeable individuals indicate that some movements occur from hatcheries on the Pacific coast. With moderate to good information available on the production systems used in the hatcheries and the farm ponds with which to assess their biosecurity, overall, data for Escape of secondary species scores 7.5 out of 10.

Conclusions and final score

Data availability for Mexican shrimp farming is highly variable by topic. While many data sources and publications are available, the timeliness and relevance of the information to the industry as a whole is often limited. Some aspects such as effluent and habitat impacts are well-studied and are considered to give a reliable representation of the impacts, but data on feed and chemical use are very limited (despite multiple efforts to contact relevant agencies or feed companies). Overall, the quality and quantity of information on Mexican shrimp farming is moderate and scores 5.9 out of 10.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.
- Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Evidence-based assessment

C2 Effluent Final Score (0-10)	**4**	**Yellow**

Brief Summary

The available information indicates shrimp farms in Mexico have a high daily water exchange rate of >15 %, and there is evidence that the discharged effluent has contributed to cumulative local and regional impacts beyond the discharge area—including trophic shifts, changes in water chemistry, and possibly harmful algal blooms that affect other species; however, these observed effects were not severe (or were uncertain), and appeared to reverse quickly upon temporary cessation of production at the end of each cycle. It has previously been noted that the Mexican regulatory system, and particularly its enforcement, has been inadequate, but since these observed impacts took place (primarily in studies published in 2013 and 2014), it seems clear that the Mexican government, through the "National Program for Compliance with Environmental Regulations in the Aquaculture Sector", is attempting to increase enforcement, with 71% of the total production area inspected in 2017. The effects of this improved enforcement on water quality in intensive shrimp farming areas and the ongoing extent of this enforcement are currently poorly understood, and increased enforcement has apparently not reached all shrimp producing regions. Overall, there continues to be a potentially high concern regarding effluent impacts from the Mexican shrimp industry but given the uncertain scale of the impacts and the temporary nature of the observations, the final score for Criterion 2 – Effluent is 4 out of 10.

Evidence-based assessment:

Studies of Mexican shrimp farm effluent, and its effects on nearby marine environments, have resulted in a number of peer-reviewed publications useful for this assessment. As such, the effluent data quality and availability is considered "good" (i.e. Criterion 1 score of 7.5 or 10 of 10 for the effluent category), and the Evidence-based assessment was utilized.

Justification of Rating

Shrimp ponds are connected to nearby marine environments by necessity: proximal estuarine and coastal ocean systems provide both a water supply and a means of effluent discharge (Páez-Osuna *et al.*, 2003; Barraza-Guardado *et al.*, 2013). Water is exchanged frequently to maintain optimal salinity and oxygen levels, to dilute antimicrobials, and to replace seepage and evaporative losses (Lithgow *et al.*, 2017); pond drainage is also a common response to disease outbreaks (Macías-Rodríguez *et al.*, 2014). Some farms discharge water from the growing ponds into a neighboring estuary or inlet, or to a ditch or cooperative canal (Lebel *et al.*, 2016) that subsequently drains to a similar location; others discharge directly into the ocean (Holtschmit and Garmendia, 2009). Older references state that very few farms make use of rudimentary treatment tools like settling or oxidation ponds (DeWalt *et al.*, 2002) and there is some evidence that this is still true (Aguilar-Manjarrez *et al.*, 2017; ASC, 2017). This is considered to be due to a lack of awareness of regulations or lack of resources and support to make such investments (Aguilar-Manjarrez *et al.*, 2017). Pond water is partially exchanged or completely drained at harvest, in between production cycles, and via a daily rate of 5-30 % d^{-1} (Holtschmit and Garmendia, 2009; SEMARNAT, 2012a; Barraza-Guardado *et al.*, 2013, 2015; Government of Sonora, 2017; Lithgow *et al.*, 2017). More precisely, the Government of Sonora requires a minimum daily replacement rate of 15 % (Government of Sonora, 2017), and several references suggest an average daily exchange rate of 18.5-20 % (Coffman, 2015; ASC, 2017). Discharge occurs only during months of active shrimp production (e.g. outside of winter fallowing months in Northern states like Sinaloa), which may vary by region (SEMARNAT, 2012a). A study of 1,350 ha of ponds in Sonora estimated pond water discharge rates of 160,000 m^3 ha^{-1} $year^{-1}$ (Barraza-Guardado *et al.*, 2013). On a 60 mile stretch of Sonoran coastline, daily combined exchange rate (not including end-of-season draining) has been estimated at over 31.8 million m^3 from shrimp farms (L. Meltzer pers. comm. 2020).

The discharge of effluent is a primary concern surrounding the Mexican shrimp industry, described as "one of the key environmental concerns with shrimp farming" (Barraza-Guardado *et al.*, 2015). Shrimp farm inputs include feed, dietary supplements, antimicrobials, algicides, and fertilizer (Lithgow *et al.*, 2017). Shrimp ponds may be fertilized at a rate of 20-40 kg ha of fertilizer per month of production (Arcia Castro, 2014); one Mexican farm certified to the Aquaculture Stewardship Council reports using about 26,000 kg of fertilizer per year, or 68 kg fertilizer per mt of shrimp produced (ASC, 2017). Another describes using 50 kg/ha of urea preceding outplant of PL (SEMARNAT, 2012a). Although these nutrients are partially utilized in the ponds, the effluents discharged include soluble organic and inorganic nitrogen and phosphorous, and particulates such as unconsumed shrimp food, feces, detritus, phytoplankton, zooplankton, and bacteria (Casillas-Hernández *et al.*, 2006). It is estimated that 18-27 % of nitrogen input to ponds is converted to shrimp biomass; 73-82 % is thus discharged to the environment (Barraza-Guardado *et al.*, 2015), and shrimp farming has previously been estimated to have a waste load of 72kg N and 13kg P per mt of harvested shrimp (Casillas-Hernández *et al.*, 2006). For the Bahia de Kino area for example (the most intensive shrimp-growing area in Mexico), this amounts to a total load of 243 mt N $year^{-1}$ and 44 mt P $year^{-1}$ from shrimp ponds (Barraza-Guardado *et al.*, 2013). Miranda *et al* (2009) estimated that the shrimp farms of Sinaloa and Sonora contribute 3,556 mt of N and 620.7 mt of P to the Gulf of California, or about 4.8 and 1.6 % of the total Gulf inputs respectively, also suggesting that these values may in fact be as high as 10.2 and 3.3 %, respectively (Miranda *et al.*, 2009). Given the scale of the Gulf of California, the potential for local impacts near the discharge sites appears high.

For example, while most Ramsar sites along the coast of Mexico do not mention shrimp farms as a specific impact (see Criterion 3 – Habitat for more information), one site - Humedales de la Laguna La Cruz - notes the main threats to the site are related to the neighboring shrimp farms and their effluents. The 2009 site description[1] notes the shrimp farm effluents contribute significant quantities of higher saline water, total suspended solids, chlorophyll, bacteria, low oxygen levels and reduced transparency, and while the lagoon has the ability to dilute the salinity, the other parameters can affect the biochemical processes and environmental condition of the lagoon. Nevertheless, there is no indication of the scale of these changes and therefore the scale of the impact in this example remains unclear. And although now more than ten years old, Miranda *et al* (2007) noted higher levels of TSS in shrimp farm effluent than inflow water in the Moroncarit lagoon--where a single farm discharged 16-20 % of the lagoon's total volume in a single day. The authors reported high contributions of N and P inputs here, and concluded that the single farm at this site was likely to contribute significantly to changes in the trophic status of the lagoon (Miranda *et al.*, 2007).

More recently, in their study of effluent discharge and associated ecological effects in one of Mexico's most important shrimp farming areas (Bahia de Kino), Barraza-Guardado et al (2013) observed total suspended solids (TSS) at 233.2 mg L^{-1}, which exceeded the 175 mg L^{-1} limit set by Mexican regulation (SEMARNAT, 1997; Barraza-Guardado *et al.*, 2014)[2]. High phytoplankton biomass and organic matter were also observed and were attributed to fertilizer addition and waste production in shrimp ponds. Barraza-Guardado et al (2013) note the linkage between high nutrient loads and elevated Chlorophyll-a (Chl-a) levels, lowered diversity of phytoplankton, and an increase in harmful algal blooms in receiving waters; they postulate that shrimp farm effluents could also contribute to hypoxic events and fish kills; such events have historically been linked in part to shrimp farms (DeWalt *et al.*, 2002) and are on the rise in this region (Páez-Osuna *et al.*, 2017). Effluent waters were additionally a source of higher concentrations of bacteria, including pathogenic *Vibrio* bacteria. Values for TSS, Chl-a, particulate organic matter (POM), viable heterotrophic bacteria, and *Vibrio*-like bacteria were 2-3 times higher than a nearby control site, and shrimp farm effluent was also noted as being of a significantly higher salinity (Barraza-Guardado *et al.*, 2013).

One year later, Barraza-Guardado et al (2014) explored the effects of shrimp farm effluents at various distances from the point of discharge and at various points in time in the production cycle. The authors observed increases in measures of water turbidity, seston (TSS, POM, total inorganic solids), Chl-a, and nitrogen, and sediment organic nitrogen at 50, 150, and 300m (well beyond the immediate vicinity of the farms) from the point of discharge during and

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[1] https://rsis.ramsar.org/RISapp/files/RISrep/MX2154RIS.pdf?language=en

[2] For reference, the Global Aquaculture Alliance-recommended shrimp farm water quality standards for TSS are <100 mg L^{-1} with a target of <50 mg L^{-1}.

immediately following the shrimp production cycle and concluded that during and immediately following production, nutrient and organic matter loads associated with shrimp farming exceeded the assimilative capacity of the receiving environment as indicated in part by a shift in the trophic state of the waterbody (Barraza-Guardado *et al.*, 2014); however, in this study, the authors noted that monitored parameters did not exceed the established limits, were not severe, and appeared to reverse quickly upon temporary cessation of production. The authors also note that the site in this study is less intensively-farmed than that explored at Bahia de Kino (Barraza-Guardado *et al.*, 2013, 2014) but that shrimp farming typically occurs in cycles that include a pond drying period (Navedo et al., 2015; SENASICA, 2017) that is encouraged by Barraza-Guardado et al as a method to allow recovery.

Lastly, Lithgow et al (2017; presenting fieldwork conducted in 2013-14) also found in their upstream vs. downstream-of-shrimp-farms study design that concentrations of dissolved oxygen (DO), chemical oxygen demand (COD), total solids (TSS, TS), salinity, phosphorus, sulfates, sodium, manganese, and four other monitored parameters significantly differed between samples taken upstream vs. downstream of shrimp farms (see also Martínez-Durazo *et al.*, 2019). The authors attributed the downstream observations to shrimp farming and describe harmful effects including the release of hydrogen sulfide, increasing soil alkalinity, formation of iron sulfide which increases downstream water alkalinity, and the transport of other pollutants with flocculated TSS. The same study included a survey of decision-maker and academic perceptions related to shrimp aquaculture and one notable conclusion was that a majority of academics viewed the effects of shrimp farm effluent as having negative effects that extended beyond locally to shrimp farms (Lithgow *et al.*, 2017).

Miranda et al (2009) concludes that shrimp farms could contribute significantly to local eutrophication and trophic shifts and the work of Barraza-Guardado *et al* (2013, 2014) demonstrates that this is occurring in some places—including some of Mexico's most important shrimp growing areas—and is a threat elsewhere if not properly explored and managed. It is accepted that production practices could have changed since these 2013-2017 studies (see information on enforcement below), and while no further or more-recent published information is readily available, in at least some areas, degradation of coastal estuaries due to shrimp farming effluents continues consistently; on an important stretch of coastline for shrimp production in Sonora, for example, the level of impairment is reported to range from "moderate" to "severe" (L. Meltzer pers. comm. 2020) and sedimentation from shrimp farm effluents has also been linked to changes in estuarine bathymetry (Jorge Alberto Miros-Gomez, Autonomous University of Baja California, pers. comm. 2020).

Regulation and enforcement

Mexico does have environmental regulations in place intended to limit discharge of effluents from industries that include aquaculture (Lebel *et al.*, 2016), such as a limit on discharge of TSS of 175 mg L^{-1} (Barraza-Guardado *et al.*, 2014) administered through a permit from the National Water Commission (Aguilar-Manjarrez *et al.*, 2017). Limits are also in place to manage cumulative impacts on water bodies—such as maximum (monthly average) concentrations of total inorganic nitrogen (15 mg L-1) and phosphorus (5 mg L-1) specific to estuaries (Barraza-Guardado *et al.*, 2014). There are suggestions that monitoring occurs in at least some instances (SEMARNAT, 2012a), but there are both historical and recent indications that effluent management in Mexico is ineffective, and particularly that the information on the environmental carrying capacity necessary to inform regulation is limited (Aguilar-Manjarrez *et al.*, 2017).

Historically, Dewalt et al (2002) noted the widespread lack of enforcement of effluent management regulations, as did Lebel et al (2016) in 2005 fieldwork, adding that no shrimp farms were treating their effluent in southern Sonora in 2004 (Lebel *et al.*, 2016). More recently (in 2013) the impact of shrimp farm effluents to water quality in the country's most important shrimp growing area was described as "inadequately managed" (Barraza-Guardado *et al.*, 2013); Lithgow et al (2017) also describe "inappropriate management" of pond inputs and effluents and a lack of water quality management and monitoring. As noted above, the shrimp farm effluent concentrations of TSS observed in the Bahia de Kino, for example, exceeded Mexican water quality standards (Barraza-Guardado *et al.*, 2013, 2014). Further indications of weak enforcement are provided by Sosa-Villalobos et al (2016) who state that effluent treatment practices have been poorly implemented in another sector of Mexico's aquaculture industry (tilapia), and Osuna-Ramirez (2017) detail unmanaged pollution issues associated with fishmeal processors in Sonora (Sosa-Villalobos *et al.*, 2016; Osuna-Ramirez *et al.*, 2017). Perevochtchikova and Andre (2013) and FAO (2009) (though somewhat dated) describe a lack of follow-up in enforcement actions to regulatory requirements owing to lack of trained staff and resources. While the FAO in 2009 described a "high-tolerance of non-compliance" by regulatory mechanisms (FAO, 2009), Aguilar-Manjarrez (2017) continue to describe extensive non-compliance with aquaculture regulations, including those related to wastewater discharge. For example, a broken drain canal has been dischargingdirectly into Laguna la Cruz in the Bahia de Kino for over a year despite authorities and producers having been notified and aware of the problem (L. Meltzer pers. comm. 2020). Weaknesses in enforcement of environmental regulations in Mexico have also been described in interviews with individuals knowledgeable on this industry (Anonymous pers. comm. 2019a, Anonymous pers. comm. 2019b).

Mexico, however, is investing in improving the situation; for example, a 2017 annual report from the federal Environmental Protection Attorney's office (PROFEPA) indicates the agency was active in inspecting shrimp farms in Sinaloa as part of a new program seeking implementation of the National Program for Compliance with Environmental Regulations in the Aquaculture Sector. Initiated in 2015, the program selected Sinaloa for a pilot effort, but it will eventually be applied to all of Mexico with the goal of a 100 % inspection rate. The program aims to improve upon the existing 8 % rate of compliance with environmental impact permitting requirements (Sinaloa), and will enforce regulations concerning land use authorization and discharge of effluents (PROFEPA, 2015, 2016, 2017).

A total of 235 farms, or 57 % of registered farms representing 71 % of total farm surface area in Sinaloa were inspected for compliance in 2017. Resulting from this work were the enforcement of 235 administrative procedures, of which 90 % were resolved with fines and corrective measures (though further details on what the violations were, whether they relate to effluent or other environmental violations, and how many farms received such procedures is not provided). An additional 5 farm inspections initiated from citizen complaints and resulted in additional enforcement actions, including closure of farms (PROFEPA, 2017). An additional 153 farms were inspected in 2016, with enforcement actions including fines, corrective actions, and farm closure of both existing and in-construction farms due to lack of federal environmental authorizations (PROFEPA, 2016). No data more recent than 2017 were available at the time of this assessment.

While investments in increased enforcement are apparently occurring in some regions, not all areas have seen increased enforcement, including in Sonora, as of 2020 (L. Meltzer pers. comm. 2020).

Conclusions and final score

The available information indicates shrimp farms in Mexico have a high daily water exchange rate of >15 %, and there is evidence that the discharged effluent has contributed to cumulative local and regional impacts beyond the discharge area—including trophic shifts, changes in water chemistry, and possibly harmful algal blooms that affect other species; however, these observed effects were not severe (or were uncertain) and appeared to reverse quickly upon temporary cessation of production at the end of each cycle. It has previously been noted that the Mexican regulatory system, and particularly its enforcement, has been inadequate, but since these observed impacts took place (primarily in studies published in 2013 and 2014), it seems clear that the Mexican government, through the "National Program for Compliance with Environmental Regulations in the Aquaculture Sector", has increased enforcement, with 71% of the total production area inspected in 2017. The effects of this improved enforcement on water quality in intensive shrimp farming areas and the ongoing extent of this enforcement are currently poorly understood and may not yet be reaching all regions. Overall, there continues to be a high concern regarding effluent impacts from the Mexican shrimp industry but given the uncertain scale of the impacts and the temporary nature of the observations, the final score for Criterion 2 – Effluent is 4 out of 10.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.
- Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.
- Principle: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		4
F3.2a Content of habitat regulations	3	
F3.2b Enforcement of habitat regulations	3	
F3.2 Regulatory or management effectiveness score		3.6
C3 Habitat Final Score (0-10)		**3.87**
Critical?	NO	**Yellow**

Brief Summary

Mexican shrimp farming grew rapidly as an industry in the 1980s and 90s, with the majority of farm acreage being constructed in high value habitats bordering the coast or estuarine wetlands and salt marshes and tropical dry forest (the remainder is reportedly in lower value terrestrial habitats or former agricultural land, though the classification of habitat types has been questioned). Mexico implemented some protections for critical habitats such as mangroves, but the effectiveness of these measures at preserving their ecosystem health are questionable. Protections for other high-value habitats such as salt marshes have been absent, and while the loss of mangrove forests specifically has been minor, the shrimp industry has driven significant losses in salt marsh locations. Environmental regulations contain some ecological considerations in siting and an environmental impact assessment processes, though with gaps relating to consideration of cumulative impacts. There is evidence that enforcement organizations have recently made major investments in seeking industry-wide compliance, but there are still indications that existing regulation and enforcement have limitations and compliance with environmental regulations is challenged. Overall, the Criterion 3—Habitat score is 3.87 out of 10.

Justification of Rating

Factor 3.1. Habitat conversion and function

Semi-intensive shrimp farming in Mexico began in 1985 with 150 ha of ponds, and following major growth from 1990-2010, has since grown to over 70,000 ha (Alatorre *et al.*, 2016;

INAPESCA, 2018). The total farm area (i.e. including non-pond areas) is larger still--for example the total area used by farm developments in 2011 was around 82,500 ha (Berlanga-Robles *et al.*, 2011a).

Due to water exchange needs, Mexican shrimp farms are usually constructed next to a bay, estuary, lagoon, or other marine or brackish water source (Stentiford et al., 2012) and the ecosystems bordering these waterbodies typically harbor salt marshes, wetlands, and mangroves which are considered high-value habitats (Paez-Osuna et al., 2013). The bulk of Mexican shrimp farming occurs in a region of globally-significant biodiversity (the Gulf of California)(Schaeffer-Novelli *et al.*, 2006). Aguilar-Manjarrez *et al.*, (2017) reports the area contains high densities of waterfowl, and Navedo *et al.*, (2015) describe several coastal wetlands recognized for their importance to migratory birds; for example, a site of Hemispheric Importance (Bahía Santa María), two Sites of International Importance (Ensenada de Pabellones and Marismas Nacionales), and a Site of Regional Importance (Laguna Huizache-Caimanero), all areas recognized within the Western Hemisphere Shorebird Reserve Network. The coastal environments where shrimp farms are commonly constructed are also home to at least 75 species of molluscs (González-Ocampo *et al.*, 2004), are used by at least 135 different species of fish as nursery and feeding areas.

The conversion of land for development of shrimp farms has impacted a variety of land covers and habitats as described below (and later listed in Table 3).

Terrestrial development

It is reported that approximately half of shrimp pond development has occurred on habitat classified as “terrestrial cover,” which may range from dry desert and low spiny forest to low deciduous forest, thorny jungle, abandoned agricultural land (Álvarez *et al.*, 2001; Lithgow *et al.*, 2019; A. Ruiz-Luna pers. comm. 2019) and coastal scrub behind sand dunes (L. Meltzer pers. comm. 2020). Coastal deserts and shrublands are considered low-value habitats because they have relatively low diversity of fauna, minimal vegetation, and provide fewer ecosystem services such as carbon sequestration or water purification. There are suggestions, however, that the classification of land cover related to shrimp farm development is questionable; for example, claims of development on uplands (non-wetlands) by farm developers may bely the destruction of valuable halophyte communities bordering wetlands—a habitat type that is also threatened and which alters the function of the wetlands (R. Brusca pers. comm., 2019). The percentage of “low value terrestrial cover” may actually be much lower than 50%, with higher-value habitat representing a larger proportion than half (R. Brusca pers. comm. 2019). In Nayarit and southern Sinaloa, for example, converted terrestrial cover has included about 20% forest vegetation (low and medium tropical dry forest)(Lithgow *et al.*, 2017), habitat that is classified as High value by Seafood Watch.

Mangroves

Mangrove forests are located in each of Mexico's shrimp-producing states, with Sinaloa (a major shrimp producer), Nayarit, and Baja California Sur (lesser shrimp producers) hosting the largest expanses of mangrove habitat. Linkage between shrimp farm development in northwest Mexico and mangrove deforestation has been suggested previously (Páez-Osuna *et al.*, 2003). Glenn et al. (2006) reports that over 95 % of the mangrove marshes in Mexico have been developed for shrimp farming, but in most cases the farms were built adjacent to the marshes (such as in coastal salt marshes and seasonal flood plains) rather than in them (Páez-Osuna *et al.*, 2003; Glenn *et al.*, 2006); the majority of the mangrove stands are therefore still intact (Glenn *et al.*, 2006, see also Aguilar-Manjarrez 2017).

Tidwell and Allan (2001) explain that shrimp pond construction often does not result in direct clearing of mangroves because these areas have acid soils and high construction costs (Tidwell and Allan, 2001), though examples exist (Lithgow *et al.*, 2017). The Comisión Nacional para el Conocimiento y Use de la Biodiversidad (CONABIO) has conducted an assessment of patterns in national mangrove habitat cover from 1985-2015, concluding that loss in mangrove extent in NW Mexico's shrimp farming region during this period have been minor (Table 2). For example, loss in total mangrove extent in Sinaloa during the 20-year period was estimated at 0.7 %; 2.3 % of mangrove habitat could currently be classified as perturbed in the same region. Though they point out some disagreement in estimates of total mangrove area, Ruiz-Luna and Berlanga-Robles (2018) agree that Sinaloa's mangroves are not heavily perturbed, with only slight perturbations detected in their assessment of the previous 40 years—despite Sinaloa being the nation's leading shrimp producer (Ruiz-Luna and Berlanga-Robles, 2018). In Sonora, Mexico's other major shrimp-producing state, CONABIO (2015) estimates that mangrove extent has *increased* about 10 % from 1985 to 2015, with almost no (~0.0008 %) mangrove forest being currently classified as perturbed. For further information on Ramsar designations, see Factor 3.2 below.

There are suggestions that in some locations, mangroves have been planted on farms for their stabilization services, and have naturally colonized drainage canals (SEMARNAT, 2012a), and other references of some recovery following impacts (Lithgow *et al.*, 2017). Berlanga-Robles et al (2011) contrasts the relatively low-impact of Mexican shrimp farming on the country's mangrove forests with Thailand, Vietnam, Ecuador, Honduras and others, where mangrove loss due to shrimp farm development has been significant.

Table 2. Patterns in mangrove extent in shrimp-producing states of NW Mexico. Unit is hectares. Adapted from CONABIO 2015.

	1970-80 Mangrove Extent (ha)		2005 Mangrove Extent (ha)		2010 Mangrove Extent (ha)		2015 Mangrove Extent (ha)	
	Total	Perturbed	Total	Perturbed	Total	Perturbed	Total	Perturbed
Baja California	36	0	36	0	36	0	39	0
Baja California Sur	26724	0	26519	0	26696	0	26579	59
Sonora	10940	0	11098	0	11342	0	12111	1
Sinaloa	82171	760	79109	954	77262	2257	81558	1851
Nayarit	78024	0	69784	4862	66932	6309	67096	6016

On the other hand, Alatorre *et al* (2015) point out that a focus on relative mangrove cover in evaluating the status of mangrove habitats overlooks the qualitative degradation, or the health of the mangrove habitat, and conclude that the development of shrimp farms has significantly impacted the health of mangrove habitat (Figure 3). While not constructed directly on mangrove habitat, ponds are often developed right next to mangrove habitat (R. Brusca pers. comm. 2019). Berlanga-Robles *et al* (2011a) point out that while shrimp farm developments may not have direct contact with mangrove cover, that much of the development—particularly in Sinaloa and Nayarit—occurred near mangrove patches, threatening mandatory buffers to protect the integrity of mangrove systems. Buffer areas are often ecologically valuable salt marsh habitat (R. Brusca pers. comm. 2019). Further, shrimp aquaculture degrades sediment conditions at pond sites, limiting passive recovery of mangrove habitat after ponds are abandoned (Lithgow *et al.*, 2017). Paez-Osuna (2003) describes how development impacts mangroves by altering hydrological patterns—reducing availability of fresh water and floodwaters and altering salinity (see also Alatorre et al 2016). Alatorre et al (2016) describe significant mangrove deforestation during the late 20th century, attribute “worsening health” of mangrove habitats to shrimp farming (see also Lithgow *et al.*, 2019), and that mangroves in Northwest Mexico are “strongly threatened” by the rapid expansion of shrimp farming since the 1980s. Conclusions are framed in present and future terms, suggesting that shrimp aquaculture is having a continued impact on these habitats.

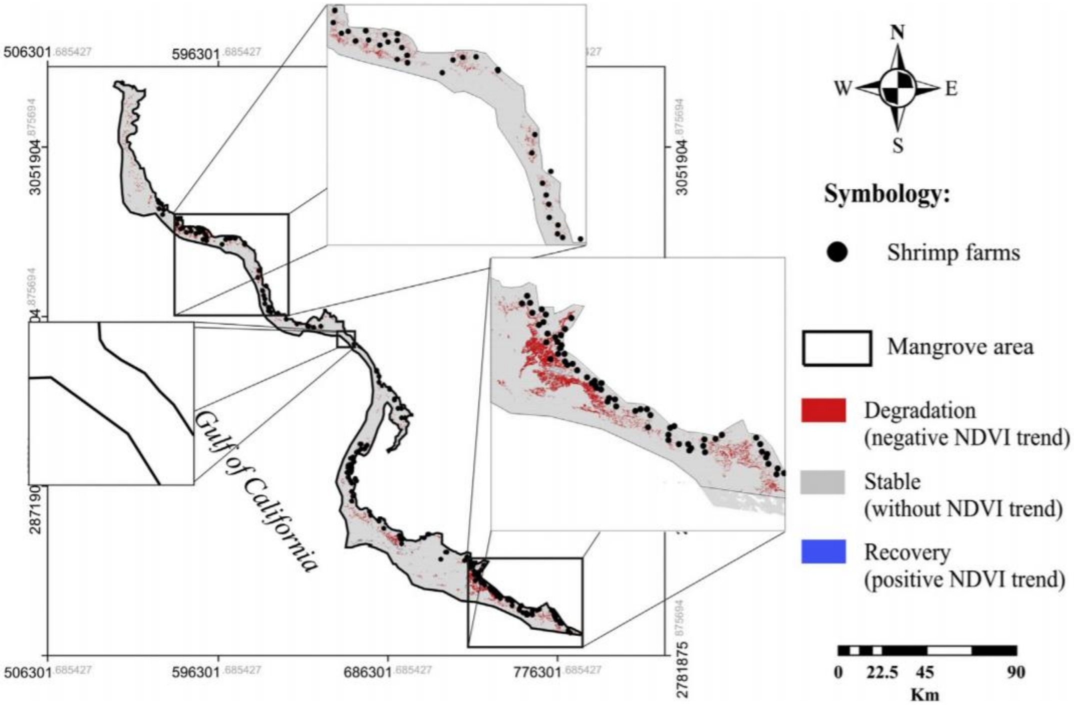

Figure 3. Spatial distribution of temporal trends (Normalized Difference Vegetation Index; NDVI) in mangrove forest and mangrove forest with pickleweed categories and location of shrimp farms in the Alatorre (2016) study area during 2010. Image shows areas of mangrove degradation in proximity to shrimp farm development. Image from Alatorre *et al.* (2016).

Further, Berlanga-Robles *et al* (2011a) calls Mexican shrimp farming "far from sustainable" from a habitat perspective due to its direct removal of other valuable natural coastal wetlands—like salt marshes. With regard to mangrove wetlands and the salt marshes below, Mexico has signed the RAMSAR treaty, and currently has more than 8.6 million hectares of land (142 sites) designated as Wetlands of International Importance. The RAMSAR website lists 18 of these sites to be threatened by marine and freshwater aquaculture, although not all of these will relate to shrimp farms. Fifteen of these 18 sites are located on the coast of Sonora, Sinaloa, and Nayarit (RAMSAR, 2016), and a search of individual sites notes only two that specifically mention negative impacts of aquaculture[3].

Salt marshes

Researchers extrapolating data from a spatial analysis conducted using satellite imagery estimate that approximately 75 % of the shrimp farms in Sinaloa are located in habitat classified as salt marsh, and 69 % in Nayarit (Berlanga-Robles *et al.*, 2011b). Of the five states included in this analysis, about 45 % of saltmarsh has been converted due to aquaculture, with this conversion reaching 56 % in Sinaloa (and another 5 % of other coastal wetlands converted here;

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[3] Humedales de la Laguna La Cruz mentions effluent as an impact to local adjacent mangroves (https://rsis.ramsar.org/ris/2154) and Marismas Nacionales (https://rsis.ramsar.org/ris/732)

Table 3). In total, this study attributed a conversion of nearly 36,000 ha of valuable coastal wetland habitat to aquaculture; another 3 % was built on land classified as *coastal estuarine and lagoon* (Table 3) (Berlanga-Robles *et al.*, 2011b, 2011a).

The topography and soil characteristics of salt marshes, as well as the perception of these habitats as “unproductive” make them appealing for shrimp pond development (Berlanga-Robles *et al.*, 2011a).

Table 3. Land use changes attributable to shrimp farm development in four Mexican shrimp-producing states. Area reported in hectares, with corresponding proportion in parentheses. Asterisk denotes that this analysis was unable to classify land converted prior to 1985. From Berlanga-Robles et al 2011a.

	State				
Subsidiary cover	Nayarit	Sinaloa	Sonora	Tamaulipas	TOTAL
Aquatic surfaces	103 (2)	1918 (5)	268 (1)	24 (1)	2313 (3)
Mangrove	392 (8)	689 (2)	85 (<1)	0	1166 (1)
Saltmarsh	1726 (35)	23225 (56)	10779 (33)	48 (6)	35778 (45)
Terrestrial covers	2507 (50)	12215 (30)	21133 (64)	929 (93)	36784 (46)
Shrimp farming*	238 (2)	3090 (2)	642 (2)	0	3970 (5)
Total shrimp farm extent (ha)	4966	41137	32907	1001	80011

It is difficult to quantify the loss of habitat functionality in the marshes bordering mangroves, however a high concentration of ponds within close proximity to each other as they are in Bahía de Kino, Sonora, for example (Figure 4), is certain to have impacts on, and a resultant loss of habitat functionality within salt marshes and wetland ecosystems (R. Brusca pers. comm. 2019).

Despite the “unproductive” perception noted above, such landscape features are naturally highly productive—supporting complex trophic assemblages and providing important marine depositional environments. Salt marshes are considered high-value habitats because they perform multiple ecosystem services: they play an important role in maintaining water quality by removing excess nitrogen from water entering the intertidal zone and maintaining a pH level conducive to life. Estuaries and lagoons are important feeding, breeding, and nursery grounds for birds, fish, crustaceans and mammals and the primary nursery environment for wild post-larval shrimp and fish because they offer substantial shelter and food (Páez-Osuna *et al.*, 2003; González-Ocampo *et al.*, 2004; Navedo *et al.*, 2015; Aguilar-Manjarrez *et al.*, 2017). Salt marshes also increase the productivity of estuaries and other coastal wetlands via continuous input of organic detritus into aquatic systems (R. Brusca pers. comm. 2019).

Salt flats are additionally naturally-limited habitat types, making them particularly vulnerable (Schaeffer-Novelli *et al.*, 2006). These particular wetlands have a role as stopover sites for migratory shorebirds--populations of many of which are in decline globally--a function that is not being properly considered in their development. Shorebirds forage on the salt flats (Schaeffer-Novelli *et al.*, 2006) and roost in the salt marshes (Navedo *et al.*, 2015) and are in decline globally due to loss of these types of habitats (Fonseca and Navedo, 2020). Many species of shorebirds use shrimp ponds for foraging, such as on polychaetes, and shrimp ponds can provide important foraging areas to some species. For example, 21 species of shorebird were documented in one study (Navedo *et al.*, 2015) and 25 species and over 25,000 individuals in another (Fonseca and Navedo, 2020). Shrimp aquaculture ponds have value to visiting shorebirds, but they represent only a fraction of the space of an undeveloped area and are only useful to shorebird foraging during the limited 2-month harvest period (Navedo *et al.*, 2015)—and may only be useful to some species for 1-2 days (Fonseca and Navedo, 2020). Although shrimp ponds do offer some value to foraging shorebirds, their development has likely contributed to reductions in shorebird numbers (Navedo *et al.*, 2015) and population declines at the hemisphere level (Schaeffer-Novelli *et al.*, 2006) and optimizing pond management and harvest practices to align with he needs of shorebirds (or other wildlife) is not yet standard practice (Fonseca and Navedo, 2020).

Figure 4. Land conversion for shrimp aquaculture, 1985-2016. Left column images depict Bahia Navachiste, Sinaloa; right column images are Bahia de Kino, Sonora. Top row (a) images are from 1985; second row (b) from 2004; and bottom row (c) from 2016. Images: Google Earth, 2019.

Some potentially-affected species, such as nesting western gull-billed terns (*Gelochelidon nilotica vanrossemi*)—a vulnerable species that has received attention as a potential Mexican Species at Risk and U.S. ESA-listed species—have been impacted by wetland losses due to in part to development of wetlands in Southern California and NW Mexico (Palacios and Mellink, 2007; Center for Biological Diversity, 2009). Some additional species that use Mexico's Pacific coast wetlands for breeding are considered officially at-risk, including the woodstork (special protection), brown pelican, snowy plover (threatened), least tern (special protection), and clapper rail (threatened) (Mellink and Riojas-López, 2017).

Pond development fragments environments, such as reducing connectivity between coastal wetlands (Berlanga-Robles and Ruiz-Luna, 2006). In addition to the impact of the ponds themselves, the accompanying infrastructure such as roads, bridges and channels can lead to extensive fragmentation of these habitats (Alatorre *et al.*, 2016). Fragmentation alters water flow and sediment supplies in the intertidal zone and threatens overall system stability (Páez-Osuna *et al.*, 2003; Berlanga-Robles *et al.*, 2011a), contributing to higher risk of coastal erosion (Lithgow *et al.*, 2017). It is estimated that due to a number of development impacts, which include (but are not limited to) shrimp aquaculture, that >62 % of Mexican wetlands have been lost nationwide (Mellink and Riojas-López, 2017). It is also evident that aquaculture activities have contributed to the complete displacement of wildlife in some areas (Aguilar-Manjarrez *et al.*, 2017). Further, shrimp ponds result in the salinization, acidification, and erosion of soils, which are also impacted by the addition of lime—effects that last beyond pond operation (Rodríguez-Valencia *et al.*, 2010).

While shrimp ponds are maintaining some functionality in offering some potentially important, but limited foraging habitat for shorebirds (and the raptors that prey on them; Navedo et al 2015), it is evident that overall loss of functionality has occurred and this assessment classifies habitat impacts as major due to large areas being completely converted and others impacted due to fragmentation and disruption of ecological processes.

With regard to the timeline of habitat conversion and the loss of ecosystem services, shrimp farming began in Mexico during the early 1980s, which means that in some cases the land dedicated to shrimp farming was altered nearly 40 years ago. The highest rates of land conversion occurred in the late 1990s, and therefore the bulk of land conversion occurred over fifteen years ago and is considered "historic" for the purposes of this assessment. New development in this industry and resulting habitat conversion has slowed (perhaps since about 2002; Scott Horton, Personal Comm., 2015 or 2005 (Lithgow *et al.*, 2017)) due to fewer available places to build and tighter regulation (R. Brusca pers. comm. 2019; A. Ruiz-Luna pers. comm. 2019). A review of historical Google Earth satellite imagery suggests that while there has been some new farm development or expansion since 2004, most farm development in Mexico's major shrimp producing states occurred over 15 years ago (Google Earth Pro, 2019). Though some conversion is considered to continue (A. Ruiz-Luna. Pers. comm. 2019), it is considered here to be minor and not to result in the further substantial loss of ecosystem functionality.

In summary, while total mangrove cover from 1970-present has been described as relatively stable, the overall health and functioning of mangrove systems has (and continues to be) impacted by shrimp farming. At least half of the land converted for shrimp aquaculture was once high-value coastal wetland and salt marsh habitat, likely more. Approximately half of land converted is classified as "low-value" terrestrial desert, dry scrublands, and grasslands (Berlanga-Robles *et al.*, 2011a; SEMARNAT, 2012a; Aguilar-Manjarrez *et al.*, 2017, Lithgow *et al.*, 2019), though there are strong opinions that at least some portion of terrestrial land conversion has in fact been important transitional habitat types around the edges of wetlands (R. Brusca pers. comm. 2019). Some has also been described as originally high-value (second-growth) tropical forest (20% in Nayarit and southern Sinaloa; Lithgow *et al.*, 2019). For High-value habitat experiencing a loss in functionality, and which was altered >15 years ago, the score for Factor 3.1 is 4 out of 10 and for low-value habitat experiencing the same impacts, the score is 6 out of 10. Due to the evidence that the majority of land converted falls into Seafood Watch's "high-value" category and to the uncertainty with regard to transitional habitats and habitat classification results, the final score for Factor 3.1 is 4 out of 10.

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

The following content relates to the current regulatory system in place for shrimp farms and it is important to note that many of the relevant regulations and references are dated during or after the main expansion of the industry occurred.

Sosa-Villalobos et al (2016) outline the regulatory framework for Mexican aquaculture:

> *The development of aquaculture in Mexico is framed in the General Law of Sustainable Fisheries and Aquaculture, which sets out the principles to order, promote, and regulate the integrated management and sustainable use of this productive activity. Additionally, the activity is subject to other federal regulations contained in the General Law of Ecological Balance and Environmental Protection, National Water Law, Regulations of National Water Act, and the Federal Law of Rights. They establish the obligation to have an environmental impact assessment prior to the implementation of the project, granting water use, and water treatment works prior to the discharge of water in order to prevent contamination of receiving water bodies (Velasco et al., 2012).*

In Mexico, shrimp aquaculture falls within the regulatory framework of two departments at the ministerial level, the Department of Agriculture and Rural Development (SADER)), and the Department of Natural Resources and Environment (SEMARNAT). Under SADER there are three agencies most concerned with aquaculture:

1. The National Commission of Aquaculture and Fisheries (CONAPESCA) deals primarily with operating permits.
2. The National Service of Alimentary Health, Quality and Innocuity (SENASICA) is in charge of animal health.
3. The National Fisheries Institute (INP) provides research and technical opinions.

Under Environment (SEMARNAT) there are four agencies involved:

1. The Directorate of Environmental Impact, which reviews environmental impact statements, sets operating restrictions and evaluates environmental permits.
2. The National Water Commission (CNA) regulates water use and discharges.
3. The Directorate of Federal Zoning, which regulates uses of the Federal Coastal Zone.
4. The Environmental Protection Attorney's Office (PROFEPA), which enforces environmental regulations.

Environmental Impact assessment and management

In 1996, LGEEPA (General Law of Ecological Balance and Environmental Protection) established a requirement that an Environmental Impact Assessment (EIA) be generated for all projects and activities in wetlands, mangroves, lagoons, rivers, lakes and estuaries connected to the ocean and fishing, aquaculture, and agriculture activities that could threaten the preservation of one or more species or cause harm to the ecosystem (SEMARNAT 2002). After initial review of the EIA documentation, SEMARNAT can require an Environmental Impact Statement (EIS) (FAO, 2016). EIAs typically outline expected impacts of a project and propose mitigation strategies (SEMARNAT, 2012a; Perevochtchikova and André, 2013; Aguilar-Manjarrez *et al.*, 2017)—including impact mitigation measures are developed for both operation and decommissioning stages (Aguilar-Manjarrez *et al.*, 2017) and there are may be requirements for the restoration of important or critical habitat or ecosystem services (FAO, 2009).

Mitigation strategies are implemented as conditions of license to aquaculture concession holders, who are obligated by SAGARPA to "assist in the preservation of the environment and the conservation and reproduction of species, including repopulation programs" (Spreij, 2005).

Siting considerations

The Director General of Aquaculture (DGA) has commissioned a series of land use planning studies to determine the most suitable places to locate aquaculture ventures (DeWalt *et al.*, 2002). The government agencies of SEMARNAT and SENASICA have constructed aquaculture management schemes defining maximum production volumes, farming techniques, and maximum effort permitted according to production type (SEMARNAT and SENASICA, 2014).

Mexico introduced the General Law for Sustainable Fisheries and Aquaculture (LGPAS) in 2007, directing aquaculture management planning to consider a more ecosystem-based management approach—including regarding spatial planning and waterbody carrying capacities. The LPGAS requires the development of aquaculture management units (UMA) and aquaculture territorial management plans (POA). Under UMAs, aquaculture development plans are required for geographic "meso-regions" with similar environmental characteristics, aquaculture techniques, and culture species (FAO 2009). For larger areas, POAs have to be aligned with the National Ecological Territorial Management Plan and the State Ecological Territorial Management Plan (Saborio Coze and Flores Nava 2009). Both UMAs and POAs influence the decisions regarding the approval of an aquaculture license.

Other protections

Mexico has signed a number of international agreements aimed at biodiversity protection—including the RAMSAR treaty—since 1984, and currently has more than 8.6 million hectares of land (142 sites) designated as Wetlands of International Importance. Combined with international and other federal, state, and municipal protected areas, an estimated 76.51 % of mangrove coverage is protected, up from 1 % in 1980 (Valderrama-Landeros *et al.*, 2017). The national Environmental law has also established national, regional, local and marine zoning plans (FAO, 2016). Each zoning plan defines the types of activities that can be conducted in the zone and strategies for preserving, protecting, and using the zone's natural resources (Ibid.)

Effectiveness of regulation

Despite the regulations listed above, Mexico has previously been described as having a history of unregulated and unrestrained shrimp aquaculture development on a large scale, which has resulted in environmental impacts (Páez-Osuna *et al.*, 2003; Aguilar-Manjarrez *et al.*, 2017), including to salt flats, salt marsh, wetlands, and lagoons--conversion of which continued unrestrained and with inadequate consideration (no protection) at least into the early-2000s (Schaeffer-Novelli *et al.*, 2006). Mellink et al (2017) argue that protection of wetlands in Mexico is still inadequate and focuses too exclusively on mangroves to the detriment of other coastal wetlands, something also confirmed by Valderrama-Landeros *et al* (2017). Berlanga-Robles *et al* (2011b) describe a pervasive perception of salt marshes as "unproductive" and state that coastal wetlands (including saltmarshes), where the bulk of shrimp farm development has occurred are "barely protected" by Mexican law; they further describe the Mexican shrimp industry as "far from sustainable" from a habitat perspective.

In the recent past, Mexico's aquaculture regulation has been criticized for often putting social or political criteria over environmental emphasis in aquaculture planning (FAO, 2009). The Mexican government has promoted aquaculture development actively (Aguilar-Manjarrez *et al.*, 2017), and the pace of growth has often exceeded government capacity to regulate for environmental protections (FAO, 2009; Clemence, 2011; Aguilar-Manjarrez *et al.*, 2017), a sentiment also expressed by industry itself (SEMARNAT, 2012a). There are additional signs that habitat management measures in general in Mexico can be ineffective; for example, the modification of land management plans to weaken existing protections and allow for major development, such as with port development in Laguna Cuyutlan in 2009 (Mellink and Riojas-López, 2017) undermines confidence in the effectiveness and enforcement of habitat management measures. Mellink and Riojas-Lopez (2017) also describe the environmental impact assessment required for the approval of the opening of a canal associated with this project as "quite poor" and that it "neglected" or "ignored" a number of available scientific resources to adequately assess habitat impacts and develop lost-cost alternatives. Further, the authors suggest that this kind of disregard for biodiversity is not unusual for Mexico; interviews with individuals familiar with this industry have made similar suggestions (Anonymous pers. comm. 2019a).

This contradiction between stated sustainability intentions and actual practice and effectiveness in Mexico has also been outlined in the past (Cruz-Torres, 2000). A 2017 survey of decision makers and academics regarding the sustainability of shrimp aquaculture in Mexico outlined the disconnect between scientific and regulatory perspectives, as a majority of academics interviews described an overall perception of negative impacts of aquaculture on the provision of ecosystem services, while the majority of decision-makers did not perceive any negative impact (Lithgow *et al.*, 2017).

Others have questioned the effectiveness of the Mexican EIA process (Perevochtchikova and André, 2013; Mellink and Riojas-López, 2017) as well as the specific geographical usefulness of environmental norms (FAO, 2009). Valderrama-Landeros et al (2017) further point out a lack of synchronization and "even antagonism" between regulation at different levels of government that in some cases makes environmental regulation even less effective. One contact interviewed for this assessment referred to ongoing corruption and even the production of "fake" environmental impact assessments (Anonymous pers. comm. 2019a); another stated that Environmental Impact Assessments are often written by private consultants to "favor" the shrimp company (Anonymous pers. comm. 2019b).

Still, Mexico has invested in updating its aquaculture laws and regulations since at least 2007's *General Law of Sustainable Fisheries and Aquaculture,* and the existing management approach does appear to contain some area-based and ecosystem functionality considerations. Mexico's regulation is set according to ecological principles, such as through conditioning permits according to environmental impact assessments (SEMARNAT, 2014a). The existing system still leaves some questions as to how cumulative impacts are considered and whether future expansion is addressed accordingly.

In summary, Mexico's regulations for onshore aquaculture siting include some laudable conservation elements such as mangrove protections, marine spatial planning, requirements for Environmental Impact Statements, and restoration requirements, however there is evidence that regulations are not adequately designed and are limited in their effectiveness. Overall, the content of Mexico's habitat management measures are therefore considered moderate, and the score for Factor 3.2a is 3 out of 5

Factor 3.2b: Enforcement of habitat management measures

Agencies that regulate and enforce aquaculture in Mexico are apparent, including PROFEPA, SEMARNAT, and CONAPESCA. Agencies are identifiable and contactable, and some enforcement information is available via government websites—but with limitations. CONAPESCA provides up to date, downloadable information on annual enforcement activity, though it is coarse and lacks much detail. For example, the agency lists having conducted over 3,000 aquatic site actions in Sinaloa and over 700 in Sonora in 2018, but does not provide additional information sufficient to understand how many of these interacted with shrimp aquaculture operations, nor the results of the actions (CONAPESCA, 2019).

PROFEPA, which conducts enforcement of environmental regulations, provides access to coarse annual activity data by state and annual reports with more specifics on its activity. The 2017 annual report, for example, indicates that the agency was active in inspecting shrimp farms in

Sinaloa as part of a new program seeking implementation of the National Program for Compliance with Environmental Regulations in the Aquaculture Sector. Initiated in 2015, the program selected Sinaloa for the pilot effort, but it will eventually be applied to all of Mexico with the goal of a 100 % inspection rate. The program aims to improve upon the existing 8 % rate of compliance with environmental impact permitting requirements (Sinaloa), and will enforce regulations concerning land use authorization and discharge of effluents (PROFEPA, 2015).

As discussed in Criterion 2 – Effluent, a total of 235 Sinaloan farms, or 57% of registered farms representing 71% of total farm surface area in the state were inspected for compliance in 2017. Resulting from this work were the enforcement of 235 administrative procedures, of which 90 % were resolved with fines and corrective measures (though further details on what the violations were, whether they relate to habitat-related or other environmental violations, and how many farms received such procedures is not provided). An additional 5 farm inspections initiated from citizen complaints and resulted in additional enforcement actions, including closure of farms (PROFEPA, 2017). An additional 153 farms were inspected in 2016, with enforcement actions including fines, corrective actions, and farm closure of both existing and in-construction farms due to lack of federal environmental authorizations (PROFEPA, 2016).

There are some additional references to historic enforcement actions, including fines and mitigation requirements against one farm that developed a drainage canal in a mangrove area in Sinaloa and destruction of 50 ha of mangroves on the largest farm in Nayarit; in the latter case, complaints were first initiated by citizen groups and non-profit environmental organizations (DeWalt *et al.*, 2002).

There are some indications in the literature that enforcement of regulations aimed at protecting valuable habitats, like mangrove forests, have limitations. Berlanga-Robles (2011a) point out for example, that while shrimp farm developments may not have direct contact with mangrove cover, much of the development—particularly in Sinaloa and Nayarit—occurred near mangrove patches "infringing upon legal rules" and threatening mandatory buffers to protect the integrity of mangrove systems. The authors also suggest that some areas need to be restored in accordance with law, suggesting non-compliance (Berlanga-Robles *et al.*, 2011a). Aguilar-Manjarrez et al (2017) also describe extensive non-compliance with aquaculture regulations in the shrimp industry in Nayarit, attributing this to ignorance of legal requirements, lack of financial resources, absence of extension support, and prohibitive costs and difficulty in conducting assessments and permitting (Aguilar-Manjarrez *et al.*, 2017).

Sosa-Villalobos et al (2016) seem to indicate that regulation of aquaculture impacts in Mexico is weak and difficult to enforce, a reality pointed out historically as well (DeWalt *et al.*, 2002). The isolation of shrimp farms in some areas, for example, makes enforcement challenging (Maria Cruz-Torres, Arizona State University, pers. comm. 2019). There are additional indications that regulations aimed at management effluent, for example, are not enforced (see Criterion 2—Effluent), though this assessment recognizes the significant effort that PROFEPA has invested in improving compliance. Although investments in increased enforcement are apparently occurring in some regions, not all areas have seen increased enforcement, including in Sonora, as of 2020 (L. Meltzer pers. comm. 2020).

In summary, there is evidence that enforcement of regulations aimed at protecting habitat exists and these institutions are identifiable and contactable. There is evidence that watchdog organizations are using a complaint-driven enforcement process, and that at least some enforcement response has occurred. PROFEPA, the federal institution charged with enforcing environmental regulations has been highly active in implementing a new program, with evidence of penalties. Some uncertainties owing to numerous references in the literature pointing to enforcement and compliance limitations, and the effect of the national expansion industry-wide of the 2015 inspection program remains to be seen. The score for Factor 3.2b is 3 out of 5.

When combined with the score for Factor 3.2a, the combined Factor 3.2 score is 3.6 out of 10.

Conclusions and final score

Mexican shrimp farming grew rapidly as an industry in the 1980s and 90s, with the majority of the farm acreage constructed in high value habitats bordering the coast or estuarine wetlands and salt marshes and tropical dry forest (the remainder is in lower value terrestrial habitats or former agricultural land). Mexico implemented some protections for critical habitats such as mangroves, but the effectiveness of these measures at preserving their ecosystem health are questionable. Protections for other high-value habitats such as salt marshes have been absent, and while the loss of mangrove forests specifically has been minor, the shrimp industry has driven significant losses in salt marsh locations. Environmental regulations contain some ecological considerations in siting and an environmental impact assessment processes, though with gaps relating to consideration of cumulative impacts. There is evidence that enforcement organizations have recently made major investments in seeking industry-wide compliance, but there are still indications that existing regulation and enforcement have limitations and compliance with environmental regulations is challenged. Overall, the Criterion 3—Habitat score is 3.87 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.
- Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments
- Principle: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**0**	
Critical?	NO	**Critical**

Brief Summary

Data on chemical use in Mexican shrimp farms is limited. It shows that in one state (Sonora) in 2018 (the latest year of data available), approximately 24% of farms used antimicrobials, of which 84% had used an antimicrobial listed as Critically-Important to human medicine by the World Health Organisation (enrofloxacin) and the remainder used either Highly-Important (oxytetracycline or florfenicol) or a mix of enrofloxacin and oxytetracycline. Regulatory restrictions are in place for the use of antimicrobials and Aquaculture Health Committees remain active in advancing animal health and biosecurity in Mexican shrimp farming, but production involves a high water exchange with the surrounding environment, and there are multiple references to acquired bacterial resistance to OTC on shrimp farms. The Sonora data indicate an increase in the number of farms using antimicrobials over time (2014 to 2018), but without more specific data to understand total overall antimicrobial usage (frequency, volumes) from Sonora and from other states, the use of Highly- and Critically-Important antimicrobials is considered significant but unknown. With the evidence of developed resistance to these antimicrobials, the final score for Criterion 4 – Chemical Use is 0 out of 10 and is a Critical conservation concern.

Justification of Rating

As discussed in Criterion 7 – Disease, the typical semi-intensive shrimp farming system possesses conditions that are ideal for the emergence and spread of disease, which is the primary reason for the use of chemicals such as pond preparation treatments, antimicrobials, or pesticides.

Antimicrobials – frequency of use

During the industry's rapid development in the 1990s, antimicrobials were relied upon to treat bacterial diseases such as vibriosis (Páez-Osuna *et al.*, 2003; Roque *et al.*, 2001; Chavez Sanchez and Montoya Rodriquez, 2006). There are suggestions from industry contacts that antimicrobials are banned in Mexico and too expensive at the farm-level to use, and thus are not widely in use (Scott Horton, Nutrimar, pers. comm. 2020), though verification is difficult. Data available in Mexico (from COSAES for Sonora only) seem to contradict this description, indicating that about 24 % of farms made use of antimicrobials in 2018 (the latest data available), up from about 18 % in 2014 (COSAES, 2014a, 2019b). Even in Sonora, for the farms using antimicrobials, there are no data available on the frequency of use or the dose, and therefore the total use of antimicrobials. There are some references that the use of antimicrobials is used only as a last resort in Mexico, and not as a prophylactic approach (SEMARNAT, 2012a) but there are no data available from the other Mexican states.

Sonora appears to have had some success in reducing the need to use antimicrobials historically, at least from 2007-2014 (**Error! Reference source not found.**5), concurrent with r eductions in serious disease outbreaks and in conjunction with aquaculture health committee activities promoting best practices. In more recent years, the trend has reversed, with the number of "medicated" farms in 2018 approximating 2007-2008 values. Overall, antimicrobial use, in terms of the number of farms medicating, has remained relatively unchanged from 2004-2018 (Figure 5). More specific data, including beyond 2018 are not publicly available and several attempts to contact COSAES, CESASIN, and SENASICA for more information for this assessment were unsuccessful.

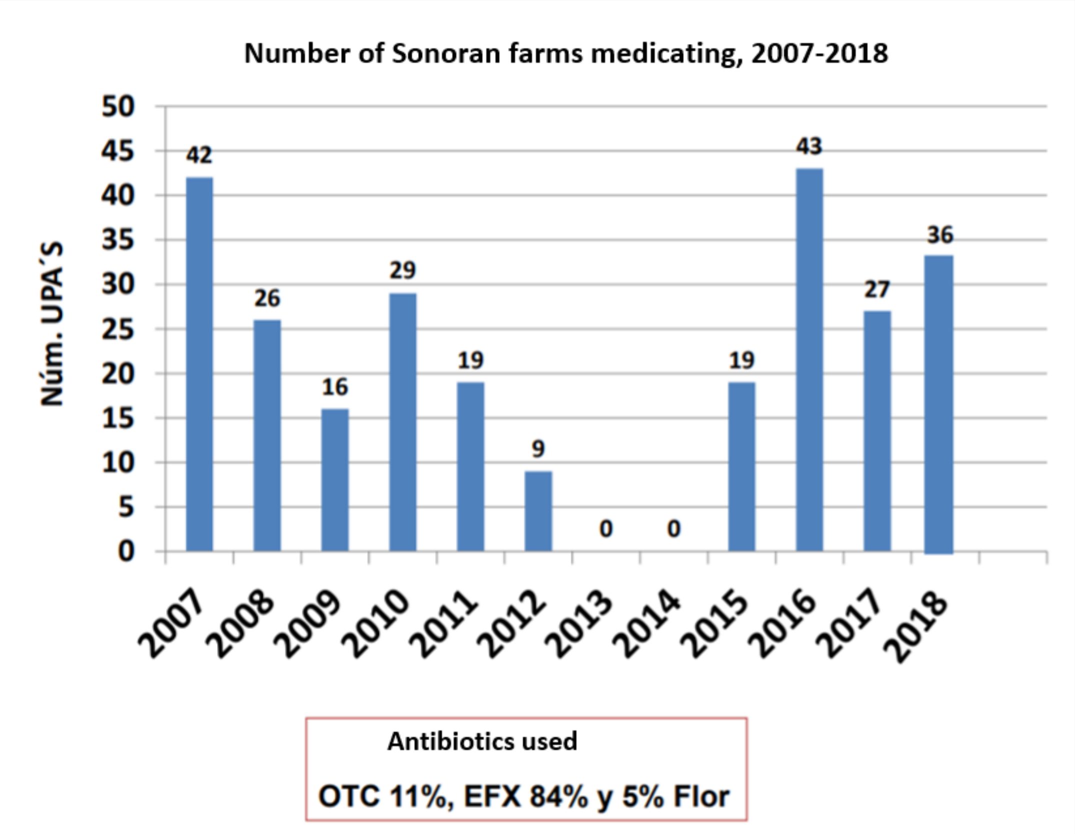

Figure 5. Antimicrobial use in Sonoran shrimp farms, 2007-2018. UPA refers to a farm. OTC=Oxytetracycline; EFX=Enrofloxacin; Flor=Florfenicol. The 2018 value represents approximately 24% of farms in Sonora. A 2014 report from COSAES describes 2014 use at about 18 % of farms (approximately 32 at that time), conflicting with the value reported in Figure 5 **(**COSAES, 2019b).

Antimicrobials – types used

Five antimicrobials are approved by Mexico's National Service of Health, Food, and Agrifood Quality (SENASICA) for use in shrimp farms (SENASICA, 2018) (Table 4). Historically, the types of antimicrobials used included oxytetracycline (OTC), florfenicol, ormethoprim-sulpamethoxazole, sarafloxacin, and enrofloxacin (Roque *et al.*, 2001; Páez-Osuna *et al.*, 2003); in 2003, oxytetracycline was the antimicrobial most often applied with 67 % of farms utilizing this therapeutant (Páez-Osuna *et al.*, 2003; see also Santiago *et al* 2009). More recently, Soto-Rodriguez *et al.*, (2015) documented the use of enrofloxacin, florfenicol, and oxytetracycline—also described in the latest data available from COSAES (for the state of Sonora only); of the farms using antimicrobials in 2018, 84 % had used Enrofloxacin, 11 % Oxytetracycline, 5 % Florfenicol (COSAES, 2019a), and farms may also use a combination--14 % used a mix of Enrofloxacin and Oxytetracycline (COSAES, 2014). It is not known if these data are representative of the other shrimp farming states.

Table 4. List of registered therapeutants used by shrimp aquaculture in Mexico (SENASICA, 2018).

Class Name	Substance Name
Amphenicols	Florfenicol*
Fluoroquinolones	Enrofloxacin**
Fosfomycin	Fosfomycin**
Streptogramins	Virginiamycin*
Tetracyclines	Oxytetracycline*

*= listed as Highly Important for human medicine by the World Health Organization; **listed as Critically Important to human health (WHO, 2019).

The United States Food and Drug Administration (U.S. FDA) has occasionally rejected imports of shrimp from Mexico for exceeding drug residue standards (4 times from 2014-2019; U.S. FDA, 2019), including nitrofurans (antimicrobials), indicating that other types of antimicrobial may be used, and that illegal antimicrobial use continues in this industry on some level (Shrimpnews.com, 2016). The number of detections of illegal antimicrobials in imported Mexican shrimp is considered low (exceptional), relative to the substantial volume of imports from Mexico (over 25,000 mt of wild and farmed shrimp combined in 2016; NMFS, 2017; USDA, 2017), but the documentation of some illegal use is nonetheless concerning and raises questions as to the effectiveness of enforcement of regulations aimed at antimicrobial use. Additional recent studies have documented OTC residues in imported Mexican shrimp, for example Mexican shrimp labelled as “wild,” contained detectable OTC—indicating either mislabeling of farmed shrimp, or wild shrimp exposed to untreated farm effluent (Done and Halden, 2015).

The World Health Organization (WHO) considers the two of the three treatments in current use (oxytetracycline, florfenicol) as antimicrobial agents *Highly Important* to human medicine; this means that they meet one of the two following criteria:

> a) “The antimicrobial class is the sole, or one of limited available therapies, to treat serious bacterial infections in people;” or
> b) “The antimicrobial class is used to treat infections in people caused by either: (1) bacteria that may be transmitted to humans from nonhuman sources, or (2) bacteria that may acquire resistance genes from nonhuman sources.” (WHO, 2019).

The third treatment (enrofloxacin) is listed as *Critically Important* to human health, meaning it meets both criteria a) and b).

Of the two other treatments listed in Table 4 (which are not currently considered to be in use), WHO also classifies Virginiamycin as *Highly Important* and Fosfomycin as *Critically Important* to human health.

Antimicrobial Regulation and Management

Rules were established in 2002 that included requirements and measures to control disease outbreaks and for use and application of antimicrobials; farmers must apply for a permit for the use of antimicrobials, follow labelling instructions, report use, and require a prescription from a competent veterinary authority (Chavez Sanchez and Ciapara, 2003; COSAES, 2018; SENASICA, 2018). The use of some chemicals (especially those banned by market jurisdictions) in shrimp farming (chloramphenicol and furazolidone) is prohibited (Chavez Sanchez and Ciapara, 2003; Páez-Osuna *et al.*, 2003), though historically, there has been some availability and use of intentionally mislabeled illegal chemicals like chloramphenicol (DeWalt *et al.*, 2002). The use of unregistered antimicrobials in shrimp farming continues to be identified as a problem by Mexican health organizations (COSAES, 2019a).

SENASICA is the federal entity regulating the use of antimicrobials and requires an Aquaculture Health Certificate for use and application of antimicrobials or veterinary drugs. It manages aquaculture health through state-level Aquaculture Health Committees. Aquaculture Health Committees oversee seek to ensure compliance with national and international standards, provide diagnostic services and disease response oversight, and offer farmer education and training in antimicrobials usage and promote best practices—including using antimicrobials as a last resort (COSAES, 2014b, 2019a). Aquaculture health committees appear active in shrimp-producing states, including in seeking to educate on the proper use of antimicrobials (see Criterion 7—Disease).

Antimicrobial resistance

The development of antimicrobial resistance by bacteria associated with use practices in shrimp farming has been extensively documented globally (e.g. Ecuador, India, Brazil, Bangladesh, Thailand, Taiwan, Philippines, Indonesia) and includes instances of resistance developed against therapeutants listed as *Highly Important* to human health by WHO (Defoirdt *et al.*, 2007; Albuquerque Costa *et al.*, 2015).

Though it was not explicitly documented at the time, anecdotal reports of hypothesized antimicrobial resistance were recorded in Mexican shrimp farming in the early 2000s (Roque *et al.*, 2001). Subsequent study has demonstrated “widespread” antimicrobial resistance among at least 26 different strains of bacteria associated with NW Mexico shrimp farms to some antimicrobials such as OTC (Molina-Aja *et al.*, 2002; Han *et al.*, 2015)—a therapeutant listed as *Highly Important* to human health by WHO (WHO, 2017), and one of the most common antimicrobials used in Mexico historically (Páez-Osuna *et al.*, 2003). There is additional documentation of antimicrobial resistant bacteria (to OTC and tetracycline) associated with NW Mexico farmed shrimp that less-explicitly links acquired resistance to shrimp aquaculture (de Jesús Hernández-Díaz *et al.*, 2015; Han *et al.*, 2015)--though this offers an additional suggestion that shrimp aquaculture is contributing to the problem of antimicrobial resistance in pathogenic bacteria. Lastly, del Carmen Bermúdez-Almada *et al.* (2014) found high Minimum Inhibitory Concentrations (MICs) for OTC in *Vibrio parahaemolyticus* bacteria cultured from NW Mexico shrimp farms, suggesting resistance has been acquired due to the frequent use of OTC on farms. del Carmen Bermúdez-Almada *et al.*, conclude: “…the use of medicated feeds has become a problem due to the increase in bacterial resistance and elevation of the OTC MICs for bacteria isolated from shrimp farms (del Carmen Bermúdez-Almada *et al.*, 2014).” Concerns regarding antimicrobial resistance exist and Mexico is currently developing an updated and comprehensive National Strategy of Action against Resistance to Antimicrobials, which will include consideration of their use in aquaculture (SEGOB, 2018).

Despite observed resistance of pathogenic bacteria to OTC historically and in the recent past, available data suggest that a fraction of antimicrobial-using farms are using OTC (11 % using OTC) in Sonora in 2018; (COSAES, 2019b)), possibly due to limited effectiveness. More farms that use antimicrobials were recorded as using enrofloxacin, (84 % of the farms that used antimicrobials in Sonora in 2018), but studies have not observed resistance issues with enrofloxacin (Molina-Aja *et al.*, 2002; del Carmen Bermúdez-Almada *et al.*, 2014).

Other chemicals

In addition to the antimicrobial data described above, (COSAES, 2014a) reported about 50 % of farms had used probiotics, and 80 % had used "other chemicals;" the COSAES report does not specify what "other" chemicals are, but they are likely to be pond treatments such as lime, sodium hypochlorite, and other viricidal or bacterial disinfectants to treat ponds experiencing disease issues following harvest—as required by law. Use of disinfectants must involve registration and approval from the government, as well as compliance with mandated treatment protocols and record-keeping requirements (Government of Sonora, 2017; SENASICA, 2017). These are not assessed at length here as the score for this criterion is considered to be driven by the antimicrobial use.

Conclusions and final score

Data on chemical use in Mexican shrimp farms is limited. It shows that in one state (Sonora) in 2018 (the latest year of data available), approximately 24% of farms used antimicrobials, of which 84% had used an antimicrobial listed as Critically-Important to human medicine by the World Health Organisation (enrofloxacin) and the remainder used either Highly-Important (oxytetracycline or florfenicol) or a mix of enrofloxacin and oxytetracycline. Regulatory restrictions are in place for the use of antimicrobials and Aquaculture Health Committees remain active in advancing animal health and biosecurity in Mexican shrimp farming, but production involves a high water exchange with the surrounding environment, and there are multiple references to acquired bacterial resistance to OTC on shrimp farms. The Sonora data indicate an increase in the number of farms using antimicrobials over time (2014 to 2018), but without more specific data to understand total overall antimicrobial usage (frequency, volumes) from Sonora and from other states, the use of Highly- and Critically-Important antimicrobials is considered significant but unknown. With the evidence of developed resistance to these antimicrobials, the final score for Criterion 4 – Chemical Use is 0 out of 10 and is a Critical conservation concern.

Criterion 5: Feed

Impact, unit of sustainability and principle

- Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary

Feed parameters	Value	Score
F5.1a Fish In: Fish Out ratio (FIFO)	1.39	6.52
F5.1b Source fishery sustainability score	-3.00	
F5.1: Wild fish use score		5.68
F5.2a Protein IN (kg/100kg fish harvested)	70.86	
F5.2b Protein OUT (kg/100kg fish harvested)	21.74	
F5.2: Net Protein Gain or Loss (%)	-69.32	3
F5.3: Feed Footprint (hectares)	10.27	6
C5 Feed Final Score (0-10)		**5.09**
Critical?	NO	**Yellow**

Brief Summary

Without recent feed data applicable to the industry as a whole (i.e. other than isolated data points for four ASC-certified farms), assumptions based on now-dated global reference values were made for the feed composition in Mexico. Using these global values alongside the limited Mexico-specific values, the FFER value was 1.39. Although with some uncertainty, it was also assumed that Mexican forage fisheries are used in shrimp feeds which are primarily MSC-certified, and the final Wild Fish Use score is 5.68 out of 10. With an estimated feed protein content of 35 %, supplied predominantly by marine and crop ingredients considered suitable for human consumption, there was a net loss of edible protein of 69.32 % and a feed footprint of 10.27 ha per mt of shrimp production. Overall, the three factors combine to give a final Criterion C5 – Feed numerical score of 5.09 out of 10

Justification of Rating

The Seafood Watch Aquaculture Standard assesses three feed-related factors: wild fish use (including the sustainability of the source), net protein gain or loss, and the feed “footprint” or global area required to supply the ingredients.

Several attempts to acquire information on shrimp feeds directly from four Mexican feed companies were unsuccessful; therefore, this assessment relies on data available from their websites, and also from scientific publications on feed research, ASC evaluation of four farms, and dated publications on commercial feed composition**.**

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

Shrimp in semi-intensive growout conditions are reliant upon manufactured feeds to supplement naturally occurring forage in ponds. While Tacon and Metian (2008) predicted improvements (i.e. reductions) in the use of marine ingredients such as fishmeal and fish oil over time, little recent data on feed composition in Mexico are available. The audit report for four farms under one company certified to the ASC use feeds including 12% fishmeal and 0% fishoil (ASC, 2018a), but the relevance of this feed to the broader industry is uncertain. Without substantial recent data from the feed companies on the inclusion levels of these ingredients, the now-dated reference median values from Tacon *et al* (2011) are averaged with the limited more recent data available. Tacon and Metian (2011) report Mexican whiteleg shrimp feeds contain 12-20 % fishmeal and 3-6 % fish oil. Averaging the median values from these authors with the more recent data available, the inclusion values assumed for this assessment are the medians of these ranges: 14 % for fishmeal and 2.25 % for fish oil.

An Economic Feed Conversion Ratio (eFCR) for Pacific white shrimp produced in semi-intensive farms ranges between 1.2 – 1.8, with a global average at 1.6 (Tacon, 2018; Boyd et al., 2017). Values for eFCR from the four certified Mexican farms (audit report dates – January 2019) are substantially higher than these global values and range from 2.75 to 3.08 (ASC, 2019). Again, it is not known if these values are representative of other farms in Mexico, or if thee farms had specific mortality event that increased their eFCR values. Therefore, an average of these values and the global average for *L. vannamei* of 2.24 is used for this assessment.

Fishmeal made from fish byproducts are commonly included in shrimp feeds (García-Galano *et al.*, 2007), and at least some Mexican fishmeal and fish oil producers are making use of byproducts from yellowfin and skipjack tuna fisheries (e.g. Mazinsa, 2018), and certified farms list tuna byproducts and salmon oil (from aquaculture byproducts) but no information is available on how much of these byproduct ingredients are used. Although the UN FAO estimates that byproducts account for 25-35 % of fishmeal and fish oil produced globally, the lack of data specific to Mexican shrimp feeds means any assumed value would be arbitrary and therefore they cannot be assumed to be used.

Table 5. Parameters used in feed calculations. Data from (Tacon *et al.*, 2011; ASC, 2017, 2018a, 2018b, 2018c, 2018d).

Parameter	Data
Fishmeal inclusion level	14 %
Percentage of fishmeal from byproducts	0 %
Fishmeal yield (from wild fish)	22.5 %
Fish oil inclusion level	2.25 %
Percentage of fish oil from byproducts	0 %
Fish oil yield	5 %
Economic Feed Conversion Ratio (eFCR)	2.24
Calculated Values	
Feed Fish Efficiency Ratio (fishmeal)	1.39
Feed Fish Efficiency Ratio (fish oil)	1.01
Seafood Watch FIFO Score (0-10)	**6.52**

Factor 5.1a –Feed Fish Efficiency Ratio scores 6.52 out of 10.

Factor 5.1b – Sustainability of the source of wild fish

Reduction fisheries in Mexico account for 35 – 50 % of all fishery landings (INAPESCA, 2012; INAPESCA, 2014). Approximately 75 % of the lesser pelagic species landed are destined for fishmeal and fish oil production, with the remainder for direct human consumption (Yurkievich and Sánchez Crispín, 2016). Although few specific data are available from feed companies to describe the inclusions of these fishery products in fishmeal and oil used in Mexican shrimp feeds, there are references specific to Pacific thread herring, Pacific sardine, and Pacific mackerel (ASC, 2019), and given the ready in-country supply, it is assumed here that these local sources are used.

Three major producers of fishmeal (one certified as IFFO Responsible representing ~10 % of total fishmeal production) located in Sonora and Sinaloa report using the species in fishmeal derived from nearby Gulf of California stocks outlined in Table 6 (IFFO, 2016; ASC, 2017; Guaymas Protein, 2018; Guaymex, 2018; Mazinsa, 2018). The most important species are: the Pacific Sardine (*Sardinops sagax*), Pacific thread herring (*Opisthonems spp.*), and Pacific anchoveta (*Cetengraulus mysticetus*). There are several other species caught in lesser volumes (Yurkievich and Sánchez Crispín, 2016; Osuna-Ramirez *et al.*, 2017) and there are additional references to the inclusion of Antarctic krill (ASC, 2017) and squid meal (ASC, 2018a). There is additionally incorporation of at least some fisheries byproducts in both fishmeal and fish oil production, such as skipjack tuna and yellowfin tuna byproducts (IFFO, 2016) and aquaculture byproduct-based salmon oil (ASC, 2019).

Table 6. Gulf of Mexico fisheries supplying Mexican fishmeal and fish oil industry.

Species/fishery	MSC Status	FishSource
Opisthonema spp./thread herring*	Certified, minor conditions	All ≥6
Sardinops sagax/Pacific sardine*	Certified, minor conditions	All ≥6
Scomber japonicus/Pacific mackerel*	Certified, minor conditions	Not assessed
Engraulis mordax/northern anchovy	Certified, minor conditions	Not assessed
Cetengraulis mysticetus/anchoveta*	Certified, minor conditions	Not assessed
Antarctic krill	One fishery certified, no conditions	All ≥6/≥8 Stock Health
Yellowfin tuna byproducts** /NE tropical Pacific purse seine	Certified, minor conditions	All ≥6 /10 Stock Health
Skipjack tuna byproducts**/ NE tropical Pacific purse seine	Certified, minor conditions	All ≥6

*Assessed by MSC as part of a "Small pelagics" purse seine fishery (MSC, 2017); **reported by one fishmeal producer (Mazinsa, 2018).

The Marine Stewardship Council has evaluated and certified the Gulf of Mexico "Small pelagics" purse seine industry as Sustainable, with minor conditions (MSC, 2017; though this is not without its controversy, see Yurkievich and Sánchez Crispín, 2016). Additionally, the Pacific sardine fishery receives FishSource scores of ≥6 for all categories.

MSC certification with minor conditions of the principal fishery supplying fishmeal, as well as FishSource scores of ≥6 (but below 8 for Stock Health), aligns with a Seafood Watch score of -3 out of -10 and a Factor 5.1b deduction from the FFER score of 0.84.

When combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1 score of 5.68 out of 10.

Factor 5.2. Net Protein Gain or Loss

L. vannamei has a protein requirement of 18-35 % (Briggs, 2006), and Mexican shrimp feed producers advertise their growout feeds as containing 30-35 % protein (Nutrimentos Acuicolas Azteca, 2018; Zeigler Feed, 2018), as do those in Ecuador (Alimentsa, 2018). Experimental feeds also use 35 % as a typical protein content (e.g. Macias-Sancho *et al.*, 2014) and available Mexican farm records indicate a 35 % protein content in Mexican shrimp feeds (ASC, 2019). For this assessment, a 35 % feed protein value is used.

An ASC audit of one Mexican shrimp farm offers some general insights into shrimp feed ingredients—for example that feed contains corn, cereals, and animal byproduct (pork blood) ingredients. Without specific data from the feed companies, Tacon et al (2011), though somewhat dated, provides the best insight into shrimp feed ingredient specifics. Assuming

Proximate composition of many of these feed ingredients is available via the FAO Feed Resources Database (FAO, 2018).

Table 7. Example commercial shrimp feed composition. All ingredient protein content values from FAO 2018, unless otherwise noted. The median of reported inclusion range values was used for calculations in this assessment. Edibility distinctions were made using Seafood Watch 2016. Data from Tacon et al (2011).

Ingredient	Inclusion range*	Median value	Edible?	% protein	% of total feed protein
Fishmeal	12-20	14**	n/a	68.6[1]	30.4
Fish oil	3-6	2.25**	n/a	--	--
Rapeseed/canola oil	1-2	1.5	Yes	--	--
Soybean meal	15-40	27.5	Yes	46.0	36.0
Wheat	12-22	17	Yes	12.0	8.0
Wheat gluten meal	3-6	4.5	Yes	75.2	9.7
Corn by-products	2-4	3	Yes	8.3	0.7
Rapeseed/canola meal	3-8	5.5	Yes	38.0	6.0
Faba bean meal	1-4	2.5	Yes	29.0	2.1
Poultry byproduct meal	2-4	3	No	53.0	5.0
Meat meal (hog/ovine)	2-4	3	No	42.7	3.7

*This assessment assumes that 16.25 % of unaccounted for ingredient inclusion is from terrestrial crops. [1]Macias-Sancho et al 2014 **Value represents median of range reported by Tacon et al (2011) averaged with values reported by ASC (2018).

Table 7 depicts global data on shrimp feed composition. Absent information specific to Mexico, these data are used in this assessment to apply to feeds used in Mexico. The protein inputs in feeds used for *L. vannamei* in Mexico area are therefore considered to be sourced from 28.9 % marine ingredients, 62.4 % crop ingredients and 8.7 % land animal ingredients. Only the land animal byproduct ingredients (8.7 % of total feed protein combined) are considered not suitable for human consumption, and therefore 91.3 % of the total protein is considered edible. With an eFCR of 2.24, the total edible protein input is 708.6 kg protein per metric ton (mt) of shrimp production.

Regarding protein outputs, the protein content of whole shrimp (*L. vannamei)* is 17.8 % (Boyd et al, 2007), and FAO (2001) states the edible yield of shrimp is 45 % (40 % of whole shrimp is the head, and a further 15 % in the shell, tail and legs). While shrimp processing wastes can be dried into a meal for further uses in animal feed (FAO, 2001), it is not known if this is done in Mexico; therefore, the default of 50 % byproduct utilization is used. After an adjustment for the conversion of crop protein to animal proteins, the edible protein output is 217.4 kg protein per mt of harvested shrimp.

Table 8. Protein data points and calculated values

Parameter	Value
Protein content of feed	35 %
Percentage of total protein from non-edible sources (by-products etc.)	8.7 %
Percentage of protein from edible sources	91.3 %
Percentage of protein from crop sources	62.4 %
Feed Conversion Ratio	2.24
Protein INPUT per ton of farmed shrimp	708.6 kg
Edible yield of harvested shrimp	45 %
Protein content of whole harvested shrimp	17.8 %
Percentage of farmed shrimp by-products utilized	50 %
Utilized **protein OUTPUT** per ton of farmed shrimp	217.4 kg
Net protein loss	-69.32 %
Seafood Watch score (0-10)	**3**

Overall, there is a net edible protein loss of 69.32 % which corresponds to a score of 3 out of 10 for Factor 5.2.

Factor 5.3. Feed Footprint

By considering the marine, terrestrial crop, and terrestrial land animal ingredients, this factor provides an estimate of the ocean and land area required to produce the ingredients necessary to produce feed required per mt of farmed shrimp. Based on the available data cited previously, the calculation was based on an inclusion level of aquatic feed ingredients of 20.5 %, an inclusion level of crop feed ingredients of 77.8 %, and an inclusion level of land animal ingredients of 6.0 %.

Table 9: Feed footprint data points and calculated values.

Parameter	Value
Inclusion level of aquatic feed ingredients	16.3 %
Inclusion level of crop feed ingredients	77.8 %
Inclusion level of land animal ingredients	6.0 %
Ocean area used per ton of farmed shrimp	9.5 ha
Land area used per ton of farmed shrimp	0.8 ha
Total area	10.3 ha
Seafood Watch Score (0-10)	**6**

The ocean area necessary for production of marine ingredients required for one ton of *L. vannamei* in Mexico is 9.5 ha/ton of farmed fish. The area necessary for production of terrestrial (crop and land animal) ingredients required for one ton of *L. vannamei* is 0.8 ha/ton. The combination of these two values results in an overall feed footprint of 10.3 ha/ton of farmed fish. This results in a final Factor 5.3 score of 6 out of 10.

Conclusions and final score

Without recent feed data applicable to the industry as a whole (i.e. other than isolated data points for four ASC-certified farms), assumptions based on now-dated global reference values were made for the feed composition in Mexico. Using these global values alongside the limited Mexico-specific values, the FFER value was 1.39. Although with some uncertainty, it was also assumed that Mexican forage fisheries are used in shrimp feeds which are primarily MSC-certified. The final Wild Fish Use score is 5.68 out of 10. With an estimated feed protein content of 35 %, supplied predominantly by marine and crop ingredients considered suitable for human consumption, there was a net loss of edible protein of 69.3 % and a feed footprint of 10.3 ha per mt of shrimp production. Overall the three factors combine to give a final Criterion C5 – Feed numerical score of 5.09 out of 10.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Escape parameters	Value	Score
F6.1 System escape risk	1	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		1
F6.2 Invasiveness		4
C6 Escape Final Score (0-10)		**2**
Critical?	NO	**Red**

Brief Summary

It is clear that farmed shrimp are escaping from farms through unintentional losses and also possibly via intentional releases of postlarvae. Escapes may be as high as 3-6 % of total farmed shrimp, and 7-14 % of shrimp collected from “wild” Pacific populations showed signs of hatchery/farm origin. *L. vannamei* are native to the Pacific coast of Mexico, but the industry relies on hatchery production of postlarvae from selectively-bred broodstock that are genetically distinct from wild shrimp. With a high genetic diversity in wild populations, genetic impacts may be unlikely, but there is currently insufficient evidence with which to conclude this. The species has additionally been detected outside of its native range in the Gulf of Mexico; this is linked to aquaculture escapes and there is potential for eventual establishment, but again, there is no evidence of establishment to date. The combination of a high risk of escape (Factor 6.1) and a moderate risk of genetic and competitive impacts (Factor 6.2) gives a final score of 2 out of 10 for Criterion 6 – Escapes.

Justification of Rating

Factor 6.1. Escape risk

Mendoza-Cano et al (2016) state that escapes of shrimp from aquaculture facilities globally has been “extensively described,” and Perez-Enriquez et al (2018) state that inadvertent release of “large numbers of shrimp to the wild” occurs in Mexico. Shrimp can escape from farms during harvest, during water exchange, during flooding events associated with tropical storms and hurricanes, from hatcheries, and during transport—with the harvest of ponds being the most likely opportunity for accidental *L. vannamei* escapement (Wakida-Kusunoki *et al.*, 2011; Perez-Enriquez *et al.*, 2018; L. Meltzer pers. comm. 2020). The Mexican shrimp industry typically operates with a pond exchange rate of 5-30 % daily in addition to water exchanged at harvest (Holtschmit and Garmendia, 2009; Barraza-Guardado *et al.*, 2013; ASC, 2019).

Conflicting reports of escapes in the form of intentional releases exist: there are some reports that hatcheries commonly release "huge numbers" of (unsold) surplus postlarvae with the belief that this benefits wild stocks; perhaps 10 % of a hatchery's production may be released in this way; further, "occasional" release of larvae may sometimes be used as an officially required mitigation measure for offsetting presumed impacts associated with dredging estuarine areas to preserve farm water intakes (Perez-Enriquez *et al.*, 2018).

Although no formal data on escape numbers or deliberate releases are available, Perez-Enriquez et al. (2018) estimate about 10 % (or 300-500 million postlarvae) of hatchery production are being released annually in Sinaloa alone, and that 500 million postlarvae have been released as mitigation measures since 2009 (Perez-Enriquez *et al.*, 2018; R. Perez-Enriquez pers. comm. 2019). Attempts to gain specifics on intentional releases for this assessment were unsuccessful and some contacts expressed doubts that this is actually occurring due to the value and limited nature of supply of shrimp postlarvae (Dr. Armando Wakida-Kusonoki, INAPESCA pers. comm. 2019).

The presence of *L. vannamei* in surveys of the Gulf of Mexico (to which it is not native) further indicates the occurrence of escapes from farms (Wakida-Kusunoki *et al.*, 2011), and the detection of hatchery-origin shrimp in genetic assessments of Pacific-coast shrimp (Perez-Enriquez *et al.*, 2018) further confirms that escapes are occurring on some level. Perez-Enriquez et al (2018) reported that about 7-14 % of shrimp collected in their samples of wild Pacific populations possessed signs of hatchery origin and offer an estimate that 3-6 % of farmed shrimp ultimately escape to the wild.

Overall, it is clear that the production system is vulnerable to large escape events and trickle losses and may deliberately release large numbers of postlarvae. The estimated values for the proportion of farmed stock escaping and their presence in the wild from Perez-Enriquez et al (2018) are the best indicators available. The 3-6% escape value straddles the 5% scoring guideline in the Seafood Watch Aquaculture Standard (score of 2 out of 10), and it is unclear whether these escapes numbers are sufficiently large to cause population-level impacts (score of 0 out of 10. Therefore, the final score for Factor 6.1 – Escape Risk is an intermediate 1 out of 10. Although there are active fisheries in the Gulf of California (and the Gulf of Mexico) there are no suitable data with which to estimate a recapture adjustment.

Factor 6.2. Invasiveness

L. vannamei, the primary species cultivated by the Mexican shrimp industry, is native to the Pacific coast region in which it is farmed. It is also farmed at a lesser extent on the Gulf of Mexico coastline, to which it is not native. As discussed in previous sections, the large majority of production occurs on the Pacific coast where the species is native.

The effects of escape and establishment as a non-native species are not well documented, but the main effects are expected to be competition with native shrimp for habitat and food, breeding interference, and introduction or spread of disease (Wakida-Kusunoki *et al.*, 2011). Where escaped cultivated shrimp are interacting with native wild, conspecific populations (Pacific coast and Gulf of California), genetic impacts are an additional concern (Perez-Enriquez *et al.*, 2018).

Postlarvae supplying the Mexican shrimp industry are produced in hatcheries where breeding selects for desirable production characteristics such as performance (survival and growth) and disease resistance (Perez-Enriquez *et al.*, 2009). Perez-Enriquez et al (2009) reported that selective breeding of shrimp had already occurred in closed breeding systems in Mexico for at least 10 generations (as of 2007), and Vela-Avitúa et al. (2013) showed that the genetic composition of hatchery-reared stocks in Mexico is different from wild shrimp most probably due to more than 20 years of domestication and selection. The industry has maintained sufficient genetic diversity for aquaculture production needs, but the farmed shrimp are genetically distinct from nearby wild populations (Perez-Enriquez *et al.*, 2009). Determining the ecological impact from the escape of these shrimp, however, is challenging.

L. vannamei is native to the Pacific coastlines of Mexico, Central America and northern South America (FAO, 2006). Although studies on the species' genetic diversity are able to identify subpopulations along the coast, they note that while genetic diversity is high in any one location, there was a lack of a specific geographical pattern and a low differentiation (i.e. genetic homogeneity) among estuaries (Valles-Jimenez *et al.*, 2004; Perez-Enriquez *et al.*, 2018). Therefore, given the high genetic diversity in the wild population as a whole plus the lack of highly discreet subpopulations (e.g. compared to salmon in which genetic introgression from escapes into highly-discreet genetic subpopulations is a high concern, Glover et al., 2017), the potential for genetic introgression of farm shrimp escapes seems presently limited. In support of this, Perez-Enriquez et al (2018) also conclude that genetic introgression of farmed shrimp alleles into wild populations in Mexico has probably been limited, but it must be emphasized that their sample sizes were very low.

Whiteleg shrimp, native to the Pacific ocean, have been observed in the wild in the Gulf of Mexico (a region representing <3% of national production)—attributed to aquaculture escapes—where potential for negative impacts on native shrimp and ecosystems is a possibility (see also Criterion 7—Disease). Establishment of this species in the Gulf of Mexico, however, has not been documented and while mortality of escaped shrimp is likely high, there is evidence that at least some shrimp are surviving—a risk of eventual establishment.

Overall, any escaping shrimp are considered to be domesticated for multiple generations, and therefore genetically discernable and to some extent genetically differentiated from wild stocks. Additionally, aquaculture of *L. vannamei* in Mexico is blamed for the detection of the species outside its native range, though not yet having become established. This indicates an initial invasiveness score (Factor 6.2) of 2 out of 10; however, the lack of evidence of establishment outside its native range in Mexico and the potential impact to the more genetically diverse wild *L. vannamei* populations along the Central American coast seems limited; therefore the score is increased to 4 out of 10 which is considered to be equivalent to three generations of selective breeding in the Seafood Watch Standard. Therefore, the score for Factor 6.2 – Invasiveness is 4 out of 10.

Conclusions and final score

It is clear that farmed shrimp are escaping from farms through unintentional losses and also possibly via intentional releases of postlarvae. Escapes may be as high as 3-6 % of total farmed shrimp, and 7-14 % of shrimp collected from “wild” Pacific populations showed signs of hatchery/farm origin. *L. vannamei* are native to the Pacific coast of Mexico, but the industry relies on hatchery production of postlarvae from selectively-bred broodstock that are genetically distinct from wild shrimp. With a high genetic diversity in wild populations, genetic impacts may be unlikely, but there is currently insufficient evidence with which to conclude this. The species has additionally been detected outside of its native range in the Gulf of Mexico; this is linked to aquaculture escapes and there is potential for eventual establishment, but again, there is no evidence of establishment to date. The combination of a high risk of escape (Factor 6.1) and a moderate risk of genetic and competitive impacts (Factor 6.2) gives a final score of 2 out of 10 for Criterion 6 – Escapes.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Pathogen and parasite parameters	Score	
C7 Disease Score (0-10)	2	
Critical?	NO	**Red**

Brief Summary

The Mexican shrimp industry has a history of introducing and spreading exotic shrimp pathogens around the country and there is evidence that these pathogens have been transmitted to, and have significantly impacted, wild shrimp at the population level (for example wild *L. stylirostrus* shrimp populations in Mexico affected by the IHHN virus). There is ongoing uncertainty with regard to other confirmed transmissions of diseases from cultured stocks to wild ones. Despite management and regulatory improvements, the pattern of disease epidemics occurring at the farm level and the open nature of the production system suggests the likelihood of both disease amplification and transmission to wild populations is an ongoing risk. There is thus a moderate-high risk that disease linked to Mexican shrimp aquaculture will cause population-level impacts to wild shrimp or other marine organisms, and the final numerical score for Criterion 7 – Disease is 2 out of 10.

Evidence-based assessment:

As disease data quality and availability are considered “good” (i.e. Criterion 1 score of 7.5 or 10 for the disease category), the Seafood Watch Evidence-based assessment was utilized.

Justification of Rating

The high animal densities in aquaculture facilities results in common outbreaks of diseases (Funge-Smith et al., 1998). Low-oxygen levels in particular, such as those that occur in poorly managed semi-intensive systems or ponds with soil bottoms, create physiological stress on shrimp, which in turn lowers the disease resistance of the animals. This reduced disease resistance of the organism can result in pond-level, farm-wide, or region-wide disease outbreaks (Leon, 2013).

Shrimp are especially susceptible to disease because they lack the key components of adaptive and innate immune response mechanisms (i.e. antibodies, lymphocytes, cytokines, interferon) which would normally fight against foreign pathogens like bacteria and viruses (Walker et al., 2010).

Like many other shrimp-producing countries, disease has been an important issue for Mexican shrimp farming, and various viruses, bacteria, and fungal pathogens have posed challenges for this industry (Roque *et al.*, 2001). The Mexican industry typically experiences a mortality rate of around 25 % (INAPESCA, 2018), though other sources report average mortality rates of 15-63% (ASC, 2019); disease-related mortality has driven mortality rates much higher episodically. The severity and dissemination of viral diseases, in particular, are described as a top challenge for this industry (Aguilar-Manjarrez *et al.*, 2017). In addition to the major disease issues that continue to hamper this industry, pond effluent remains largely untreated and release of pond water and draining of ponds is a common response to a disease outbreaks (Macías-Rodríguez et al., 2014), though at least in some cases disinfectant treatment may be applied before draining (SEMARNAT, 2012a). As systems with regular water exchange with the surrounding environment, shrimp ponds represent a disease risk to the marine environment. Further, escapes of farmed shrimp have been documented and described as a risk of transmitting pathogens to wild populations and causing ecological harm (Wakida-Kusunoki *et al.*, 2011; Mendoza-Cano *et al.*, 2016). The apparent intentional releases of excess hatchery postlarvae discussed in Criterion 6 – Escapes, despite the development of SPF strains, also represents a vector of disease to wild populations.

Important diseases are discussed below:

Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV/PstDV1)

IHHNV was introduced to Mexican shrimp farms from imported shrimp in the late 1980s (Galaviz and Molina, 2014), with imports of *Penaeus monodon* from the Philippines a likely origin (Lim and Webster, 2001; Lightner, 2003). The viral disease drives significant losses following introduction and led to an industry switch from cultivation of highly-susceptible *Litopenaeus stylirostris* to the more resilient *L. vannamei* cultivated now; while less fatal to *P. vannamei*, IHHNV causes deformities and dwarfism (Galaviz and Molina, 2014). Following introduction to farmed shrimp, IHHNV was later found in wild-sourced broodstock due to an introduction of the causative virus to wild shrimp stocks from cultured ones (Lightner *et al.*, 1992). The virus is blamed for the collapse of the wildstock fishery of *L. stylirostris* in the northern Gulf of California (Lim and Webster, 2001; Lightner, 2003) and following recovery, continued to be found at high levels of prevalence (26-100 %) in wild *L. stylirostris, Farfantepenaeus* californiensis, and *L. vannamei* in the Gulf of California (Lightner, 2003; Macías-Rodríguez *et al.*, 2014) and the Pacific state of Nayarit (Lightner, 2003). It has been detected in at least 3 other wild shrimp species and it has also been detected in wild Gulf of Mexico shrimp(Guzman-Saenz *et al.*, 2009; Galaviz and Molina, 2014), suggested to be linked to the possible establishment of escaped farmed *L. vannamei* here or to movement of aquaculture shrimp from northwest Mexico to Gulf of Mexico states (Mendoza-Cano *et al.*, 2016). It has also been detected in crabs and fishes in areas proximal to Mexican shrimp farms (Macías-Rodríguez *et al.*, 2014). In Sonoran shrimp farms, IHHNV has been widely distributed among farms and steadily on the rise beginning in 2004 (Figure 6)(COSAES, 2019a). It has also caused problems in other states throughout the industry (Aguilar-Manjarrez *et al.*, 2017). An illegal introduction of larvae or broodstock has been suggested as a possible source of a 2013 outbreak (López-Téllez *et al.*, 2019).

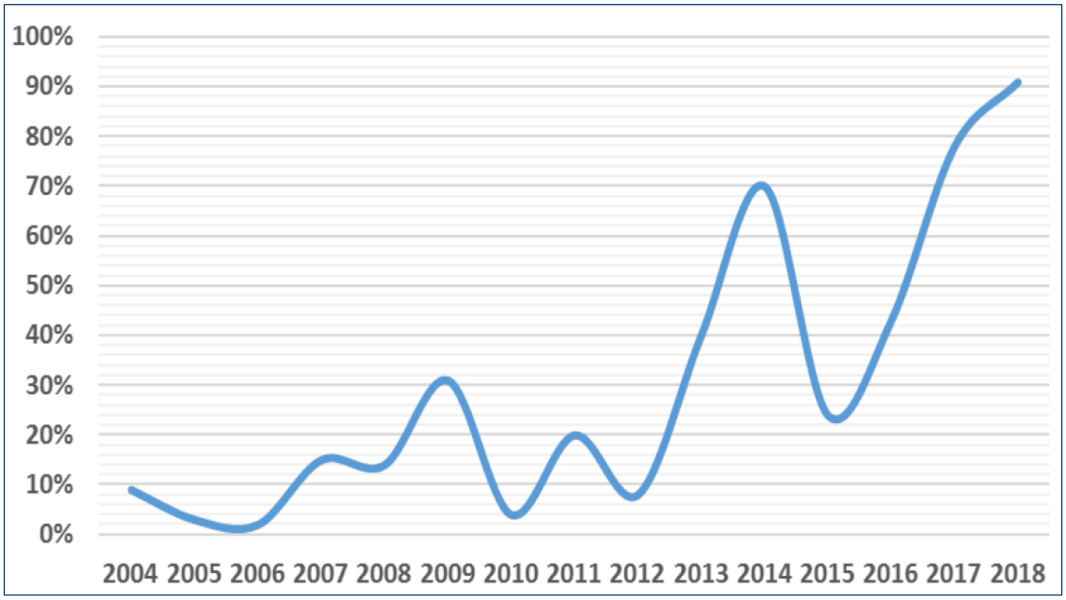

Figure 6. Prevalence of IHHNV on Sonora shrimp farms, 2004-2018. IHHNV has been on the rise in recent years (COSAES, 2019a).

Taura Syndrome Virus (TSV)

TSV is believed to have been introduced to Mexico in the mid-1990s, via import of live shrimp by the aquaculture industry--where it has caused significant losses in places and persists at a lower prevalence today. TSV has since spread to at least two species of wild shrimp in the Gulf of Mexico (Galaviz and Molina, 2014), though it has previously been described as lacking discernable impacts to wild populations elsewhere (Lim and Webster, 2001; Lightner, 2003). Since the initial introductions of IHHNV and TSV, significant advancements have been made in the Mexican shrimp industry, in management, and in the development of Specific-Pathogen-Free sources of post-larvae. COSAES reports that TSV has not been a significant issue since 2007, though their public dataset only extends to 2014

White spot syndrome virus (WSSV)

WSSV was first reported in Mexico in 1999 and a major outbreak in 2005 cost the industry $100 million USD; production losses reached 80-100 % (Galaviz and Molina, 2014). WSSV is also blamed for production instabilities from 2003-2013. A 2012-13 emergence of Early Mortality Syndrome/Acute Hemapatopancreatic Necrosis Disease (EMS/AHPND), combined with losses associated with WSSV, drove major production losses (55 % decline in production nationally from 2012-2013)(Hernandez-Llamas *et al.*, 2014). WSSV is believed to have been introduced via frozen shrimp products from Asia (Lightner, 2003). In Sonora, COSAES reports a downward trend in the prevalence of WSSV statewide from 2010-18 (Figure 7**Error! Reference source not found.**)(COSAES, 2019a).

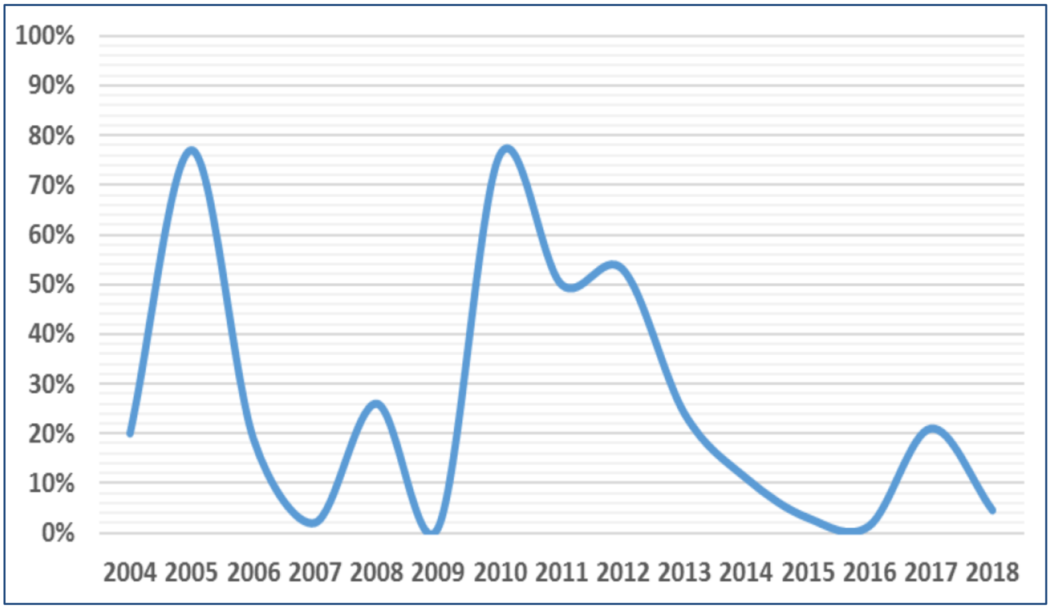

Figure 7. Prevalence of WSSV on Sonora shrimp farms, 2004-2018. WSV prevalence has been on a decline after major outbreaks in 2010-12 (COSAES, 2019b).

Vibriosis

Bacterial vibriosis outbreaks are a problem for Mexico shrimp farms (Bermúdez-Almada and Espinosa-Plascencia, 2012), particularly in the Bahia de Kino; most bacterial diseases in shrimp farming are caused by *Vibrio* bacteria. When released as effluent, *Vibrio* can negatively impact native fish and crustaceans, and cultivated populations (such as oysters) in the surrounding waters (Barraza-Guardado *et al.*, 2013). *Vibrio* bacteria have been documented as part of shrimp farm effluents—one study found abundance of *Vibrio*-like bacteria to be 2-3 times higher in shrimp farm effluent than control sites. An emerging disease issue for shrimp farms, Acute Hepatopancreatic Bacterial Necrosis Disease (AHPND aka Early Mortality Syndrome or EMS), is caused by *Vibrio parahaemolyticus*, and causes significant early mortality in recently-stocked shrimp ponds--representing another management challenge for this industry (Zorriehzahra and Banaederakhshan, 2015). AHPND has been blamed for a 40,000 mt reduction in production in 2013 (López-Téllez *et al.*, 2019).

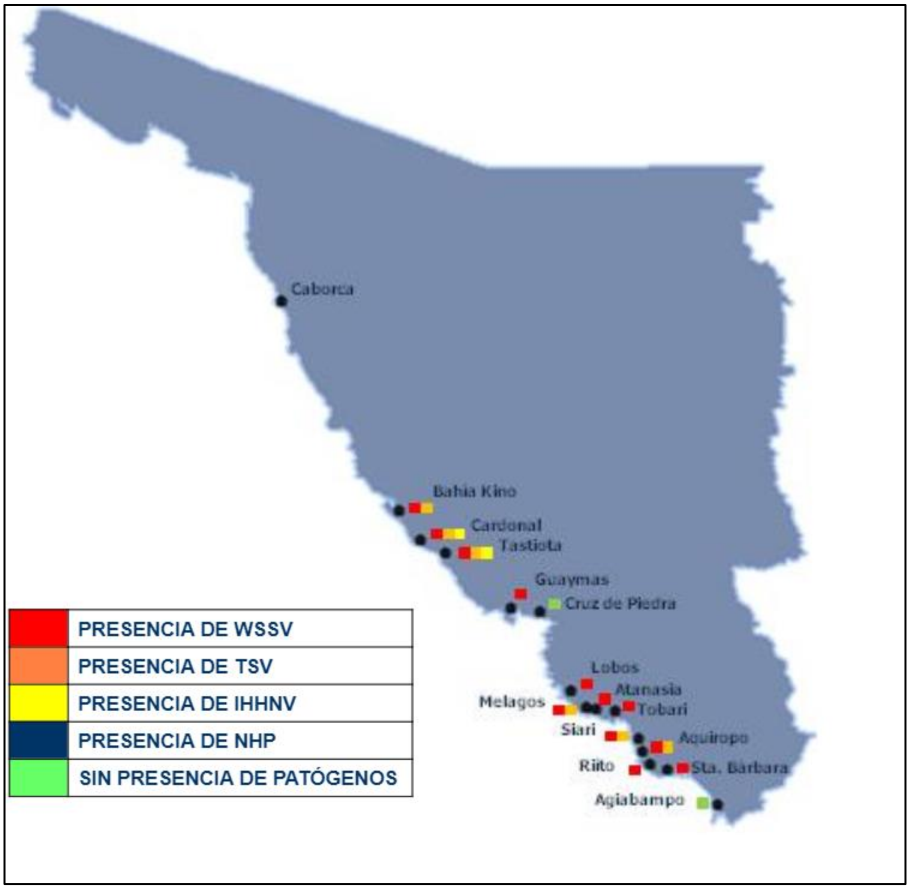

Figure 8. Presence of various shrimp diseases (WSSV, TSV, IHHNV, and NHP) at Sonoran shrimp farms in 2012 (image from COSAES 2012).

Disease prevalence is high and distributed widely in the Mexican shrimp industry, often with multiple diseases affecting the industry simultaneously (Figure 9). The prevalence of WSSV on farms surveyed in Sinaloa in 2008-2010 ranged from 18-90 % of farms by district (Hernandez-Llamas *et al.*, 2014). In 2014, the state of Sonora reported a total of 125 shrimp farms, or approximately 19,215 hectares of ponds, were affected by sanitary issues. Ninety-eight of these farms suffered from bacterial issues; 13 were diagnosed with EMS, 42 with IHHNV, 38 with necrotizing hepatopancreatitis (NHP), and 62 with parasites. This resulted in an overall estimated production loss of 70 %. The number of Sonoran shrimp farms infected in 2015 was dramatically fewer than the previous year: approximately 58 farms reported sanitary issues (bacteria, IHHNV, parasite, NHP, or WSSV). The prevalence of each of these sanitary issues was also reduced from observations in 2014 (COSAES, 2016). Specific data for years following 2015 are harder to find, but a report from SAGARPA on 2016 production describes continued shrimp health issues—including 158 cases of "health problems" during the growout cycle, with IHHNV, NHV, WSSV, and bacteriosis listed as specific challenges. Though it is unclear how much mortality is attributed to these reported disease issues, producers experienced a 43 % mortality rate in 2016 (SAGARPA, 2016). Annual industry-wide mortality rates have ranged between 20-50 % in 2017-18, and a mix of disease, bacterial issues, and environmental conditions have been suggested as causes (Undercurrent News, 2018).

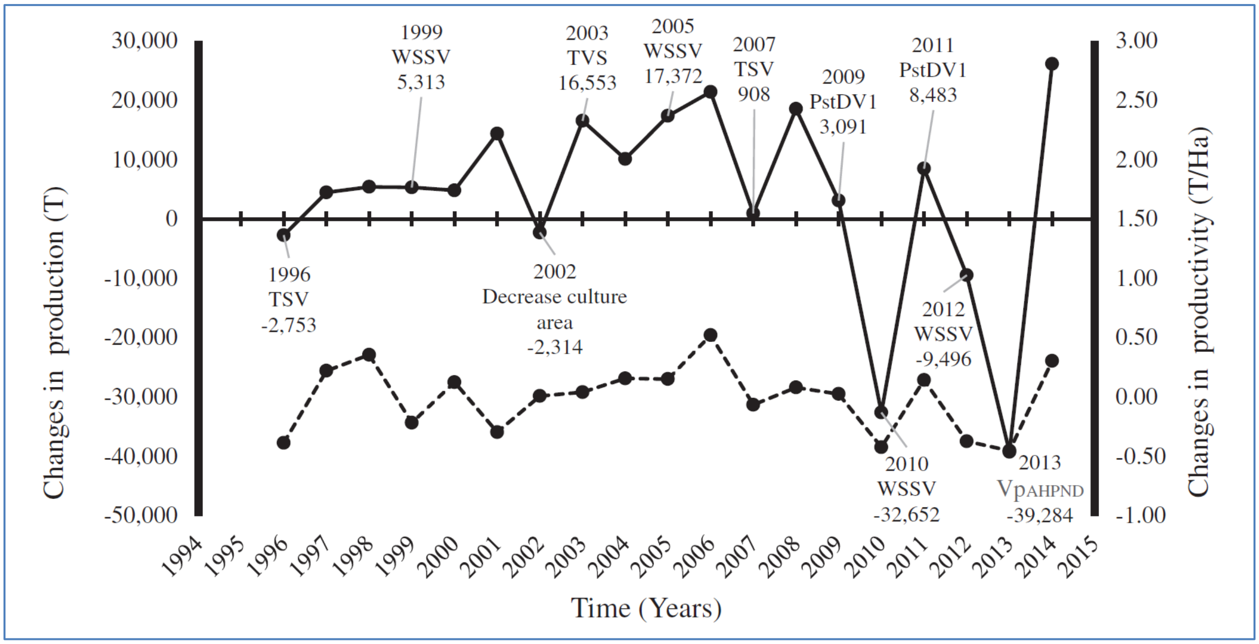

Figure 9. Shrimp disease impacts on Mexican shrimp production, 1994-2015. From (López-Téllez *et al.*, 2019).

Disease continues to be an important source of mortality limiting Mexican shrimp production, with 50 % farm mortality not atypical (SEMARNAT, 2012a; Undercurrent News, 2018) and recently reported incidents of high mortality (>50%) in some hatcheries (COSAES, 2019a). Sonora reports reductions in prevalence of some issues like EMS, but increasing prevalence of IHNNV and Sinaloa reports that 40% of farms were affected by health issues in the first cycle of 2019 (far fewer issues were reported in cycles 2 and 3)—most commonly IHHNV. Reported farm mortality rates in some districts reached 30%, averaging 13% statewide (CESASIN, 2020). The industry is also clearly amplifying and spreading pathogens to wild populations. Hernandez-Perez (2017) summarizes the risk of the Mexican shrimp aquaculture industry to wild populations as thus: "In Mexico, similar to other countries, the role of aquaculture in harboring and spreading disease in the aquatic environment has become evident."

Regulation and Management

The most relevant national legislation associated with diseases and pathogens affecting shrimp farms is NOM-EM-006-PESC-2004. This law establishes sanitary requirements for the production of aquatic crustaceans, both living and deceased, and the products and by-products associated with their production in Mexico in order to avoid disease outbreaks and ensure overall organism health (SAGARPA, 2013). In addition to these water quality parameters, SAGARPA via the Carta Nacional (National Fisheries Report) provides guidance to shrimp farmers directing filtration of influent water using 500 micron and 300 micron mechanical filters, pumping water only during high tide, and whenever possible, avoiding use of water that was discharged from another farm (SAGARPA 2013). Wild organisms can serve as intermediate hosts for many viruses and *Vibrio* bacteria strains that are believed to be naturally occurring in the environment (Stentiford et al. 2012; Gervais, 2014a). Therefore, most farms follow this guidance and filter water to exclude organisms like fish and crustacean larvae that carry viruses (Scott Horton, Personal Comm., 2015).

Aquaculture Health Committees

Mexico uses state-level aquaculture health committees to promote health practices among aquaculture farms, track disease outbreaks, apply prevention measures, and collect farm-level data throughout the growout season. The committees were set up in cooperation with SENASICA (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria). The Committees include representatives from academia, state government and federal government and have regulatory authorities over ensuring animal health and farm biosecurity. Shrimp farmers must join their state committees and comply with the aquatic health regulations (Rosenberry 2008). They additionally provide screening of animals to certify SPF status of hatchery broodstock and PL and for disease diagnosis (COSAES, 2014a) and establish schedules for pond filling, draining, harvest, and seasonal fallowing (COSAES, 2016).

The state of Sonora's rise as Mexico's top producer is partly accredited to the 2001 formation of its health committee, COSAES--the first in Mexico. Under COSAES, stocking and harvest permits for all farms and hatcheries in the state would become conditional upon adoption of the state's sanitation protocols—which include annual drying, disinfecting ponds following harvest, hatchery water filtration, stocking density standards, and basic biosecurity protocols (Holtschmit and Garmendia, 2009; SEMARNAT, 2012a; Navedo *et al.*, 2015; COSAES, 2016; Government of Sonora, 2017; SENASICA, 2017). The provinces of Sinaloa, Nayarit, and Baja California Sur followed with their own aquaculture health committees in 2004 and aquaculture health committees now operate in 28 states nationwide (CESASIN, 2018). Sonora has been able to successfully reduce the prevalence in WSSV (**Error! Reference source not found.**), TSV, and N HP since 2004 following the creation of its health committee (COSAES, 2014b). Aquaculture health committees have also developed Best Practices guidelines for their producers and the State of Sonora, for example, reports 78 % compliance by 2012 (Figure 100), the most recent year for which data are available (COSAES, 2014b). There is some additional evidence that health plans have been developed and are in use at the farm level (ASC, 2017), though also evidence of the contrary (ASC, 2018b). In Nayarit, "most" farmers are registered in the local Aquaculture Health Committee, which is active in promoting biosecurity (Aguilar-Manjarrez *et al.*, 2017).

Concept	Initial % compliant	Final % compliant
Legal and technical documentation	41.19	80.32
Risk reduction in new and existing operators	41.19	80.32
Water quality and supply	33.70	74.11
Production facilities, toilets, equipment, utensils	37.38	74.24
Pest control	60.65	82.14

Waste management	14.83	70.42
Production and personal hygiene	43.28	75.55
Water and ice supply	36.33	72.21
Aquatic health criteria	17.06	77.61
Food handling	24.49	92.32
Handling of chemical substances, disinfectants, and drugs	43.54	86.56
Harvest	41.34	79.96
Training	30.75	67.88
Averages	**35.83 %**	**77.97 %**

Figure 10. COSAES Best Practices compliance, 2012. Percentages correspond to portion of industry meeting standards developed by COSAES to promote lower-disease-risk production practices (COSAES, 2014b).

Though attempts to contact Health committees for this assessment were largely unsuccessful, committees appear to be active. For example:

- COSAES provides annual reports from 2003-2014 that include inspection data, among a range of other useful information on their website (COSAES, 2014b). Newer reporting (2018) is hosted on SENASICA's website.
- In 2018, COSAES reports making 2,569 visits to farms in the region, conducting over 1,100 sampling events at farms, conducting over 300 water/wild organism sampling events, and hosting 6 training events for farmers. A total of 784 records of permits for planting and harvesting were issued (COSAES, 2019a).
- CESASIN, of Sinaloa, is clearly very active in providing health screening and diagnostic services
- CESANAY, the aquaculture health committee of Nayarit describes a stated objectives of carrying out sanitary followup in 586 aquaculture production units as part of its Certification of Aquaculture Facilities program in 2018 (CESANAY, 2018).
- Data gathered by health committees have also been used in published research supporting management of shrimp aquaculture (Hernandez-Llamas *et al.*, 2014; Aguilar-Manjarrez *et al.*, 2017).
- Committees also appear to be active in at least Sinaloa and Baja California Sur (Aguilar-Manjarrez *et al.*, 2017; CESASIN, 2018)(Ana Trasviña, Comite Sanidad Acuicola Baja California Sur, pers. comm. 2019).
- Some committees are actively maintaining their web presence by providing educational and outreach materials on social media sites.

Biosecurity

Some producers make use of nurseries, which offer enhanced biosecurity control for early stages of production. For example, the country has been recognized for a handful of "[recently developed], sophisticated, one and two phase hyper-intensive nursery systems" where newly hatched shrimp spend 3-5 weeks in bio-secure environments (Gervais, 2014). Mexican shrimp hatchery facilities have also been recognized for biosecurity measures to exclude pathogens, though some facilities have weaknesses in their pathogen monitoring program designs due, for example, to lack of comparison groups applicable to analysis (Mendoza-Cano *et al.*, 2016).

Shrimp farmers have been required to stock only Specific Pathogen Free (SPF) shrimp that tests negative for WSSV and TSV and the industry has made major strides in working towards a system using SPF animals (Lightner, 2003). Several hatcheries appear to offer SPF PL (Blue Genetics, 2018; GAM, 2018), and there is evidence that producers are using SPF PL (SEMARNAT, 2012a), however, there are also suggestions that SPF PL may not reach all growers (ASC, 2017, 2019; S. Horton pers. comm. 2020) and while SPF shrimp offer lower risk related to some pathogens, they don't guarantee freedom from all pathogens (e.g. PstDV1; Mendoza-Cano *et al*, 2016). As part of long-term disease risk mitigation, disease resistance, including to WSSV, Taura virus and others, is actively being researched or has been successfully selectively bred for (Castillo-Juárez et al., 2015). A small segment of the industry is also exploring intensive culture designs with more environmental control to combat disease issues like EMS (Shrimpnews.com, 2014).

While the Mexican shrimp industry appears to be making strides in reducing the impact of disease in production, the Mexican shrimp aquaculture industry has been beset by major disease issues--including in recent years. This industry also has a history serving as a vector for the introduction of pathogens from the farm environment to wild populations of shrimp and other taxa, with major impacts to wild populations documented. Despite having made progress in shrimp health and disease management, the industry is a risk for the amplification of pathogens, their release to the surrounding environment, and impacts to wild populations.

Conclusions and final score

The Mexican shrimp industry has a history of introducing and spreading exotic shrimp pathogens around the country and there is evidence that these pathogens have been transmitted to, and have significantly impacted, wild shrimp at the population level (for example wild *L. stylirostrus* shrimp populations in Mexico affected by the IHHN virus). There is ongoing uncertainty with regard to other confirmed transmissions of diseases from cultured stocks to wild ones. Despite management and regulatory improvements, the pattern of disease epidemics occurring at the farm level and the open nature of the production system suggests the likelihood of both disease amplification and transmission to wild populations is an ongoing risk. There is thus a moderate-high risk that disease linked to Mexican shrimp aquaculture will cause population-level impacts to wild shrimp or other marine organisms, and the final numerical score for Criterion 7 – Disease is 2 out of 10.

Criterion 8X: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

- Impact: the removal of fish from wild populations for on-growing to harvest size in farms
- Sustainability unit: wild fish populations
- Principle: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact

Criterion 8X Summary

Source of stock parameters	Score	
C8 Independence from unsustainable wild fisheries (0-10)	0	
Critical?	NO	Green

Brief Summary

Mexican shrimp farming initially utilized wild post-larvae as the main source of stock and later still used them when hatchery-stocks were in short supply, but the industry now relies entirely on hatchery production from 34 hatcheries in the country which produce about 10.5 billion postlarvae annually. It is therefore now considered to be completely independent of wild shrimp populations for broodstock or postlarvae, and the score for Criterion 8X – Source of Stock is a deduction of 0 out of -10.

Justification of Rating

Early shrimp farming operations in Mexico used wild-captured broodstock to produce postlarvae, or extracted postlarvae and juveniles from wild nurseries to be stocked directly into ponds, but the Mexican shrimp industry's heavy focus on developing hatcheries, selective breeding programs, and biosecurity management resulted in the rapid development of hatchery-raised broodstock that produce shrimp with artificially-selected traits favorable to aquaculture—including growth and disease resistance. Mexico has a large number of hatcheries (34) that supply the industry with about 10.5 billion postlarvae annually (Perez-Enriquez *et al.*, 2018). By 2002, at least 90 % of postlarvae were provided by hatchery production (DeWalt *et al.*, 2002), and (Holtschmit and Garmendia, 2009; Perez-Enriquez *et al.*, 2009) reported that all farming operations producing Pacific white shrimp at that time in Mexico used hatchery-raised broodstock as the source for their post-larvae. Hatchery production of PL occurs in both the Gulf of California/Pacific and Gulf of Mexico (Mendoza-Cano *et al.*, 2016).

Conclusions and final score

The Mexican Pacific white shrimp industry relies entirely on hatchery-raised broodstock and postlarvae and is completely independent of wild shrimp populations. The score for Criterion 8X – Source of Stock is a deduction of 0 out of -10.

Criterion 9X: Wildlife and predator mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: aquaculture populations pose no substantial risk of deleterious effects to wildlife or predator populations that may interact with farm sites.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0-10)	**-4**	
Critical?	NO	**Yellow**

Brief Summary

Specific information on wildlife interactions in Mexican shrimp farms is limited, and no data are available on mortality numbers of any species. There is clearly some interaction with predatory and scavenging birds, which present nuisances in the form of product loss and biosecurity risk. The birds most likely to visit a shrimp pond are classified as Least Concern by the IUCN, although a few of these species (such as the gull-billed tern) are believed to be in population declines in part of their range, including Mexico. Farms apparently makes use of non-lethal exclusion strategies, such as human presence and scaring tactics for birds and use of nets and screens to exclude marine organisms from intakes, but there are also (dated and/or anecdotal) references to the shooting of birds, and while this is now illegal, there are no data on the enforcement. There are also suggestions that bird predation is not a significant issue for this industry and that non-lethal management is largely effective. Without more precise information, it is assumed that wildlife mortalities occur beyond exceptional cases, but that population sizes are not significantly affected. The final numerical score for Criterion 9X – Wildlife Mortalities is -4 out of -10.

Justification of Rating

The region containing the bulk of Mexico's shrimp aquaculture, the Gulf of California, is one of the most biologically diverse regions in the world and is its own unique ecoregion. It hosts over 6,000 described macrofaunal species (and probably an equal number of yet-to-be-described species; R. Brusca pers. comm 2019)—including marine mammals, birds, and reptiles as well as fish and shellfish, and contains important breeding grounds for many species of animals, including a wide variety of birds (Páez-Osuna *et al.*, 2003; Brusca et al. 2005; WWF, 2018).

There are no data available on mortality numbers of any species from Mexican shrimp farms. Birds are common visitors to shrimp ponds, potentially in large numbers (Vanpatten *et al.*, 2004), and are considered here to be the most likely animal group to interact with farms. At least 21 species of migratory shorebirds forage on Mexican shrimp pond benthic communities and are of no direct threat to shrimp crops (Navedo *et al.*, 2015), whereas others, including herons, egrets, terns, cormorants, ducks, and gulls present problems for the shrimp farmers by preying upon shrimp, a common problem for shrimp farmers globally (Vanpatten *et al.*, 2004; New *et al.*, 2009; Roshnath *et al.*, 2014; Navedo *et al.*, 2015; Hortomallas Co., 2018). Western gull-billed terns, which have previously been petitioned for U.S. ESA listing (Center for Biological Diversity, 2009), as well as garnering support for Mexican Species at Risk listing (Palacios and Mellink, 2007) have also been documented visiting aquaculture ponds in this region.

A partial inventory of predatory bird species for this region of Mexico includes: great egret (*Ardea alba*), little blue egret (*Egretta caerulea*), snowy egret (*E. thula*), tricolored heron (*E. tricolor*), blackcrowned night-heron (*Nycticorax nycticorax*), yellow-crowned night-heron (*Nyctanassa violacea*), green heron (*Butorides virescens),* cattle egret (*Bubulcus ibis*), roseate spoonbill (*Platalea ajaja*), white ibis (*Eudocimus albus*), wood stork (*Mycteria americana*), neotropic cormorant (*Phalacrocorax brasilianus*), least term (*Sternula antillarum*), royal tern (*Thalasseus maximus)*, and gull-billed tern (*Gelochelidon nilotica*) (Mellink and Riojas-López, 2017) and brown pelican (*Pelecanus occidentalis*)(SENASICA, 2017). Each of these species is classified as Least Concern by the IUCN (IUCN, 2018), though the gull-billed tern has received conservation attention (Palacios and Mellink, 2007; Center for Biological Diversity, 2009). Of these species, cormorants may be a predator of primary concern (Dewalt, 2002) and gulls have been described as an important farm nuisance (Lightner, 2003; Vanpatten *et al.*, 2004; Olachea, 2011; SEMARNAT, 2012a; Roshnath *et al.*, 2014). Birds are reportedly not a major issue for all farms (SEMARNAT, 2012a; ASC, 2017) or all areas (DeWalt *et al.*, 2002), however there are few data indicating the rate of predation or quantity of losses suffered by farms as a result of their presence.

Figure 11. Birds visiting a shrimp pond. From SENASICA (2017).

In addition to birds, fish such as corvina and ronchaco that find their way into shrimp ponds may be a predator issue for some farms, while other species may enter as larvae and later become a competitive nuisance (Valenzuela Quiñónez *et al.*, 2004; SEMARNAT, 2012b; ASC, 2017; SENASICA, 2017). Mortality of such organisms occurs on shrimp farms (Figure 12), though the existence of data on mortalities is not apparent.

Figure 12. Dead marine animals observed following draining of a shrimp pond. From SENASICA (2017).

<u>Regulation and management</u>

Mexican law permits only non-lethal means of controlling predators—such as acoustic and visual deterrents (SEMARNAT, 2014b). Species of conservation concern are additionally protected via NOM-059-SEMARNAT-2010. There is no information readily available on the effectiveness of any enforcement measures for these protections.

Entirely excluding birds from shrimp farms is difficult; instead multiple non-lethal approaches are recommended (Chavez Sanchez and Montoya Rodriquez, 2006; SENASICA, 2017) and are apparently employed (DeWalt *et al.*, 2002; ASC, 2018a). Plastic netting as a deterrent is apparently effective and economical (SENASICA, 2017; Hortomallas Co., 2018), although some level of entanglement mortality is likely. Environmental impact assessments describe the use of other non-lethal deterrents like flagging, ribbons, and fireworks to scare birds (Olachea, 2011; ASC, 2017; SENASICA, 2017) and that the presence of working staff deters birds (SEMARNAT, 2012a; ASC, 2018a). There may also be use of guard dogs as a wildlife deterrence (SENASICA, 2017). In other shrimp producing countries, use of netting is an option where economical and non-lethal scare deterrents (noise-makers, human presence, “scarecrow”-type devices) are often employed (Roshnath *et al.*, 2014). It has been suggested that in practice, non-lethal scaring tactics are a primary management approach in Mexico (DeWalt *et al.*, 2002), though suggestions that shooting may occur also exist (DeWalt *et al.*, 2002; Seafood Watch, 2010), and may even be common (J. Miros-Gomez pers. comm. 2020). Bird predation at shrimp farms may not be a significant issue, however (R. Brusca pers. comm. 2019), suggesting that existing management approaches are largely effective.

Aquatic predators and competitors are managed with excluder screening at pump line, reservoir, and pond intakes (Figure 133) (Valenzuela Quiñónez *et al.*, 2004; SEMARNAT, 2012b; ASC, 2017; SENASICA, 2017)—required for shrimp farms (A. Ruiz-Luna pers. comm. 2019). The Mexican government promotes the use of excluder systems that return organisms to outside waters alive (SENASICA, 2017), though information on the ubiquity and effectiveness of such designs is unavailable and there is clearly some mortality of aquatic animals associated with shrimp aquaculture (SENASICA, 2017).

Figure 13. Exclusion infrastructure at canal intakes. From SENASICA (2017).

There is additional concern that pump intakes can have impacts to local populations of fish and shrimp by accidental destruction of larvae in some places (Álvarez *et al.*, 2001; Valenzuela Quiñónez *et al.*, 2004; Rodríguez-Valencia *et al.*, 2010), though definitive conclusions on the significance of this phenomenon in Mexico are hard to identify.

Conclusions and final score

Specific information on wildlife interactions in Mexican shrimp farms is limited, and no data are available on mortality numbers of any species. There is clearly some interaction with predatory and scavenging birds, which present nuisances in the form of product loss and biosecurity risk. The birds most likely to visit a shrimp pond are classified as Least Concern by the IUCN, although a few of these species (such as the gull-billed tern) are believed to be in population declines in part of their range, including Mexico. Farms apparently makes use of non-lethal exclusion strategies, such as human presence and scaring tactics for birds and use of nets and screens to exclude marine organisms from intakes, but there are also (dated and/or anecdotal) references to the shooting of birds, and while this is now illegal, there are no data on the enforcement. There are also suggestions that bird predation is not a significant issue for this industry and that non-lethal management is largely effective. Without more precise information, it is assumed that wildlife mortalities occur beyond exceptional cases, but that population sizes are not significantly affected. The final numerical score for Criterion 9X – Wildlife Mortalities is -4 out of -10.

Criterion 10X: Escape of secondary species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Impact: aquaculture operations by design, management or regulation avoid reliance on the movement of live animals, therefore reducing the risk of introduction of unintended species.

This is an “exceptional” criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Escape of secondary species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	9	
F10Xb Biosecurity of source/destination	6	
C10X Escape of secondaryspecies Final Score	**-0.40**	**Green**

Brief Summary

The large majority of Mexican shrimp farms are in the northwest of the country and are supplied by PL from hatcheries in the same region. Although the information is not certain, a small amount of production on the Atlantic coast is considered to be supplied by the same hatcheries and therefore represent trans-waterbody movements of live animals across Mexico. The hatcheries supplying the PL are considered to have a low-moderate risk of introducing secondary, unintended organisms during the shipments, and therefore overall, there is a low risk of introducing unintended species in Mexican shrimp production. The final numerical score for Criterion 10X – Escape of secondary Species is -0.4 out of -10.

Justification of Rating

In the past, the Mexican *L. vannamei* aquaculture industry has been implicated as the vector for spreading and introducing pathogens around the country—including to wild populations. For example (as discussed in Criterion 7 – Disease), the import of live shrimp from Central America and Hawaii in the late 1980s was blamed for the introduction of IHHNV (Lightner *et al.*, 1992; Lightner, 2003) which caused population-level impacts to wild shrimp populations in the Gulf of California (Lim and Webster, 2001; Lightner, 2003). The detection of IHHNV and TSV in the Gulf of Mexico in the mid-late 2000s is also linked to shrimp aquaculture, though it is not known if TSV was introduced by the Mexican industry or that in nearby Texas (del Río-Rodríguez *et al.*, 2013; Hernández-Pérez *et al.*, 2017). More recently, *L. vannamei* aquaculture is suggested as the likely vector for the spread of decapod penstyldensovirus (PstDV1) within Mexico, including introduction to the Gulf of Mexico along with non-native *L. vannamei* (Mendoza-Cano *et al.*, 2016). PstDV1 may have impacts on other species of wild shrimp as well, including species considered overfished (*e.g. L. stylirostris*) or vulnerable to overfishing (*e.g. F. aztecus*) (Mendoza-Cano *et al.*, 2016; Seafood Watch, 2017)

Although not ignoring the historic spread of these pathogens due to live shrimp movements, this criterion assesses any ongoing movements (Factor 10Xa) and the biosecurity of their source and destination (Factor 10Xb).

Factor 10Xa International or trans-waterbody live animal shipments

The Mexican shrimp industry is currently supplied by domestic hatcheries producing about 10.5 billion postlarvae annually (Perez-Enriquez *et al.*, 2018), most of which are located in the Northwestern states of Sonora (about 82 % total PL production in 2014) and Sinaloa (about 12 % total PL production in 2014; COSAES 2014). There are also 4 hatcheries in Baja California Sur producing postlarvae (about 6 % in 2014), most of which is sold to producers in Sinaloa and Sonora (Naegel, 2010), and at least 5 hatcheries in the Gulf of Mexico states of Veracruz and Campeche (Mendoza-Cano *et al.*, 2016).

The movement of PL between these hatcheries and growout farms in the same areas are not considered to occur either internationally or between ecologically distinct waterbodies, but despite the five hatcheries on the Gulf of Mexico coast in Veracruz and Campeche, there is some evidence that movements of shrimp across Mexico are occurring from hatcheries on the Pacific coast is (for example see PstDV1 in Criterion 7—Disease)(Mendoza-Cano *et al.*, 2016; A. Wakida-Kusonoki pers. comm. 2019). These states previously relied on hatcheries located on Mexico's west coast and Texas for PL (DeWalt *et al.*, 2002), but the quantity of frequency of current movements is not known.

For the purposes of this assessment (and using a precautionary approach), it is assumed that shrimp farms currently operating on the Gulf of Mexico (Atlantic) coast are sourced on some level by the significant hatchery production of PL on Mexico's west coast (Pacific). Given that 3 % of national shrimp production comes from the Gulf of Mexico coast, but that this region is producing approximately 1 % of PLs nationally, it is assumed for this assessment that 2 % of national production involves the trans-waterbody movement of shrimp. The score for Factor 10Xa is therefore 9 out of 10.

Factor 10Xb Biosecurity of source/destination

<u>Source</u>

Following disease outbreaks in the 1990s, hatcheries improved their biosecurity and moved toward a closed production cycle, reducing or avoiding the introduction of outside organisms such as broodstock (DeWalt *et al.*, 2002). Hatcheries supplying the industry must have a health certificate verifying compliance with biosecurity and testing requirements issued from the state health committee (Government of Sonora, 2017). Extensive details of entire biosecurity and best practice recommendations and requirements are available via state governments (Government of Sonora, 2017), aquaculture health committees (COSAES, 2014b; CESABCS, 2018; CESASIN, 2018), and other institutions (AERI, 2013), covering everything from tank cleaning and water filtration, to disease sampling protocols and pest control (Chavez Sanchez and Montoya Rodriquez, 2006; COSAES, 2012; CESASIN, 2018). For example, Sonora requires that hatcheries filter intake water using a maximum screen size of 50 microns and have a disinfection method such as UV and ozone treatment. There are additional requirements for emergency isolation capacity (such as retention of all water during security vacuum periods; though there are indications that release of pond water is a common disease-response practice (Macías-Rodríguez *et al.*, 2014)). Hatcheries may also use caution in purchasing feeds for shrimp broodstock, acquiring only from trusted sources, to prevent introduction of pathogens.

Mexico requires that PL be certified as Specified Pathogen Free (SPF) before planting in ponds (Lightner, 2003; Naegel, 2010) though SPF only involves testing for specific pathogens and doesn't necessarily guarantee freedom from all potential pathogens; there is also evidence that SPF PLs are not always available to all growers (ASC, 2017). Health committees also certify diagnostic laboratories, offer training in biosecurity, and produce information to aid industry biosecurity practices and there is evidence that testing and inspection by health committees remains active (COSAES, 2012, 2014b; AERI, 2013; Hernandez-Llamas *et al.*, 2014; SAGARPA, 2016; CESASIN, 2018, A. Trasvina pers. comm. 2019).

Overall, the hatcheries that represent the source of live animal shipments are considered to have a low-moderate risk of introducing secondary organisms to live animal shipments and the score for Factor 10Xa is 6 out of 10.

<u>Destination</u>

While growout farms have some biosecurity measures in place aimed at reducing risk of disease outbreaks (Hernandez-Llamas *et al.*, 2014), the high-exchange nature of pond systems that release untreated effluents, and which are also located in flood-prone areas, makes farms a moderate-high risk for escape of unintentionally introduced species, like shrimp pathogens. That shrimp farms have been repeatedly suggested as the source of numerous pathogen introductions is evidence of this risk. The destination scores 2 out of 10 for being high-exchange ponds that don't treat effluent and thus, are high-risk of releasing any secondary organism arriving in a shipment of live shrimp such as PL.

The score for Factor 10Xb is the higher of the two source and destination scores (see the Seafood Watch Aquaculture Standard for more details) and is therefore 6 out of 10.

Conclusions and final score

The large majority of Mexican shrimp farms are in the northwest of the country and are supplied by PL from hatcheries in the same region. Although the information is not certain, a small amount of production on the Atlantic coast is considered to be supplied by the same hatcheries and therefore represent trans-waterbody movements of live animals across Mexico. The hatcheries supplying the PL are considered to have a low-moderate risk of introducing secondary, unintended organisms during the shipments, and therefore overall, there is a low risk of introducing unintended species in Mexican shrimp production. The final numerical score for Criterion 10X – Escape of secondary Species is -0.4 out of -10.

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About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org . The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives" or "Avoid". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch®'s sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

Disclaimer

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

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[4] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:
- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture

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[4] "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving practices for some criteria may lead to more energy intensive production systems (e.g. promoting more energy-intensive closed recirculation systems)

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Appendix 1 - Data points and all scoring calculations

Criterion 1: Data quality and availability

Data Category	**Data Quality (0-10)**
Industry or production statistics	7.5
Management	5
Effluent	7.5
Habitats	7.5
Chemical use	2.5
Feed	2.5
Escapes	5
Disease	5
Source of stock	10
Predators and wildlife	5
Unintentional introduction	7.5
Other – (e.g. GHG emissions)	n/a
Total	**65**

C1 Data Final Score (0-10)	**5.91**	**YELLOW**

Criterion 2: Effluents

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	**4**	**YELLOW**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0-10)	4

Factor 3.2 – Management of farm-level and cumulative habitat impacts

3.2a Content of habiat management measure	3
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	**3.6**

C3 Habitat Final Score (0-10)	**4**	**YELLOW**
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	**Score**

C4 Chemical Use Score (0-10)	**0**	
C4 Chemical Use Final Score (0-10)	**0**	**CRITICAL**
Critical?	YES	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	**Score**
5.1a Fish In : Fish Out (FIFO)	
Fishmeal inclusion level (%)	14
Fishmeal from by-products (%)	0
% FM	14
Fish oil inclusion level (%)	2.25
Fish oil from by-products (%)	0
% FO	2.25
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	2.24
FIFO fishmeal	1.39
FIFO fish oil	1.01
FIFO Score (0-10)	**6.52**
Critical?	NO
5.1b Susutainability of Source fisheries	
Sustainability score	-3
Calculated sustainability ajustment	-0.84
Critical?	NO
F5.1 Wild Fish Use Score (0-10)	**5.68**
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	35
eFCR	2.24
Feed protein from fishmeal (%)	
Feed protein from EDIBLE sources (%)	90.38
Feed protein from NON-EDIBLE sources (%)	9.62
Protein OUTPUTS	
Protein content of whole harvested fish (%)	17.8
Edible yield of harvested fish (%)	45
Use of non-edible by-products from harvested fish (%)	50
Total protein input kg/100kg fish	78.4
Edible protein IN kg/100kg fish	70.86
Utilized protein OUT kg/100kg fish	21.74

Net protein gain or loss (%)	-69.32
Critical?	NO
F5.2 Net protein Score (0-10)	**3**

5.3. Feed Footprint

5.3a Ocean Area appropriated per ton of seafood	
Inclusion level of aquatic feed ingredients (%)	16.25
eFCR	2.24
Carbon required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Ocean productivity (C) for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	9.47
5.3b Land area appropriated per ton of seafood	
Inclusion level of crop feed ingredients (%)	77.75
Inclusion level of land animal products (%)	6
Conversion ratio of crop ingedients to land animal products	*2.88*
eFCR	2.24
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.81
Total area (Ocean + Land Area) (ha)	10.27
F5.3 Feed Footprint Score (0-10)	6

Feed Final Score

C5 Feed Final Score (0-10)	**5.09**	**YELLOW**
Critical?	**NO**	

Criterion 6: Escapes

6.1a System escape Risk (0-10)	1	
6.1a Adjustment for recpatures (0-10)	0	
6.1a Escape Risk Score (0-10)	**1**	
6.2. Invasiveness score (0-10)	**4**	
C6 Escapes Final Score (0-10)	**2**	**RED**
CriticaL?	**NO**	

Criterion 7: Diseases

Disease Evidence-based assessment (0-10)		
Disease Risk-based assessment (0-10)	2	
C7 Disease Final Score (0-10)	**2**	**RED**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	0	
C8 Source of stock Final Score (0-10)	**0**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and predator mortalities

C9X Wildlife and Predator Score (0-10)	**-4**	
C9X Wildlife and Predator Final Score (0-10)	**-4**	**YELLOW**
Critical?	NO	

Criterion 10X: Escape of unintentionally introduced species

F10Xa live animal shipments score (0-10)	9.00	
F10Xb Biosecurity of source/destination score (0-10)	6.00	
C10X Escape of unintentionally introduced species Final Score (0-10)	**-0.40**	**GREEN**
Critical?	n/a	