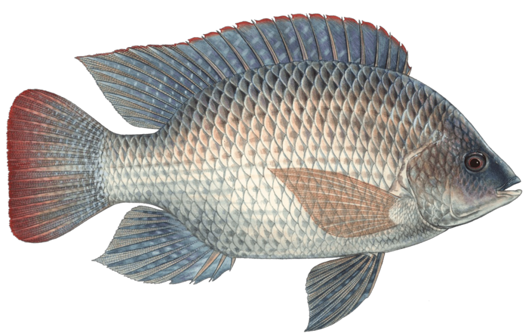
Monterey Bay Aquarium Seafood Watch

Draft Assessment for Review

March 2024

Tilapia

Oreochromis niloticus



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Mexico

Net pens and Pond

Report ID 27845

Seafood Watch Standard used in this assessment: Aquaculture Standard v4

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 Watch Assessment. Each assessment 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." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, 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 assessments 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 Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] 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 farms must possess to be considered sustainable by the Seafood Watch program. Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts available for analysis;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be available for analysis.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms minimize or avoid the production and 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.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g. by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.
7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**

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

Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.

8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites;**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals;**
   Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

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: Buy first, they're well managed and caught or farmed in ways that cause little harm to habitats or other wildlife.

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

Avoid/Red: Don't buy, they're overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Tilapia (Nile) produced in net pens and ponds in Mexico

Criterion	Score		
	Mega Farm (Net Pens)	**Net Pens**	**Ponds**
C1 Data	8.41	5.46	5.23
C2 Effluent	4.00	4.00	4.00
C3 Habitat	7.20	7.20	3.87
C4 Chemical Use	8.00	0.00	0.00
C5 Feed	5.45	4.39	3.86
C6 Escapes	10.00	10.00	6.00
C7 Disease	4.00	2.00	2.00
C8X Source of Stock	0.00	0.00	0.00
C9X Wildlife mortalities	-2.00	-6.00	-6.00
C10X Escape of secondary species	-0.40	-3.20	-3.20
Total	**44.66**	**23.84**	**15.75**
Final score (0-10)	**6.38**	**3.41**	**2.25**

OVERALL RATING

Final Score	**6.38**	**3.41**	**2.25**
Initial rating	Yellow	Yellow	Red
Red criteria	0	2	2
Interim rating	Yellow	Red	Red
Critical Criteria?	0	0	0
Final rating	**Yellow**	**Red**	**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. White text with a black background indicates a Critical score. Two or more Red criteria, or one Critical criterion result in a Red final result.

Summary

The final numerical scores for tilapia produced by the existing mega farm (in net pens), by all other producers in net pens, and by all producers in ponds in Mexico are 6.38 out of 10, 3.41 out of 10, and 2.25 out of 10, respectively. With no Red or Critical criteria, the final recommendation for the existing mega farm is a "Good Alternative." With two Red criteria, the final recommendation for the rest of net pen and pond tilapia producers in Mexico is "Avoid".

Executive Summary

From Mexico's total aquaculture production for human consumption of 286,797.3 metric tons (mt) in 2020, tilapia accounted for 54,941.84 mt or 19.2%, corresponding to less than 1% of global tilapia production. Mexico exported roughly 4,500 mt of tilapia products in 2020, and the vast majority went the U.S. market. There is a substantial appetite for tilapia in Mexico, reflected by being the second-largest tilapia importer globally after the U.S., responsible for 16% of the world tilapia imports (over 86,000 mt in 2018).

Out of the eight tilapia species produced in Mexico through fisheries and aquaculture, the genetically improved farmed tilapia (GIFT) strain of Nile tilapia (*Oreochromis niloticus*), is the baseline genetic lineage in virtually all private hatcheries, making it the most important species farmed in the country. As of 2017, there were a total of 4,623 registered tilapia farms in Mexico, out of which 2,371 were in operation, including ten large-scale enterprises (more than 10 mt of production per year), 400 small and medium-scale farms (between 720 kg and 10 mt of production per year), and 1,961 subsistence farms (less than 720 kg production per year).

Subsistence farms, which predominantly employ ponds and tanks as their production system, constitute nearly 60% of the total aquaculture production units (UPAs) in Mexico. These farms have a production capacity of less than 0.5 mt per year per farm. Small-scale farmers make up 25% of tilapia UPAs and primarily utilize tanks as their production system. Their production capacity ranges from 0.6 to 50 mt per year per farm. Medium-scale farmers account for 15% of tilapia UPAs, while large-scale farmers represent only 0.5%. Medium-scale farmers' production capacity ranges from 51 to 500 mt per year per farm, while large-scale farmers produce between 500 and 10,000 mt annually.

Tilapia aquaculture in Mexico is primarily conducted in net pens located in water reservoirs, and in ponds and tanks near freshwater sources. Although net pens contribute to the majority of the volume produced, ponds and tanks represent the majority of aquaculture production units spread across the country. While a significant proportion of subsistence farms and small-scale producers opt for tank-based production systems, their production output appears to be notably less when contrasted with tilapia production in ponds. As such, for the scope of this evaluation, the focus will primarily be on ponds as the chosen production system under examination, alongside net pens. Relevant information pertaining to tank-based production systems, where applicable, will be integrated into the pond assessment and delineated accordingly.

As of the date of this report, Acuagranjas Dos Lagos SA de CV, owned by Regal Springs, is the sole producer in Mexico exceeding 10,000 mt per year and falls under the classification of a mega farm, as described by Martinez-Cordero et al. (2021). Henceforth, the term "existing mega farm" will be employed to refer to Regal Springs within the subsequent sections of the report. There may be occasional exceptions in instances where it becomes necessary to explicitly mention the company's name.

Medium, large, and mega-scale tilapia farmers predominantly adopt floating cages as their production system. The top five cage culture operations collectively possess a total production capacity of 36,000 metric tons per year, representing approximately 65% of the total aquaculture-produced tilapia in Mexico in 2020 (Martinez-Cordero 2021; CONAPESCA 2020).

The assessment involves criteria covering impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability.[1] In Mexico, net pen production systems are widely utilized across many farms, but as mentioned before, the existing mega farm is by far the largest. Identifying specific production characteristics of tilapia farms in the country can be challenging. However, publicly available audit reports from the certification of the existing mega farm to the Aquaculture Stewardship Council offer a wealth of information regarding this company's production practices. It is important to note that the score for Criterion 1 - Data is substantially higher for the existing mega farm compared to other assessed systems. Therefore, apart from the general net pen recommendation (and the recommendation for ponds), a separate and specific overall recommendation is provided to tilapia produced by the existing mega farm in Mexico for many of the criteria assessed in this report. It should be noted that Seafood Watch also has separate recommendations for farmed tilapia certified to various assurance schemes. See Seafood Watch information on certified seafood here[2].

Data availability for Mexican tilapia farming is highly variable by topic and by production system. 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). In the case of the existing mega farm, the additional information available through publicly available ASC audits provides more certainty to evaluate most of the criteria assessed here. Overall, the quality and quantity of information for the existing mega farm is moderate-high and scores 8.41 out of 10; and for the rest of producers is moderate and scores 5.46 out of 10 for net pens and 5.23 out of 10 for ponds.

The analyses presented here found no clear relationship between the level of tilapia production and the water quality indicators at the reservoir and state levels. While there are contradictory findings with respect to water quality and trophic level analysis, the INAPESCA's carrying capacity studies suggest that the largest tilapia-producing reservoirs in Mexico (Malpaso and Peñitas) operate below their estimated carrying capacities, as do other reservoirs such as La Angostura, and El Infiernillo. INAPESCA's studies also conclude that Malpaso, Peñitas, and La Angostura reservoirs classify as oligotrophic to mesotrophic based on the modified Toledo index. There is evidence that aquaculture production is not permitted in reservoirs that exceed their carrying capacity for reasons unrelated to aquaculture. The largest producer operating in both Malpaso and Peñitas reservoirs (the existing mega farm), complies with all of ASC's water quality requirements, which is also indicative of the level of impacts generated by the tilapia industry in Chiapas, as many active producers share these two water bodies. There are no discernible trends indicating that higher tilapia production in certain reservoirs leads to poorer water quality compared to others, perhaps due to the many other nutrient inputs and nutrient dynamics in the lakes, particularly agriculture and municipal wastes. The cascading arrangement of reservoirs does not result in pollution accumulation or worsening water quality as anthropogenic inputs increase. However, there is an increasing trend in the biological and chemical oxygen demand for the Malpaso reservoir (from 2012 to 2020), and official data derived from CONAGUA's BOD and COD samples in 2020, underscore

[1] The full Seafood Watch Aquaculture Standard is available at:
http://www.seafoodwatch.org/seafoodrecommendations/

our-standards

[2] https://www.seafoodwatch.org/recommendations/certified-seafood

the recurrent classification of "contaminated" for La Angostura, Chicoasen, and Malpaso reservoirs on multiple occasions; with the Malpaso reservoir exhibiting contamination in as much as 38% of the BOD samples. Moreover, nutrient inputs in tilapia production reservoirs in Chiapas, and the analyzed data for total nitrogen and phosphorus suggest higher trophic levels than those previously reported. For instance, in 2020 there was a high proportion of total nitrogen samples classified as eutrophic (as high as 30 and 70% for La Angostura and Malpaso, respectively) and hypereutrophic (as high as 70 and 80% for La Angostura and Chicoasen, respectively) for the four reservoirs in Chiapas. Similarly, the four reservoirs resulted in considerable proportions of total phosphorus samples classified as eutrophic (as high as 45 and 57% for Chicoasen and La Angostura, respectively) and three reservoirs as hypereutrophic (as high as 38% for Chicoasen). Therefore, it is determined that tilapia aquaculture results in temporary contributions to regional cumulative impacts. These temporary impacts generated by tilapia production in net pens may extend to other regions in the country. Overall, the score for Criterion 2—Effluent for net pens is a moderate score of 4 out of 10.

Without sufficient data to understand the effluent impacts (or lack thereof) of pond farms, the risk-based assessment was used. Considering the available information on typical feed and fertilizer use, it is estimated that there is a total nitrogen input of 122.8 kg N/mt of tilapia (a value slightly higher to that stated in an independent certification audit of a net pen producer). After the removal of nitrogen in harvested tilapia, the total waste nitrogen produced is 100.4 kg N per mt. Approximately half of this is considered to be discharged from the ponds to the environment (51.2 kg N/mt, and a score of 4 out of 10 for Factor 2.1). The application process for aquaculture discharge permits in Mexico is thorough and involves coordination among multiple agencies. The comprehensive nature of this process, combined with monitoring efforts by CONAGUA, indicates that the cumulative impacts of aquaculture producers, as well as other industries and municipal waste, are taken into account during the permit approval process. However, the uptake of the necessary permits remains low, and the majority of tilapia farms continue to operate without complying with the legal requirements. The costs associated with achieving compliance continue to pose a significant challenge for most tilapia producers. Thus, with low effective enforcement, the effluent management score (Factor 2.2) is 3.2 out of 10 for ponds. The scores combine to give a final score for Criterion 2—Effluent of 4 out of 10 for ponds.

The habitat impacts associated with floating net pens in artificial environments, such as reservoirs, are generally considered to be limited. However, considering their number and distribution, it is still likely that these net pens have some degree of impact on the remaining ecosystem services provided by these waterbodies, but it is considered here to be minimal. The Habitat Conversion and Function score (Factor 3.1) for net pens is 9 out of 10. For pond farms, the available evidence indicates that the majority of farms in Mexico have been built in low value habitats (e.g., former agricultural land or scrubland), and there are unlikely to be substantial cumulative habitat impacts such as fragmentation due to the generally dispersed nature of the farms. However, habitat impacts have also been observed to riparian forests and other forest areas, which are considered moderate-value habitat, and overall, this results in a final score of 4 out of 10 for Factor 3.1 - habitat conversion and function score concerning ponds.

The management of tilapia production in reservoirs and ponds is governed by interconnected legislations such as the General Law of Sustainable Aquaculture and the Fisheries General Law of Ecological Balance and Environmental Protection. There appears to be strong coordination between agencies involved in the permitting process. However, it is evident that the existing regulations are not adequately designed to address the loss of ecosystem services, and they have limitations in terms of their effectiveness. Furthermore, while enforcement efforts aimed at protecting habitat exist and the responsible institutions are identifiable and contactable, the issue of cumulative impacts is not adequately addressed. The Farm Siting Regulation and Management score (Factor 3.2) is 3.6 out of 10 for net pens and ponds. The final score for Criterion 3 — Habitat for net pens is 7.2 out of 10, and for ponds is 3.9 out of 10.

The increasing scale and intensity of production have led to the emergence of diseases as a common and severe problem in global tilapia aquaculture, including in Mexico, introducing the potential for veterinary medicines and treatments. Ten products are specifically listed for use in fish in Mexico: four antimicrobials, one antiparasitic treatment, four vaccines, and one hormone, but there are no readily available data with which to understand their use in Mexico's tilapia farms. Despite a lack of readily available data, experts suggest that pharmaceutical treatments are utilized to control diseases, and academic studies suggest it is common. For example, a recent survey of 40 farms in the Malpaso reservoir indicated more than three-quarters used antimicrobials. In addition, one of the state-level Aquaculture Health Committees reported the use of streptomycin, which is not authorized in Mexico, and raises concerns about their illegal use. Therefore, although regulations and best management practices are apparent, they may not be followed in practice, which poses both environmental risks and economic losses for producers. While there is no evidence of prophylactic antimicrobial use in Mexico, the metaphylactic use of antimicrobials to treat entire populations remains prevalent. The rejection of imported shrimp from Mexico by the United States Food and Drug Administration due to drug residue violations indicates potential illegal antimicrobial use in the shrimp industry in Mexico, but no rejections have been reported for tilapia products.

Additionally, Mexico, like other low- and middle-income countries, has been linked to higher levels of antimicrobial-resistant bacteria, including in tilapia farming. Antimicrobial-resistant genes have been isolated in tilapia, and the presence of these genes is associated with the use of specific antimicrobials. The use of antimicrobials in aquaculture poses environmental challenges, as residues can accumulate in sediments and contribute to the selection of antimicrobial-resistant species and genes, impacting natural ecosystems. However, a definitive link between antimicrobial use in aquaculture and the development of resistance in bacterial populations has yet to be established.

Although there is considerable circumstantial information available, the frequency and scale of chemical use in Mexico's tilapia farms is essentially unknown regarding the specific data (or lack thereof) from the thousands of farms. Circumstantial evidence indicates that antimicrobials highly and critically important for human medicine are being used in unknown quantities, resulting in a final score for Criterion 4—Chemical Use of 0 out of 10, for ponds and net pens (excluding the existing mega farm). In contrast, the existing mega farm does have good data availability through third-party audits from the Aquaculture Stewardship Council, and has only used one antimicrobial treatment since 2015 (in 2022). Therefore, chemical use is considered to be less than once per production cycle, and the final score for the existing mega farm for Criterion 4—Chemical Use is 8 out of 10.

Specific data on the composition of tilapia feeds are limited. Given the importance of robust data to the outcomes of this criterion, attempts were made to contact feed companies and access feed data through the Federal Committee of Animal Feeds and Nutrition (CONAFAB), but none of these efforts were successful. The available information indicates that fishmeal and fish oil levels are low and the feeds are dominated by crop ingredients across production systems. The fish meal and fish oil values were considered to be higher in pond feed based on the limited information available and a necessary precautionary approach. The feed conversion ratios may vary according to the production system, but without better data, the estimated eFCRs considered in this assessment are as follows: for the existing mega farm an eCFR of 2.0 was obtained through third party ASC-certification audit reports, but without specific details for the rest of producers in Mexico, an average value obtained through the literature of 1.6 was used. General aquaculture literature indicates that the use of by-product sources for fishmeal and fish oil might be substantial, but with the limited specific information available for Mexican tilapia feeds, a 20% inclusion was assigned to the existing mega farm (based on ASC audit reports), but no by-product inclusion was considered for the rest of producers. The Forage Fish Efficiency Ratio (FFER) is estimated at 0.80, 0.64, and 0.86 for the existing mega farm, net pen, and ponds producers, respectively. Using pond production as an example, this FFER value means that, from first principles, 0.86 mt of wild fish must be caught to supply the fish oil to grow 1 mt of tilapia. Again, this value varies across farms and production systems. The source fisheries for the marine ingredients used by the existing mega farm are listed in ASC audit reports, and can be seen to be moderately sustainable, and the Wild Fish Use score is 6.90 out of 10. Due to the unknown source of fisheries for the marine ingredients used by several feed manufacturers, the Wild Fish Use for rest of tilapia producers in Mexico, scores are 4.77 for net pens and 3.72 for pond producers. Based on four feed company websites and on four additional references reporting on Mexico tilapia feed protein levels, the averaged feed protein content over a production cycle used in this assessment is 30%. With a whole tilapia protein content of 14% (and the eFCRs considered in this assessment), there is a substantial net loss of protein (-76.67% for the existing mega farm and -70.83% for net pen and pond producers, resulting in a score of 2 out of 10 for all producers). The feed footprint calculated as the embedded climate change impact (kg CO2-eq) resulted in an estimated kg CO_2-eq per kg of farmed seafood protein 14.58, 14.37, and 14.16 for the existing mega farm, net pen, and pond producers, respectively. These values are equivalent to a score of 6 out of 10 for all production systems. The three scores combine to give final scores for Criterion 5—Feed of 5.45 out of 10 for the existing mega farm; 4.39 for net pens; and 3.86 for ponds (See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Net pen aquaculture systems for tilapia carry a high risk of escape, but best practices for escape management, including the use of all male or sterile fish, are considered widespread. Similarly, ponds are also likely to be at risk of flooding or other fish losses during production (e.g., if ponds are drained at harvest). While the existing mega farm's net pens still entail a high risk of escape, the producer has implemented an escape containment plan and a comprehensive net inspection program, which are monitored through ASC audits and reported publicly. While there are no data available on escapes events in Mexico or on post-escape recaptures; the potential impacts are reduced when the species has been historically introduced and continue to be actively stocked into the environment, especially for net pen producers which mainly operate in the same reservoirs that have been actively stocked up until recent years (2020). Tilapia were strategically introduced to Mexico by the government to enhance inland fisheries during the 1960s and 1970s, and since then, it appears several species became established in the wild across the country. Although this occurred before the large-scale development of the aquaculture industry took place, it is likely that aquaculture introductions (and subsequent escapes) increased the range of tilapia in Mexico. Hence, tilapia, including the dominant farmed Nile tilapia species, are considered fully established in Mexico for the purposes of this assessment, but partly due to aquaculture. The potential habitat effects and impacts on native biota resulting from aquaculture escapes are considered by SEMARNAT during the evaluation of project proposals and are integral to the EIA approval process. Nonetheless, it remains unclear if there is an ongoing potential for tilapia to be introduced to additional waterbodies in Mexico where they are not yet present. The final escape criterion score is based on the interaction of the risk of escape (Factor 6.1; scores of 4 of 10 for the existing mega farm and pond producers, and 2 out of 10 for the rest of net pen producers) and the risk of competitive and genetic interactions with wild species (Factor 6.2; score of 10 out of 10 for all net pen producers and 9 out of 10 for pond producers in Mexico). This results in a final score for Criterion 6—Escapes of 10 out of 10 for all net pen producers and 6 out of 10 for pond producers.

Despite being recognized for its inherent disease resistance, tilapia is susceptible to various infectious and noninfectious diseases, particularly as global and Mexican production intensifies. Major diseases affecting cultured tilapia in the Americas include gram-negative and gram-positive bacteria, fungi, parasites, and copepods. While there are several studies of the diseases affecting cultured tilapia in the country, information around how these diseases are impacting wild populations, is not readily available. Both net pens and pond farms are considered to be "open" to the environment, in terms of the potential for amplification of pathogens within them and the subsequent release of those pathogens into waters shared with wild fish. Although some biosecurity measures and best practices have been established (by the government's National Service of Health, Safety, and Agri-Food Quality), their level of implementation among farms is uncertain. An exception here is the existing mega farm, for which the publicly available ASC audit reports document the implementation of the company's biosecurity protocols. While some of literature suggests that disease prevalence and mortality positively correlate with the intensity of production, this cannot be confirmed, as diseases and parasites have been detected throughout the country regardless of the production level associated with each region. There is a demonstrable risk that pathogens will be amplified on farms and wild fish in the vicinity of farms will be exposed to them, but the potential impacts to wild fish populations remain uncertain. The limited amount of data, particularly on the potential impacts to wild fish, means that the risk-based assessment has been used (the Data Criterion score for the disease section is <7.5 out of 10). The known pathogen and parasitic transfer risk to wild species, the openness of the production systems, the unknown level of implementation and enforcement of biosecurity regulations and management measures, plus the registered events with high disease-related mortality rates, result in a final score for Criterion 7—Disease for both net pens and ponds (excluding the existing mega farm) of 2 out of 10. The existing mega farm's final score for Criterion 7—Disease (net pens) is 4 out of 10, based on the company's documented implementation of biosecurity protocols, but also on the fact that their production system is still open to the introduction and discharge of pathogens and parasites.

Tilapia strains used in aquaculture have been domesticated for decades; for example, Watanabe et al. (2002) describe the process to develop red tilapia stocks in the 1980s, along with the domestication of Nile tilapia. After the first seeds of Tilapia were imported from Auburn University in Alabama in 1964, it probably didn't take long for producers to become fully dependent on public and local hatcheries for their seed supply. This reliance on hatcheries has persisted in the industry up to the present day(Martinez-Cordero, 2021; ATT Innova, 2015). Also, as a non-native species, if any "wild" tilapia from Mexico were used as broodstock, they would not be included in the scoring of this criterion (i.e., there would not be any sustainability concerns with their capture and use). Therefore, Mexico's tilapia culture is considered to be fully independent of wild fish stocks, and the score for the exceptional Criterion 8X is a deduction score of 0 out of –10.

Detailed information on wildlife interactions in Mexican tilapia farms remains scarce, and there is a lack of data regarding the mortality numbers or population impacts (or lack thereof) of any species resulting from these interactions. Nevertheless, the widespread distribution of tilapia farms across diverse ecosystems in the country suggests that some degree of interaction between tilapia farming and wildlife is inevitable. Notably, Chiapas, the primary region for tilapia production in Mexico, harbors at least eleven species of ecological concern. Although non-lethal exclusion strategies, such as human presence, bird scaring tactics, and the use of nets to prevent avian entry into net pens or ponds, are apparently employed by these farms, dated and anecdotal evidence suggests that bird shooting might have been practiced, despite being illegal. According to third-party audits conducted on the existing mega farm, no registered wildlife mortalities have been reported, and the company has implemented a wildlife interaction plan. Based on these factors, it can be inferred that wildlife mortalities on this specific farm are likely limited to exceptional cases, such as accidental incidents. Therefore, the final numerical score for the existing mega farm for Criterion 9X – Wildlife Mortalities is -2 out of -10. In the case of other net pen and pond producers, the available information is not specific enough to draw definitive conclusions. It was determined that regulation and management practices for non-harmful exclusion and control are in place, but the enforcement and mortality numbers are unknown. Therefore, the final numerical score for Criterion 9X – Wildlife Mortalities for the net pen and pond producers is -6 out of -10.

The spread of pathogens such as tilapia lake virus and helminths, and introductions of new species of aquatic plants are examples of unintentional introductions of non-native species during movements of live tilapia or other fish species into and within Mexico. Although tilapia fingerlings were previously known to be shipped into Mexico from hatcheries in the U.S., Panama, United Kingdom, Vietnam, and Cuba, the current scale of this practice is unclear. The development of hatcheries in the main tilapia-producing states of Mexico is likely to have reduced such international movements substantially. The importation of smaller numbers of selectively bred tilapia broodstock from breeding centers elsewhere likely continues, but is now accompanied by quarantine and inspection requirements at the port of entry. This assessment is therefore based on the movements of tilapia within Mexico. Although there are 29 hatcheries, the broad distribution of farms means that there are considered to be substantial transwaterbody movements of tilapia produced in net pens and ponds (estimated to be 70-80% of production and a score of 2 out of 10 for Factor 10Xa). In contrast, publicly available audit reports from the existing mega farm show that their hatcheries are all located in close proximity to the growout location (and therefore <10% of the existing mega farm's production is considered to be based on transwaterbody movements and a score of 9 out of 10 for Factor 10Xa). Although the sources of live animal movements have some potential for biosecurity (e.g., reduced or zero water exchange, along with quarantine and monitoring), the movements of tilapia into and within Mexico continue to present a risk of unintentionally introducing non-native species, and the score for Factor 10Xb is 6 out of 10. The final score for Criterion 10X—Escape of Unintentionally Introduced Species is a deduction of –0.4 out of –10 for the mega farm, and –3.2 out of –10 for the rest of net pen and pond producers in Mexico.

The final numerical scores for tilapia produced by the existing mega farm (in net pens), by all other producers in net pens, and by all producers in ponds in Mexico are 5.98 out of 10, 2.69 out of 10, and 2.25 out of 10, respectively. With no Red or Critical criteria, the final recommendation for the existing mega farm is a "Good Alternative." With two Red criteria, the final recommendation for the rest of net pen and pond tilapia producers in Mexico is "Avoid".

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species
Redbreast tilapia, Nile tilapia, Blue tilapia, Mozambique tilapia, Wami tilapia (*Coptodon rendalli, Oreochromis niloticus, O. aureus, O. mossambicus, O. urolepis*) (INAPESCA 2018).

Geographic Coverage:
Mexico.

Production Method(s)
Freshwater net pens
Freshwater ponds

Species Overview

Tilapia, Sarotherodon, and Oreochromis genera are all commonly known as tilapia and are freshwater fish belonging to the Cichlidae family (ASFIS – species item). They are a fast-growing tropical species native to Africa, introduced into other tropical, subtropical, and temperate world regions over the second half of the 20th century (El-Sayed 2020). While only ten countries dominate 90 percent of global tilapia production, it is farmed in over 120 countries and territories, making it one of the most popular species produced in aquaculture (FAO 2018). Their ability to ingest a wide variety of natural foods like plankton, aquatic macrophytes, planktonic and benthic invertebrates, larval fish, and decomposing organic matter substantially reduces feeding costs for farmers. Tilapia can also survive dissolved oxygen (DO) concentrations of less than 0.3 mg/L, considerably below other cultured species' limits. Compared to most other cultured species, tilapia are more resistant to viral, bacterial, and parasitic diseases (Popma and Masser, 1999). Additionally, they can survive in broader ranges of pH (5 to 10), ammonia (as high as 3 mg/L), and nitrite (89 mg/L) while also being able to tolerate waters with up to 25 parts per thousand (ppt) (Boyd, 2004; Popma and Masser, 1999). However, one problematic constraint when cultivating tilapia is their low-temperature tolerance, typically lethal when exposed to 50 to 52° F water for several days. Tilapia generally stop feeding when the water temperature drops below 63° F.

Nile tilapia (*Oreochromis niloticus)* has been predominant in the wide variety of tilapia species produced by aquaculture, contributing about 75 percent of global tilapia production in 2018 (Martinez-Cordero 2021). Accordingly, out of the eight tilapia species produced in Mexico through fisheries and aquaculture, the genetically improved farmed tilapia (GIFT) strain of Nile tilapia, which was imported from Norway in 2007, is the baseline genetic lineage in virtually all private hatcheries, making it the primary and most important species farmed in the country, and the one considered in this assessment (Osiap[2], no date; Martinez-Cordero 2021).

Production system
From the 1970s to 2010, Mexico's federal or state-owned hatcheries provided tilapia fingerlings free of charge to farmers. However, the shortage of high-quality tilapia seed supply allowed private hatcheries

[2] https://osiap.org.mx/senasica/sites/default/files/Peces%20y%20crustaceos.pdf

to join the value chain, making free seeds obsolete. Still, 27 public hatcheries remain operational, accounting for 11% of total fingerling production. The 41 private hatcheries in the country account for the remaining 89% of fingerling production (Martinez-Cordero 2021). Thanks to the application of 17α-methyltestosterone, a sex reversal technology introduced to Mexico from the U.S. in 1997, producers now obtain monosex seed (> 95% male tilapia), which reduces the growth period for a 500 g fish from 8-9 months to 5-6 months and mitigates breeding in the culture environment (Martinez-Cordero 2021). While this is the most common method to prevent overpopulation and stunting, it has become controversial due to its indiscriminate use and possible accumulation of synthetic hormones in waterbodies (see Criterion 4 – Chemical Use) (Alcántar-Vázquez et al. 2014). Alternatives have been adopted at a country level, like manually separating sexes based on visual examination, hybridizing species that produce all-male offspring, and most recently, the breeding of super-males (YY-males) with normal females (XX) to obtain 100% male populations (XY) (Alcántar-Vázquez et al. 2014).

As of 2017, there were a total of 4,623 registered tilapia farms in Mexico, out of which 2,371 were in operation, including ten large-scale enterprises (more than 10 metric tons (mt) of production per year), 400 small and medium-scale farms (between 720 kg and 10 mt of production per year), and 1,961 subsistence farms (less than 720 kg production per year) (Martinez-Cordero 2021).

Mexico's tilapia farmers use multiple production systems depending on scale. For instance, earthen ponds and plastic tanks with extensive or semi-intensive culture techniques are the most common farming system, widely adopted by micro/subsistence farms. Subsistence farms may represent up to 50 percent of producers in rural areas, yet they are usually not included in official statistics because they are unregistered or unauthorized operations (Ortega-Mejia et al., 2023; Martinez-Cordero 2021). These farmers mostly rely on natural feeds, such as plankton, water lentils (*Lemna sp*.), or water spinach (*Ipomoea aquatica*), and are usually located in warmer areas. Depending on site characteristics and capital availability, farmers either use soil bottoms, cover bottoms with polyethylene liners, or invest in stone/cement banks. Subsistence farms constitute nearly 60% of the total aquaculture production units (UPAs) in Mexico and have a production capacity of less than 0.5 mt per year per farm (Martinez-Cordero 2021). Farmers harvest tilapia after four months when they reach an average weight between 150 and 250 g, resulting in three crops per year. Of subsistence farmers' total production, about 30% is destined for self-consumption, and the rest is sold locally. States in southern Mexico are well suited to pond and tank aquaculture due to freshwater availability, but they are also subject to a relatively high flooding risk (Martinez-Cordero 2021). Even though pond and tank culture is not limited to the country's southern geographic conditions, farmers must have relatively easy access to water sources like rivers, lakes, or springs. All the other operations categories (small to large farms) also feature farmers using ponds and tanks but to a lower degree than micro-farms. When larger farms adopt these production systems, they usually increase stocking densities using formulated feed and aeration equipment.

Small farmers account for 25% of tilapia UPAs in Mexico, and their production capacity ranges from 0.6 to 50 mt per year per farm. In this case, the most common production system is earthen ponds and plastic tanks. In the case of plastic tanks, these would typically consist of a circular geomembrane ranging from 9 m (small operations) to 25 m (large operations) in diameter and around 1.2 m in depth. In this system, farmers usually use aeration and water pumps to maintain higher stocking densities, ranging from 7 to 15 kg fish/m^3. Tilapia reach harvest size (300-500 grams) after six months, allowing farmers to have two crops per year. Due to increased energy consumption, the higher operational cost makes this business model more suitable for niche markets demanding a greater quality product, such as restaurants and retail stores (Martinez-Cordero 2021).

As of the date of this report, Acuagranjas Dos Lagos SA de CV, owned by Regal Springs, is the sole producer in Mexico exceeding 10,000 mt per year and falls under the classification of a mega farm, as described by Martinez-Cordero et al. (2021). Medium, large, and mega-scale tilapia farmers predominantly adopt floating cages as their production system. The top five cage culture operations collectively possess a total production capacity of 36,000 metric tons per year, representing approximately 65% of the total aquaculture-produced tilapia in Mexico in 2020 (Martinez-Cordero 2021; CONAPESCA 2020).

Medium-scale farmers account for 15% of tilapia UPAs, and large-scale farmers represent only 0.5%. While medium-scale farmers' production capacity ranges from 51 to 500 mt per year per farm, large-scale farmers produce between 500 and 10,000 mt annually (Martinez-Cordero 2021). The most common floating cages used by these type of producers are squared or rectangular shaped, with dimensions ranging from 3 by 3 meters to 12 by 12 meters of surface area and 6 to 7 meters in depth (ATT innova, 2015). The top five cage culture operations have a total production capacity of 36,000 mt per year, equivalent to 65% of the total aquaculture produced tilapia in Mexico in 2020 (Martinez-Cordero 2021; CONAPESCA 2020). The need for aeration and water pumps is minimal and usually limited to the hatchery production stage, though manufactured pellet feeds are applied at every stage. Farmers can increase their stocking density and harvest size to 15 to 30 kg fish/m3 and 500 to 1000 grams, respectively, and still have two crops per year. In Mexico, 180 dams have created reservoirs with a total water capacity of 127,372 m^3, making the country suitable to adopt this large-scale technology. The Mexican government also supports the sustainable farming of tilapia in the 1.25 million ha of brackish water coastal lagoons accessible in the country. However, cage farming in coastal habitats remains a concern because of possible environmental impacts caused by escapees. Additionally, producers face operational challenges, including shallow depths, lack of water flow, high water temperature, and variable climate conditions (Martinez-Cordero 2021).

Production Statistics

Global tilapia production in 2021 was 6.3 million mt and has increased at an average rate of 7.7% per year from 2010 to 2019 (FAO FishStatJ, 2023; Tveteras et al. 2019). In 2018, FAO data positioned Mexico as the 13th largest producer of cultured tilapia, with roughly 52,700 mt, corresponding to 0.87% of global production. In Mexico, tilapia is also known as mojarra, and is harvested both from capture fisheries ad aquaculture. According to national statistics, the country produced an average of 140,647 mt per year from 2013 to 2020, of which aquaculture accounted for an annual average of 49,284.19 mt per year, equivalent to 34.5% of the total output (Figure 1) (CONAPESCA 2020). Tilapia was responsible for 21% of Mexico's 247,000 mt of aquaculture production in 2018, making it the second-largest aquaculture commodity after whiteleg shrimp (Martinez-Cordero 2021). All 31 states of Mexico, plus Mexico City, produce tilapia through capture fisheries or aquaculture. From 2016 to 2020, the top eight aquaculture-producing states by volume were Chiapas, Campeche, Jalisco, Veracruz, Nayarit, Tabasco, Sinaloa, and Sonora, in ranking order (CONAPESCA 2020). Accordingly, these eight states also accounted for over three-quarters of the country's tilapia seed production capacity in 2018 (Martinez-Cordero 2021). It is noteworthy that although production statistics were derived from official data sources, the credibility of national statistics has been subject to scrutiny due to insufficient data validation procedures to identify errors and inconsistencies. Consequently, caution should be exercised when undertaking analyses based on these statistics (Ortega-Mejia et al., 2023).

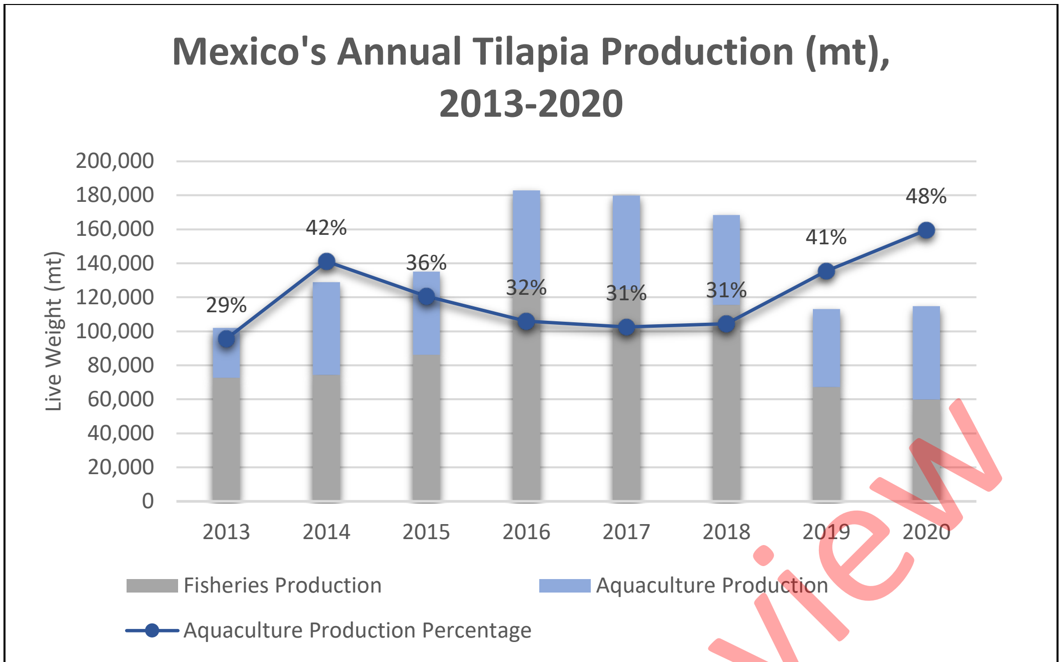

Figure 1. Total (captured and cultured) and aquaculture tilapia production in Mexico 2013-2020. Source CONAPESCA 2020.

Chiapas' preeminence in tilapia production is mainly due to hosting the only existing mega farm in the country, an international tilapia of producer and as mentioned before, the largest in Mexico, which generated nearly half of the cultured tilapia in the country in 2018, with around 25,000 mt produced in floating cages (Martinez-Cordero 2021). Out of the approximately 30,000 mt produced in Chiapas in 2020, 19% was consumed locally, and the rest was almost entirely destined for the domestic market, mainly consumed in the states of Tabasco and Veracruz (INIFAP, 2021). Even though Sonora occupies 8th place in production by state, it hosts the second largest cage producer, Acuicola GEMSO, with 8,000 mt of production capacity per year (CONAPESCA 2020) (Martinez-Cordero 2021).

Import and Export Sources and Statistics

According to FAO statistics (2021), Mexico's tilapia imports have increased since 2015, from 51,056 mt to 85,157 mt in 2019 (See Table 1). The highest imported quantity was recorded in 2018, accounting for 14% of the country's total value of aquatic imported products (Martinez-Cordero 2021). That same year, Mexico was the second-largest tilapia importer globally after the U.S., responsible for 16% of the world tilapia imports tonnage. Almost the entirety of imports came from China and were primarily composed of frozen fillets (92%) and frozen whole tilapia (8%), based on import value (Martinez-Cordero 2021).

Table 1. Imports and exports of Mexico's tilapia, 2013-2019. FAO 2021.

	Imports and exports of Mexico's 'fresh, chilled, frozen' tilapia whole fish and fillets (aggregated mt)						
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Imports	52,046	51,644	51,056	66,251	64,790	86,170	85,157
Exports	1,320	4,168	4,480	3,170	3,078	2,984	4,440

Mexico's tilapia exports experienced a steady decline from approximately 4,480 mt (fresh and frozen weight) in 2015 to 2,984 mt in 2018 (See Table 1). However, exports ramped back up to 4,440 mt in 2019 (FAO 2021). On average, the difference between Mexico's tilapia exports reported by FAO and the U.S. imports of tilapia from Mexico reported by NOAA Foreign Trade is 6% from 2013 to 2019; therefore, it is safe to assume that the vast majority of the tilapia exported from Mexico went the U.S. market. This trade consists primarily of whole frozen tilapia and fresh fillets (Figure 2).

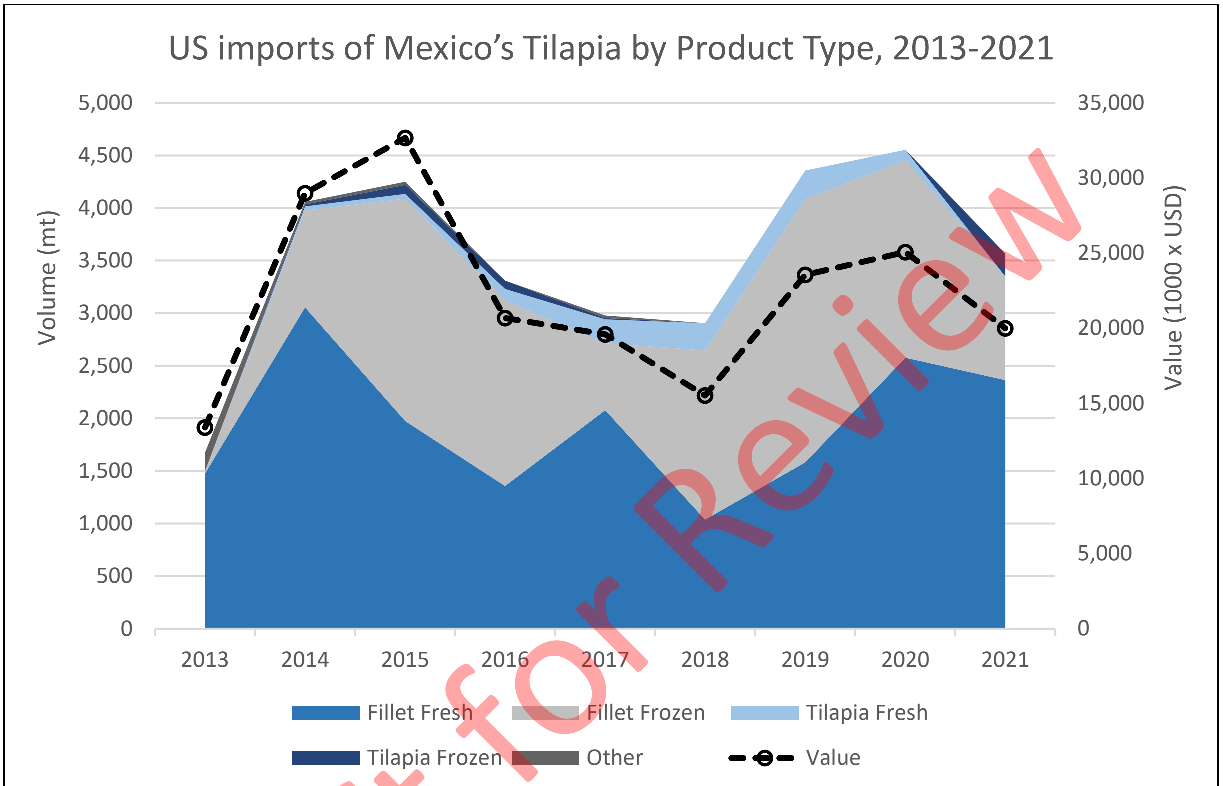

Figure 2. US imports of Mexico's farmed tilapia products in volume (mt) and total annual traded value (black-dotted line - 1000 x USD) (NOAA Foreign Trade, 2022).

Based on the total trade volume (mt) reported in Figure 2 and on conversion factors described in EUMOFA 2019, Mexico exported on average, 17.8% of its total tilapia aquaculture production from 2013 to 2020. Mexico's exports accounted for 1 percent (in value) of the country's total aquatic products exported in 2018 (with a value of USD 15.5 million) (Martinez-Cordero 2021) (NOAA Foreign Trade 2022). Regal Springs is the largest single exporter to the U.S. (Martinez-Cordero 2021).

Analysis

Scoring guide

- With the exception of the exceptional factors (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional factors result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available here http://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/2015%20standard%20revision/mba_seafoodwatch_aquaculture%20criteria_final.pdf?la=en
- The full data values and scoring calculations are available in Appendix 1

Criterion 1: Data

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.
- *Unit of sustainability:* The ability to make a robust sustainability assessment
- *Principle:* Having robust and up-to-date information on production practices and their impacts available for analysis.

Criterion 1 Summary

Data Category	Data Quality		
	Mega farm	**Net pens**	**Ponds**
Industry or production statistics	10	10	10
Management	10	5	5
Effluent	7.5	7.5	5
Habitat	7.5	7.5	7.5
Chemical use	7.5	2.5	2.5
Feed	7.5	2.5	2.5
Escapes	7.5	5	5
Disease	5	5	5
Source of stock	10	10	10
Wildlife mortalities	10	2.5	2.5
Introduction of secondary species	10	2.5	2.5
C1 Data Final Score (0–10)	**8.41**	**5.46**	**5.23**
	Green	**Yellow**	**Yellow**

Brief Summary

Data availability for Mexican tilapia farming is highly variable by topic and by production system. 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). In the case of the existing mega farm, the additional information available through publicly available ASC audits, coupled with details shared through personal communication provides more certainty to evaluate most of the criteria assessed here. Overall, the quality and quantity of information for the existing mega farm is moderate-high and scores 8.41 out of 10; and for the rest of producers is moderate and scores 5.46 out of 10 for net pens and 5.23 out of 10 for ponds.

Industry and production statistics
Production statistics are available from the United Nations Food and Agriculture Organization (FAO) (through 2021) data base, and from a FAO-report elaborated in coordination with researchers in Mexico, published in 2021 (Martinez-Cordero et al., 2021). Moreover, the Mexican federal government, through its National Commission on Aquaculture and Fisheries[3], regularly publishes state and national tilapia production levels up to 2020. Additional production data are accessible through published literature (e.g. Tveteras et al. 2019; INIFAP, 2021). Pertinent information concerning production systems, including typical farm sizes, is also available from these sources (e.g., Martinez-Cordero et al., 2021). For a more localized perspective, state-level information, and in some cases, information at the individual farm level (e.g., farm locations, contact details, and offered products) can be obtained from the National Service for Health, Safety, and Quality of Agro-foods (SENASICA) and State organizations such as aquaculture health committees. Publicly available Environmental Impact Assessments and carrying capacity studies provide additional specifics (e.g., Romero-Beltran et al., 2021), as does some information gleaned from 3rd-party (Aquaculture Stewardship Council) environmental audits (ASC, 2022) and interviews with individuals familiar with the industry. The information gives a reliable presentation of the industry's production, and with a third-party thorough report available (Martinez-Cordero et al., 2021), the data score is 10 out of 10 for all producers.

Management and Regulations
Regulatory information pertinent to the Mexican tilapia industry is accessible through government websites and published literature. While website links to regulatory agencies may offer specific details on their work, it is important to note that some links may not function, and the available information may not always be up to date or may lack context regarding the methodology or data reported (e.g. COSAES and CESANAY's reports on diseases). Additional information can be sourced from technical documents and academic papers, which compile lists of relevant legislation and often indicate the degree of enforcement. An illustration of this is evident in the carrying capacity studies available for water reservoirs in Chiapas (Romero-Beltran et al., 2021). Notably, although dated, SENASICA's publication of the Best Practice Tilapia Manual in 2008 also provides guidance for producers to navigate the regulatory framework in Mexico. 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. Despite these sources, substantial uncertainty remains about the content and particularly the application and enforcement of the various regulations and management practices in Mexican tilapia farms. The third-party ASC audits plus the willingness to share requested information provided additional insights into on-farm practices for the existing mega farm in the country. As such, the data score for management and regulations is 7.5 out of 10 for the existing mega farm, and 5 out of 10 for the rest of net pen and pond producers.

Effluent
For net pens, estimates of annual production (CONAPESCA, 2020) can be compared with valuable information included in carrying capacity studies carried-out for various water reservoirs in Mexico, particularly in the most significant net pen growing region, Chiapas (e.g., Romero-Beltran et al., 2021; INIFAP, 2021; Romero-Beltran et al., 2020; Hernandez-Acuayte et al., 2018; and ATT Innova, 2015). The National Water Commission (Comisión Nacional del Agua, CONAGUA) has played a crucial role in

[3] https://www.gob.mx/conapesca/documentos/anuario-estadistico-de-acuacultura-y-pesca

assessing water resource quality through an extensive monitoring network (see Figure 4). This monitoring effort has been instrumental in evaluating the impact levels of effluents from net pen farms operating in water reservoirs. Overall, the data score for Effluent in net pens is 7.5 out of 10.

However, addressing the impacts of effluents from tilapia ponds poses challenges due to the lack of available literature or data in this area. Additionally, the wide distribution of tilapia ponds across the country (see Figure 13) makes it impractical to apply CONAGUA's water quality data. Consequently, specific data to understand the impact (or lack thereof) of effluents from ponds are not available. As a result, estimates of nutrient inputs are derived from feed conversion ratios (e.g., from Hasan et al., 2019) and fertilizer inputs (e.g., SAGARPA, 2012; FAO, 2009). Through official sources and published literature, a typical water exchange range for tilapia pond-farms has been determined (e.g., Guzman-Luna et al., 2021; INAPESCA, 2018; Ortega, 2017). While the management measures outlined by CONAGUA, such as norms CONAGUA-02-001, CONAGUA-02-002, and CONAGUA-01-006, are well-intentioned and comprehensive, the available literature strongly suggests that enforcement measures concerning aquaculture effluents are not effectively implemented (e.g., Guzman-Cesar, 2014; Perevochtchikova and Andre, 2013; and FAO, 2009). Therefore, the Effluent data score for ponds is 5 out of 10.

Habitat

There are several official sources of information and published literature that contribute to an understanding of the habitat impacts associated with both net pen and pond production systems in Mexico. Regarding net pens, Mexico features a considerable number of large inland water bodies suitable for tilapia culture in net pens (Martinez-Cordero, 2021; CONAGUA, 2017). It is worth noting that while dams have undeniably contributed to human development and yielded notable benefits, they also represent highly modified artificial environments. As a result, the impacts produced by aquaculture net pen production do not directly affect the natural environment (Martinez-Yrizar et al., 2012). Nevertheless, research has shown that net pens and their associated structures actually enhance habitat complexity (McKindsey, 2011). Carrying capacity studies have been instrumental in understanding how tilapia aquaculture affects the functionality of these artificial habitats and the ecosystem services that water reservoirs provide (e.g., Romero-Beltran et al., 2021; INIFAP, 2021; Romero-Beltran et al., 2020; Hernandez-Acuayte et al., 2018; and ATT Innova, 2015). Although fully comprehending the habitat impacts of floating net pens in artificial reservoirs remains a challenge, the data score for Habitat, considering all net pen producers, is 7.5 out of 10.

To comprehensively assess the impacts of pond production, several mapping resources from official sources and the literature have been crucial in identifying the location of farms and the extent of land used for tilapia farming, as well as evaluating the effectiveness of regulations (i.e., CONAPESCA, accessed June 2023; INEGI, accessed June 2023; SENASICA, 2020). Furthermore, the historical image function of Google Earth Pro has proven to be a valuable tool in understanding the former habitats of pond farms. Publicly available Environmental Impact Assessments provide a wealth of detailed information, shedding light on various aspects of habitat impacts. Regulations aimed at habitat protection are accessible through government websites, and scientific literature offers insightful commentary on these 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 for ponds is 7.5 out of 10.

Chemical Use

There do not appear to be any readily available data on chemical use in Mexico, and no academic studies could be found that robustly defined their use (or non-use). Personal communication with experts in the industry, official reports, and published literature suggest that pharmaceutical treatments are employed in Mexico to control diseases and raised concerns about their unregulated use among a significant portion of producers (pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; pers. comm., Anonymous, Asia-Pacific Economic Cooperation, April 2023; Velazquez, 2022; Todo Tilapia, 2021; Ortega et al., 2017). The federal entity regulating the use of antimicrobials or veterinary drugs, SENASICA, provided a list of registered chemicals for aquaculture; however, SENASICA confirmed that there was no data available on the volume or frequency of their use (pers. comm., SENASICA representatives, May 2022). The only specific data points available from tilapia farms in Mexico are the audit reports of the existing mega farm certified by a third party (ASC, 2022). Furthermore, state-level Aquaculture Health Committees are responsible of monitoring chemical usage and diseases within the aquaculture sector, and inform the available results to the public (COSAES[4]; CESASIN[5]; CESAJ [6]; CESANAY[7]; accessed May 2023). However, it is noteworthy that the websites of these committees are frequently unavailable, and the limited information provided through the accessible websites appears to be unreliable. The lack of detailed and contextual information regarding the reported data raises concerns about the accuracy and completeness of the information provided. The academic literature contains several references to developed antimicrobial resistance (i.e., Hossain et al., 2022; Velazquez, 2022; Soto-Rodriguez, 2013). Given that the existing mega farm discloses the types of chemicals used, their frequency, and quantity, through publicly available third-party audit reports, this producer receives a Data score for Chemical Use of 7.5 out of 10. Due to the lack of data availability, the Data score for Chemical Use is 2.5 out of 10 for the rest of net pen and pond producers.

Feed

Several attempts to acquire information on tilapia feeds directly from nine Mexican feed companies were unsuccessful. As tilapia aquaculture is significant at the global scale, published literature on feeds is available, though specific on detail readily applicable to Mexican tilapia production is limited to the audit reports of the existing mega farm certified to the Aquaculture Stewardship Council (ASC). Specific to Mexico, there are publications suggesting the use of local reduction fisheries for fishmeal and fish oil used in aquaculture feed, but no linkages between these species and tilapia feed were able to be made. The feed companies' websites provide some useful information, mainly around protein inclusion, but provide no details for ingredients. It is important to note that to enhance the accuracy of calculations and prevent the reliance on averages and aggregated data, additional specific details concerning the existing mega farm's diets were necessary, but were not disclosed. Therefore, the existing mega farm receives a Data score for Feed of 7.5 out of 10; and the rest of net pen and pond producers receive a Data score for Feed of 2.5 out of 10.

Escapes

General academic references establish the fundamental risks of escape from aquaculture systems, but there are no specific data on escape events from net pens or pond farms in Mexico. The regulatory requirements addressing the potential habitat effects and impacts on native biota resulting from aquaculture escapes are clearly established by SEMARNAT and are integral to the EIA approval process

[4] https://www.cosaes.org/nosotros
[5] https://cesasin.mx/conocenos/
[6] https://osiap.org.mx/senasica/sector-estado/jalisco/Acuicola
[7] https://cesanay.org/cesanay/nosotros/

(DOF, 2014; SEMARNAT, 2002). The EIA also requires producers to account for flooding risks in their evaluation, and there was published literature and a mapping tool available to inform around flooding risks in Mexico (i.e., Vazquez-Vera and Chavez-Carreno, 2022; CENAPRED, accessed July 2023). Regarding the invasiveness of tilapia, the history of the introduction and establishment in Mexico is documented (e.g., Gracida-Juarez, 2020; Aguilar-Moreno and Aguilar-Aguilar, 2019; Esselman and Schmitter-Soto, 2013; Martin et al., 2010). Overall, despite a lack of specific escape data, the circumstantial evidence gives a moderate understanding of the ongoing risk. The data score for Escapes is 7.5 out of 10 for the existing mega farm, and 5 out of 10 for the rest of net pen and pond producers.

Disease

There is a substantial global literature on diseases in farmed tilapia, and there are some useful official reports and academic studies in Mexico (e.g., CESANAY's website, accessed in May 2023; Velazquez, 2022; COSAES, 2020; Ortega et al., 2016 and 2018; Soto-Rodriguez, 2009; or Soto-Rodriguez, 2013); which mostly inform about occurrence, prevalence, and effects of disease issues with this industry. Even with state-level aquaculture health committees operating in Mexico, practical information on the occurrence and severity of disease outbreaks (e.g., mortality rates) is limited. While best management practices for tilapia's disease prevention are not directly addressed in legislation, they are covered in the Best Practice Tilapia Manual. However, the level of adherence to these guidelines by producers remains uncertain. The existing mega farm's implementation of biosecurity protocols is evident, as they comply with the required standards set by the ASC certification process. There is some information on the impacts of disease transmission from farmed stocks to wild (e.g., Alcantara-Jauregui, 2022; Garcia-Prieto et al., 2022; Garcia-Vasquez et al., 2021 and 2017; Soto-Rodriguez, 2013); but it is still deemed as incomplete, given that the extent of disease transmission and its impact on wild populations is not well-documented. With substantial general (global) information on tilapia diseases, but limited specific and ongoing information from Mexico, particularly concerning wildlife impacts resulting from disease transmission, the data score for the Disease criterion is 5 out of 10 for all producers.

Source of Stock

It has been established for many decades that the tilapia used in aquaculture is domesticated, and no longer relies on wild caught broodstock or fry to supply the needs of hatcheries, nurseries, and grow-out farms. For example, 20 years ago, Watanabe et al. (2002) describe the domestication of Nile tilapia and the development of the red tilapia strains that occurred in the 1980s. Published literature confirms that reliance on hatcheries has persisted in the industry in Mexico up to the present day (Martinez-Cordero, 2021; ATT Innova, 2015). Thus, the data score for the Source of Stock is 10 out of 10 for all producers.

Wildlife Mortalities

Data availability for wildlife mortalities in Mexico is quite limited. Other than for the existing mega farm, there is no additional farm-level records of wildlife mortalities for the other production systems assessed here. Some information on typical species of relevance is available from ASC audit reports (e.g., ASC, 2022), from which checks can be made against the IUCN Red List, but these few examples cannot be considered relevant to the thousands of farms in Mexico. Some information and visual examples of the use of predator nets are available, but again cannot be extrapolated to typical practices. The use of only non-lethal means of controlling predators are permitted in aquaculture, and SEMARNAT requires producers to list the species present in their production area through the EIA process (e.g., SEMARNAT, 2014; The General Law of Wildlife, 2021). However, there is high uncertainty around the effectiveness of enforcement measures for these protections. With third-party audits reporting no mortalities and no use of lethal predator controls (ASC, 2022), the existing mega farm’s data score for Wildlife Mortalities is

10 out of 10. The data availability score for Wildlife Mortalities is 2.5 of 10 for the rest of net pen and pond producers.

Introduction of Secondary Species

Examples of nonnative species introductions during live fish movements in Mexico are available in Mendoza-Alfaro et al. (2021) and SENASICA (2020). Various reports provide some information on potential live fish movements into and within Mexico, including the status of domestic hatchery production, but they are far from conclusive (e.g., Martinez-Cordero et al., 2021; INAPESCA, 2003). The regulations clearly establish the requirement of a pre-approved health and safety certificate from SENASICA, for movement within Mexico, or for imported aquatic living organism. Also, a couple of official norms (NOM-010-PESC-1993 and NOM-011-PESC-1993) provides some basic information on the quarantine requirements for the import of live fish into Mexico. While the existing mega farm did not provide additional information about their hatchery biosecurity protocols, they stated that they operated their own hatchery within the same state as their growout sites. Additionally, the ASC audits confirmed the implementation of biosecurity protocols at growout locations and the complaint use of transport containers with no escape paths for fish. Hence, the data score for the Escape of Unintentionally Introduced Species for the existing mega farm is 7.5 out of 10. The data score for the Escape of Unintentionally Introduced Species for the rest of net pen and pond producers is 2.5 out of 10.

Conclusions and final score

Data availability for Mexican tilapia farming is highly variable by topic and by production system. 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). In the case of the existing mega farm, the additional information available through publicly available ASC audits provides more certainty to evaluate most of the criteria assessed here. Overall, the quality and quantity of information for the existing mega farm is moderate-high and scores 8.64 out of 10; and for the rest of producers is moderate and scores 5.46 out of 10 for net pens and 5.23 out of 10 for ponds.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- *Impact:* Aquaculture species, production systems and management methods vary in the amount of waste produced per unit of production. The combined discharge of farms, groups of farms or industries contribute to local and regional nutrient loads.
- *Unit of sustainability:* The carrying or assimilative capacity of the local and regional receiving waters
- *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

Net Pens

Effluent Evidence-based assessment

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

Ponds

Effluent Risk-based assessment

C2 Effluent Final Score (0-10)	**Value**	**Score**
F2.1a Waste (nitrogen) production per of fish (kg N ton–1)	100.4	
F2.1b Waste discharged from farm (%)	51.2	
F2.1b Boundary adjustment (0–1)	0.0	
F2.1 Waste discharge score (0–10)		4
F2.2a Content of regulations (0–5)	2	
F2.2b Enforcement of regulations (0–5)	4	
F2.2 Regulatory or management effectiveness score (0–10)		3.2
C2 Effluent Final Score (0–10)		**4**
Critical?	No	**Yellow**

Brief Summary

The analyses presented here found no clear relationship between the level of tilapia production and the water quality indicators at the reservoir and state levels. While there are contradictory findings with respect to water quality and trophic level analysis, the INAPESCA's carrying capacity studies suggest that the largest tilapia-producing reservoirs in Mexico (Malpaso and Peñitas) operate below their estimated carrying capacities, as do other reservoirs such as La Angostura, and El Infiernillo. INAPESCA's studies also conclude that Malpaso, Peñitas, and La Angostura reservoirs classify as oligotrophic to mesotrophic based on the modified Toledo index. There is evidence that aquaculture production is not permitted in reservoirs that exceed their carrying capacity for reasons unrelated to aquaculture. The largest producer operating in both Malpaso and Peñitas reservoirs (the existing mega farm), complies with all of ASC's water quality requirements, which is also indicative of the level of impacts generated by the tilapia industry in Chiapas, as many active producers share these two water bodies. There are no discernible trends indicating that higher tilapia production in certain reservoirs leads to poorer water quality compared to others, perhaps due to the many other nutrient inputs and nutrient dynamics in the lakes, particularly agriculture and municipal wastes. The cascading arrangement of reservoirs does not result in pollution accumulation or worsening water quality as anthropogenic inputs increase. However, there is an increasing trend in the biological and chemical oxygen demand for the Malpaso reservoir (from 2012 to 2020), and official data derived from CONAGUA's BOD and COD samples in 2020, underscore the recurrent classification of “contaminated” for La Angostura, Chicoasen, and Malpaso reservoirs on multiple occasions; with the Malpaso reservoir exhibiting contamination in as much as 38% of the BOD samples. Moreover, nutrient inputs in tilapia production reservoirs in Chiapas, and the analyzed data for total nitrogen and phosphorus suggest higher trophic levels than those previously reported. For instance, in 2020 there was a high proportion of total nitrogen samples classified as eutrophic (as high as 30 and 70% for La Angostura and Malpaso, respectively) and hypereutrophic (as high as 70 and 80% for La Angostura and Chicoasen, respectively) for the four reservoirs in Chiapas. Similarly, the four reservoirs resulted in considerable proportions of total phosphorus samples classified as eutrophic (as high as 45 and 57% for Chicoasen and La Angostura, respectively) and three reservoirs as hypereutrophic (as high as 38% for Chicoasen). Therefore, it is determined that tilapia aquaculture results in temporary contributions to regional cumulative impacts. These temporary impacts generated by tilapia production in net pens may extend to other regions in the country. Overall, the score for Criterion 2—Effluent for net pens is a moderate score of 4 out of 10.

Without sufficient data to understand the effluent impacts (or lack thereof) of pond farms, the risk-based assessment was used. Considering the available information on typical feed and fertilizer use, it is estimated that there is a total nitrogen input of 122.8 kg N/mt of tilapia (a value slightly higher to that stated in an independent certification audit of a net pen producer). After the removal of nitrogen in harvested tilapia, the total waste nitrogen produced is 100.4 kg N per mt. Approximately half of this is considered to be discharged from the ponds to the environment (51.2 kg N/mt, and a score of 4 out of 10 for Factor 2.1). The application process for aquaculture discharge permits in Mexico is thorough and involves coordination among multiple agencies. The comprehensive nature of this process, combined with monitoring efforts by CONAGUA, indicates that the cumulative impacts of aquaculture producers, as well as other industries and municipal waste, are taken into account during the permit approval process. However, the uptake of the necessary permits remains low, and the majority of tilapia farms continue to operate without complying with the legal requirements. The costs associated with achieving compliance continue to pose a significant challenge for most tilapia producers. Thus, with low effective enforcement, the effluent management score (Factor 2.2) is 3.2 out of 10 for ponds. The scores combine to give a final score for Criterion 2—Effluent of 4 out of 10 for ponds.

Justification of Ranking
Mexico's aquaculture industry (inclusive of all species) is experiencing growth, particularly in net pen production, which offers advantages such as utilizing existing water bodies, lower capital investment, and relatively simple technologies (Romero-Beltran et al., 2021). However, this type of production leads to direct nutrient discharges, primarily nitrogen and phosphorus, due to uneaten feed waste and fish excretion (Romero-Beltran et al., 2021). These nutrients can disrupt the water ecosystem, increasing the risk of eutrophication, algal blooms, reduced oxygen availability, and elevated concentrations of organic matter and metals (Romero-Beltran et al., 2021).

Considering that Chiapas is the largest tilapia-producing state in Mexico, accounting for approximately 66% of total aquaculture production in 2019 and 2020, and that most of the production in the state occurs in net pens within four water reservoirs, the findings in Chiapas can be considered representative of the industry's net pen production (Martinez-Cordero, 2021; CONAPESCA, 2020). Therefore, for net pens, this assessment focuses on the effluent impacts studied in Chiapas while also considering water quality at the state level, prioritizing data from the eight most productive states for tilapia production (Chiapas, Veracruz, Jalisco, Campeche, Michoacan, Nayarit, Tabasco, and Sonora) which collectively contribute over 85% of total aquaculture production during the assessed period (2012-2021) (CONAPESCA, 2020).

In Mexico, pond production systems are utilized by aquaculture producers ranging from micro or "resource-limited aquaculture" farmers with annual production volumes of less than 0.5 mt, to large-scale farmers generating over 500 mt per year (Martinez-Cordero et al., 2021). However, ponds predominantly serve as the primary production system for micro to small-scale farmers, constituting nearly 4,000 aquaculture production units distributed across various geographical regions in Mexico, including hills, flat lands, coastal areas, forests, suburban regions, and other locations with convenient access to water sources such as rivers, lakes, or springs (Martinez-Cordero et al., 2021). Furthermore, a significant proportion of these farmers operate without official registration, making it challenging to ascertain their specific locations and evaluate the potential impacts of their effluents (Ortega-Mejia et al., 2023; Martinez-Cordero et al., 2021).

With sufficient data and information to understand the nutrient dynamics of tilapia aquaculture in net pens in Mexico, the evidence-based assessment has been used. But, with limited information on the impacts (or lack of impacts) from tilapia pond effluents, the risk-based assessment has been used. Net pens and ponds are assessed separately below.

Effluent: Net Pens

Net pen production in Chiapas is primarily concentrated within four interconnected water reservoirs along the Grijalva River – starting with the reservoir at the highest elevation La Angostura, it then connects to Chicoasen, followed by Netzahualcoyotl (Malpaso), and Peñitas (see Figure 3) (Pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; INIFAP, 2021). Among these reservoirs, Malpaso and Peñitas account for the vast majority of Chiapas tilapia's total production, fluctuating around 60% and 40%, respectively (ASC, 2022; Romero-Beltran et al., 2021; INIFAP, 2021). The exact production volumes in the La Angostura and Chicoasen reservoirs were not specified in the available references. The estimation of carrying capacity for fish farming in these aquatic environments is important in mitigating potential adverse effects on water quality. However, it is worth acknowledging the complex nature of this task, given the existence of other anthropogenic nutrient sources, including agricultural, livestock, mining, municipal, and industrial discharges, as highlighted by Romero-Beltran et al. (2021). Consequently, evaluating the hydrological dynamics and water quality of these bodies of water over time emerges as a viable approach, by better understanding the nutrient dynamics and facilitating the determination of their trophic level status.

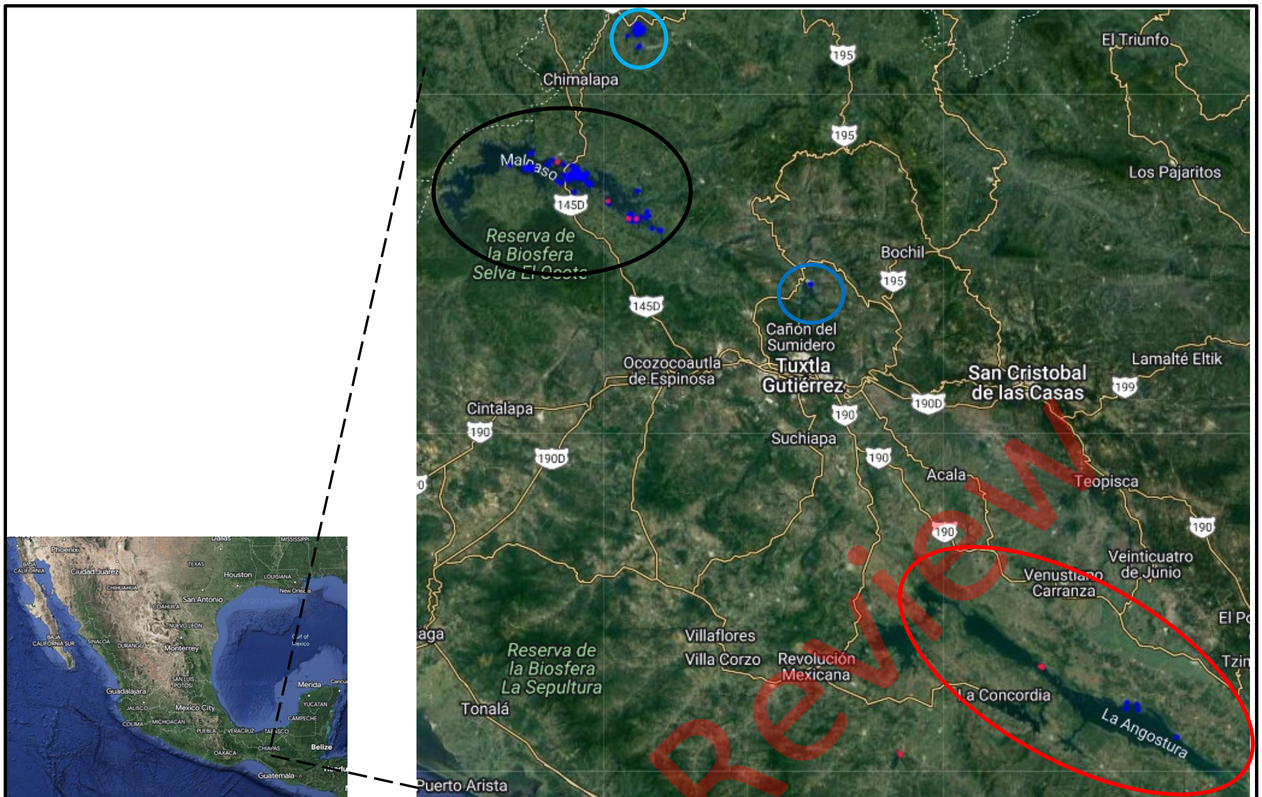

Figure 3. Water reservoirs producing tilapia in Chiapas, Mexico, and approved aquaculture concession (blue dots) and concessions waiting for approval (red dots). Light blue circle shows location for Peñitas reservoir, black circle for Malpaso (Nezahualcoyotl), dark blue for Chicoasen, and red circle for La Angostura.

INAPESCA conducted studies during 2020 and 2021 to identify suitable areas for aquaculture (UPAs) and estimate the ecological and physical carrying capacity for Malpaso, Peñitas, and La Angostura reservoirs (Roman-Beltran, et al., 2021, 2020a, and 2020b). The environmental parameters considered in these studies are included in Table 2 and encompass bathymetry (depth), hydrology (currents and water flow), dissolved oxygen concentration, temperature, total nitrogen, ammonia concentrations, total phosphorus, pH levels, total suspended solids, chlorophyll (Clα), and turbidity. The findings led INAPESCA to conclude that the three reservoirs classified as oligotrophic to mesotrophic based on the modified Toledo index presented in Table 3. Additional information and carrying capacity estimates for each reservoir are described ahead. However, it is important to consider the contradictory analysis shown in Figure 7, which suggests the presence of eutrophic and hypereutrophic nutrient enrichment levels across the three reservoirs (i.e., for nitrogen and phosphorous).

Table 2. Ranges and averages of water quality parameters for Malpaso, Peñitas, and La Angostura Reservoirs, as reported in INAPESCA's carrying capacity studies conducted in 2020 and 2021(Roman-Beltran, et al., 2021, 2020a, and 2020b).

	Malpaso		Peñitas		La Angostura	
Parameter	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**
Dissolved oxygen (mg/L)	2.00 – 13.00	8.26	4.90 – 11.30	4.25	2.00 – 11.00	4.50
Temperature (ºC)	22.0 – 33.0	26.7	23.0 – 25.0	24.0	25.0 – 32.0	26.9
Total nitrogen (mg/L)	0.00 – 0.90	0.30	0.18 – 2.60	1.33	0.00 – 0.88	0.43
Ammonia (NH3) concentration (mg/L)	0.000 – 0.034	0.006	0 – 0.036	0.022	0 – 0.065	0.002
Total phosphorus (P) (mg/L)	0.008 – 0.060	0.016	0.008 – 0.035	0.018	0.008 – 0.030	0.009
pH	6.00 – 9.30	8.50	8.55 – 8.69	8.61	7.90 – 8.40	8.10
Total suspended solids (mg/L)	24.0 – 130.0	39.7	24.0 – 130.0	NA	24.0 – 230.0	37.0
Chlorophyll (Clα) concentration (µg/L)	0.00 – 15.00	3.48	0.00 – 11.00	3.48	0.00 – 23.00	3.80
Turbidity (m)	0.1 – 2.5	1.4	0.6 – 1.6	1.2	0.2 – 3.1	2.1
Current velocity (m/s)	0.02 – 0.14	0.07	0.00 – 0.30	0.05	0.01 - 0.34	0.08

Table 3. Trophic level classification thresholds of tropical freshwater bodies based on nitrogen, phosphorus, and chlorophyll-a concentrations, and turbidity, based on the modified trophic Toledo index (IET).(Romero-Beltran et al., 2021a; LCWA[8], accessed, June 2023).

Classification	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorophyll a (µg/L)	Turbidity (m)
Oligotrophic	< 0.40	< 0.026	0.52 - 3.81	7.7 - 2.0
Mesotrophic	0.41 – 0.60	0.027 – 0.052	3.82 - 10.34	1.9 - 1.0
Eutrophic	0.6 1– 1.50	0.053 – 0.211	10.35- 76.06	0.9 - 0.3
Hypereutrophic	> 1.51	> 0.211	>76.06	< 0.3

Malpaso reservoir spans a total area of approximately 30,759 ha and is geographically delimited by the Central Depression to the west, the South Sierra Madre to the south, and the Central Highlands to the north (Romero-Beltran, 2021; ATT Innova, 2015). The water depth in the reservoir ranges from 2 to 72 m with an overall average of 32.6m (Romero-Beltran, 2021). The reservoir's hydrological balance results in a low annual water exchange rate of 0.34 and an extended residence time of 2.9 years (Roman-Beltran, et al., 2021). The total water capacity is slightly higher than 8,000 hm^3, but the viable water capacity to continue operations is 5,000 hm^3, which is an indicator of high-water usage for this reservoir (Romero-Beltran, 2021). In 2015, tilapia production in Malpaso reservoir involved the use of 1,253 cages, roughly producing more than 20,000 mt, and covers a surface area of 572 ha (ATT Innova, 2015; CONAPESCA 2021). The average stocking density in these cages is approximately 15 kilograms per cubic meter (INIFAP, 2021).

The water quality parameters for the Malpaso reservoir were obtained across 10 sampling sites by personnel from INAPESCA during the months of July and November in 2019 and February in 2020, and are presented in Table 2. Dissolved oxygen levels ranged from 2.00 to 13.00 mg/L, with an average of 8.26 mg/L, which was better than those observed in two other reservoirs (Peñitas = 4.25 mg/L and La Angostura = 4.5 mg/L). Upon comparing Malpaso's parameters with the trophic level index thresholds developed by Carlson (1977) and modified by Toledo (1983) and outlined in Table 3, it becomes apparent that the upper values within the ranges for total nitrogen, total phosphorus, and chlorophyll a concentrations (0.9 mg/L, 0.06 mg/L, and 15 µg/L, respectively), fall under the eutrophic classification; and turbidity (0.1 m) falls under the hypereutrophic classification. However, when considering the reported averages for total nitrogen, total phosphorus, and chlorophyll-a concentration (0.3, 0.016, and 3.48, respectively), these fall within the oligotrophic classification. The average turbidity (1.4 m) aligns with the mesotrophic classification. Additionally, concentrations of ammonia and phosphorus reported by the existing mega farm closely align with figures reported by INAPESCA (pers. comm., Regal Springs representative, September 2023; Roman-Beltran et al., 2021). For instance, the annual average ammonia concentration fluctuated around 0.006 mg/L from 2018 to 2023, with an overall six-year average of 0.0065 mg/L, consistent with INAPESCA's reported average of 0.006 mg/L. Similarly, while some of the highest reported phosphorus concentration levels between 2018 and 2022 by the existing mega farm classify under the eutrophic or hypereutrophic trophic level (as per Table 3), all the annual averages fall within the oligotrophic and mesotrophic classification (pers. comm., Regal Springs representative, September 2023). In light of the reported environmental parameters, it is evident that the Malpaso reservoir maintains favorable water quality conditions across all assessed sites.

To compute the physical carrying capacity of the Malpaso reservoir, INAPESCA integrated the environmental parameters using a Geographic Information System. Worth noting that INAPESCA's carrying capacity assessment identified phosphorus as the limiting nutrient. The study determined that the phosphorus concentration before any fish introduction into the reservoir was 0.0137 mg/L, which aligns with oligo-mesotrophic conditions according to the modified Toledo index (see Table 3). INAPESCA indicates that an additional 1,230 mt of phosphorus would be required to transition the Malpaso reservoir from an oligotrophic to a mesotrophic classification. The study considered a feed conversion ratio (FCR) of 1.6 and a phosphorus content in feeds of 0.84%, which results in the introduction of 5.201 kg of phosphorus into the environment for every metric ton of fish produced. Hence, INAPESCA concluded that the Malpaso reservoir has not exceeded its ecological carrying capacity as a biomass of 236,654 mt of cultivable fish would be required to transition from an oligotrophic to mesotrophic classification. However, when considering INAPESCA's recommended total area for aquaculture production of 4,195 ha, the carrying capacity for this proposed coverage area is calculated to be 30,741 mt. Given the aggregated fish production in Chiapas, which amounted to approximately 36,000 mt in 2020, and recognizing that approximately 15,000 mt of this total originates from the Peñitas reservoir, it becomes apparent that the production in Malpaso stands at approximately 20,000 mt. This falls significantly below the estimated carrying capacity projected by INAPESCA.

The Peñitas reservoir, commissioned in 1987, is situated 72 km downstream from the Malpaso reservoir along the Grijalva River, which contributes 57.3% of the reservoir's inflow (Roman-Beltran, et al., 2020a). The remaining 42.7% of the water supply is sourced from the Zayula River. The reservoir encompasses an area of approximately 1,402 km^2, with an average depth of 13.5 m (maximum depth reaching 26 m) and a total water storage capacity of 600 million m^3 (Roman-Beltran, et al., 2020a). The reservoir's hydrological balance results in a low annual water exchange rate of 0.45 and an extended residence time of slightly over 2 years (Roman-Beltran, et al., 2020a).

As mentioned before, INAPESCA conducted a study in 2020 to identify suitable areas for aquaculture (UPAs) within the Peñitas reservoir and estimate its ecological and physical carrying capacity (Roman-Beltran, et al., 2020a). During this study, water samples were collected from nine locations distributed throughout the reservoir in November 2019 and February 2020. The findings revealed that the water flow velocities maintained an average of 0.52 meters per second, while turbidity exhibited a range between 0.6 and 1.6 m, with an average of 1.2 m. The average temperature recorded was 24.0°C. Notably, the values for these three parameters were comparatively lower for the Peñitas reservoir in contrast to the other two reservoirs outlined in Table 2.

Upon comparing Peñitas's parameters with the trophic level thresholds delineated in Table 3, it becomes evident that the upper values within the ranges for total nitrogen and chlorophyll-a concentrations (2.6 mg/L and 11.0 µg/L, respectively) classify under the hypereutrophic and eutrophic categories. On the other hand, the upper values within the ranges for total phosphorus concentration (0.035 mg/L) and turbidity (0.1 m) fall within the mesotrophic classification. However, when considering the reported averages for total phosphorus, chlorophyll-a concentration, and turbidity (0.018, 3.48, and 1.2, respectively), these averages align with either the oligotrophic or mesotrophic classification. It is noteworthy, however, that the average total nitrogen concentration (1.33 mg/L) corresponds to the eutrophic classification (Roman-Beltran, et al., 2020a).

Moreover, although certain water quality outcomes reported by the existing mega farm for their Peñitas operation closely correspond with figures reported by INAPESCA, there were some differences worth highlighting (pers. comm., Regal Springs representative, September 2023; Roman-Beltran et al., 2020a). For example, the annual ammonia concentrations from the existing mega farm varied from the highest average of 0.0097 mg/L in 2018 to 0.0076 mg/L in 2022, with an overall average of 0.0078 mg/L between 2018 and 2023, a value lower than the ammonia concentration average (0.022 mg/L) reported by INAPESCA. Similarly, though some of the highest reported phosphorus concentration levels during 2018-2022 by the existing mega farm fall within the eutrophic level classification in Table 3, all the annual averages align with the oligotrophic and mesotrophic classifications, except for 2021 when the annual phosphorus concentration averaged 0.054 mg/L, classifying as eutrophic by the modified trophic Toledo index (pers. comm., Regal Springs representative, September 2023).

Analysis of dissolved oxygen levels reported by the existing mega farm indicates that over half of the samples collected at all growout sites during 2022 and 2023 exceeded the established minimum threshold set by the producer. These thresholds are established based on optimal water quality criteria for tilapia production. These reported dissolved oxygen levels consistently oscillate around the average dissolved oxygen levels reported by INAPESCA, at approximately 4.25 mg/L (pers. comm., Regal Springs representative, September 2023; Roman-Beltran et al., 2020a). Furthermore, the four growout sites of the existing mega farm in Peñitas display a decline in dissolved oxygen levels during the second half of the year, typically around day 170. This decline is less pronounced at their pre-growout site, where most samples consistently maintain levels above the minimum threshold, even during the second half of the year. This difference may be attributed to the higher fish biomass present in the growout sites, leading to increased oxygen demand and subsequently lower dissolved oxygen levels. The temperature ranges provided by the existing mega farm also exhibit fluctuations within the range reported by INAPESCA, typically falling within the 23-25 °C range. Moreover, the overall average turbidity for 2023, reported as

1.49 m, aligns with the range of 0.6 to 1.6 m specified by INAPESCA (pers. comm., Regal Springs representative, September 2023; Roman-Beltran et al., 2020a).

Although the reported environmental parameters by INAPESCA and the existing mega farm for the Peñitas reservoir indicate favorable water quality conditions across all assessed sites, it remains imperative to uphold an effective water quality monitoring system. This proactive approach is crucial in preventing eutrophication, particularly in light of the reported average for total nitrogen concentration (1.33 mg/L) falling within the eutrophic classification.

Furthermore, INAPESCA's study estimated that the phosphorus concentration before any fish were introduced into the reservoir was 0.0197 mg/L. Utilizing the modified Toledo index (1983), INAPESCA classified the current trophic level of the reservoir as oligo-mesotrophic. INAPESCA further specifies that an additional 91 metric tons of phosphorus would be necessary to facilitate the transition of the Peñitas reservoir from an oligotrophic to a mesotrophic classification. The study took into account an FCR of 1.7 and a phosphorus content in feeds of 0.77%, which results in the introduction of 5.040 kg of phosphorus into the environment for every metric ton of fish produced. Consequently, the ecological carrying capacity of the Peñitas reservoir was estimated at 18,207 mt (Roman-Beltran et al., 2020a). While there is no precise estimate available for the total tilapia production in Peñitas, ASC audit reports for the existing mega farm indicate that 15,248.75 mt were produced in 2020, which nearly encompasses the entirety of the tilapia production in this reservoir. Consequently, it appears that the carrying capacity of the Peñitas reservoir has not been fully realized, and based on 2020 data, is operating approximately 3,000 mt below its limit (ASC, 2022; Roman-Beltran, et al., 2020a).

The La Angostura reservoir is situated at the base of the Sierra Madre de Chiapas, while the other three reservoirs are located in an area known as the Central Depression (Figure 3). Among the four reservoirs, La Angostura is the largest in Chiapas, covering approximately 51,548 ha. However, as of 2017, only about half of the total number of cages found in Malpaso are operated by small farmers in La Angostura, distributed across a total area of 372.2 ha (Romero-Beltran et al., 2020b). Despite having an estimate of the number of operating cages in La Angostura, the present level of production remains unclear. However, based on official production statistics, it is reasonable to infer that the production level is minimal in comparison to Malpaso and Peñitas (CONAPESCA, 2020; ASC 2022). Furthermore, within the context of the interconnected water body network, there exist indications that the aquaculture production within the La Angostura reservoir could undergo expansion, such as the environmental impact manifest approved for Regal Springs and the recently assessed potential of the reservoir (Romero-Beltran et al., 2020b; SEMARNAT, 2019). Therefore, it is relevant to also consider the prevailing water quality and the effluent-related impacts potential consequences stemming from effluent discharge.

Specific Feedback Request from Expert Review
Further information is requested with regard to the production level of tilapia in La Angostura reservoir.
Response:

The maximum water depth in La Angostura reservoir is 84 m, with an average depth of 19.6 m, and it has a total water capacity of 19 billion cubic meters (Romero-Beltran et al., 2020b). Although INAPESCA indicates that current velocities in the reservoir are currently below the optimal range (averaging between 0 and 0.3 meters per second), the reservoir still maintains viable current velocities suitable for aquaculture production (Romero-Beltran et al., 2020b). La Angostura's average turbidity was recorded at 2.1 meters, with the lowest visibility observed at the river entry points. Water temperature ranges from 25 to 32°C throughout the year, with an average of 26.9°C (Romero-Beltran et al., 2020b). The communities surrounding La Angostura reservoir primarily engage in activities such as fishing, irrigation agriculture, and livestock production (Romero-Beltran et al., 2020b).

Similar to the studies conducted for the Malpaso and Peñitas reservoirs, INAPESCA undertook a carrying capacity assessment for the La Angostura reservoir during July and November of 2019 and February and April of 2020 at nine sampling sites. The findings led INAPESCA to conclude that the La Angostura reservoir is oligotrophic based on the modified Toledo index. This classification indicates a low level of nutrient enrichment, limited planktonic development, low productivity, sparse presence of aquatic plants, predominance of sandy or rocky areas along the coastline, and high dissolved oxygen content (Romero-Beltran et al., 2020b). INAPESCA's study indicates that the reservoir has not reached its carrying capacity, and transitioning from an oligotrophic to mesotrophic state would require a biomass of over 500,000 mt of cultivable fish. The estimated phosphorus input for La Angostura to transition from oligotrophic to mesotrophic is 2,620 mt. Furthermore, the estimated phosphorus discharge per mt of produced fish is 4.58 kilograms, resulting in a capacity of 572,089 mt of fish production. However, when considering INAPESCA's recommended total area for aquaculture production of 10,372 ha, the carrying capacity for this proposed coverage area is calculated to be 59,338 mt. As mentioned before, the total tilapia production in La Angostura reservoir remains unclear but is considered minimal compared to Malpaso and Peñitas. Therefore, it is safe to assume that the carrying capacity estimate is far from being reached (Romero-Beltran et al., 2020b).

The National Water Commission (Comisión Nacional del Agua, CONAGUA), through official decree, is responsible for enforcing the use of water bodies for domestic, public, and ecological purposes throughout Mexico. This includes maintaining specific water volumes of 5,204.0 and 13,144.8 million cubic meters in Malpaso and Peñitas dams, respectively (DOF[9], 2018), as well as monitoring water quality in the country's reservoirs. The National Commission on Aquaculture and Fisheries (Comisión Nacional de Acuacultura y Pesca, CONAPESCA) is responsible for granting aquaculture concessions. To obtain an aquaculture concession, farmers are required to have a preapproved environmental impact assessment from the Secretariat of Environment and Natural Resources (Secretaría del Medio Ambiente y Recursos Naturales, SEMARNAT). Although water quality may not be the sole limiting factor for obtaining a permit, it is considered during the decision-making process (ATT Innova, 2015). It is worth noting that industry stakeholders have expressed concerns about the limited communication and coordination among these government organizations (pers. comm., Soledad Delgadillo, FAO, September 2023). For further details on the regulatory procedures for aquaculture production in Mexico, please refer to Criterion 3 – Habitat.

Under ASC certification, the existing mega farm is obligated to maintain monthly records of various water quality parameters in the receiving water body. These parameters include dissolved oxygen, conductivity, temperature, oxygen saturation, turbidity, total and dissolved phosphorus, ammonia nitrogen, and chlorophyll a. Furthermore, they must ensure that the dissolved oxygen in the receiving waters experiences an average diurnal change of less than 65% relative to the dissolved oxygen saturation levels for the specific salinity and temperature of the water. The annual average turbidity (as

[9] https://www.dof.gob.mx/nota_detalle.php?codigo=5525361&fecha=06/06/2018#gsc.tab=0

measured by Secchi disk) should not exceed 10 meters, otherwise, the production is not certifiable (i.e., the certification system will no certify aquaculture in those rare exceedingly clear oligotrophic waterbodies with Secchi depths >10m). The existing mega farm comply with ASC's turbidity requirements (Secchi disk visibility less or equal to 5.0 meters), with an annual range of Secchi depths in 2022 of 1.3 to 4 meters and an annual average of 2.1 meters; and is exempt from reporting total phosphorus and chlorophyll-a concentrations on the receiving waters (requirements, 2.4.3 and 2.4.4 form the ASC Tilapia Standard).

Outside of the existing mega farm, the majority of smaller producers operating in these four reservoirs do not follow a technical program that includes keeping records of physical-chemical and biological production parameters (Todo Acuicola[10], 2021). Velazquez (2022), reports that 80% of the surveyed producers (a total of 40 UPAs) do not monitor water quality, and the remaining 20% only monitor dissolved oxygen levels and water temperature.

CONAGUA has implemented an extensive water monitoring network to assess the quality of water resources in various surface and underground water bodies across the country, with particular focus on areas that experience significant anthropogenic influence. As of 2017, this network consisted of 5,028 monitoring sites strategically distributed throughout Mexico. These sites included 2,685 locations for surface water monitoring, 1,096 sites for groundwater monitoring, 856 sites in coastal zones, 289 sites at discharge points, and 102 sites designated for "special studies." For visual reference, Figure 4 displays the spatial distribution of these sampling sites nationwide. However, a more comprehensive analysis of the water quality parameters reported by CONAGUA is presented subsequently, with Figure 4 providing an illustrative example utilizing the biochemical oxygen demand indicator.

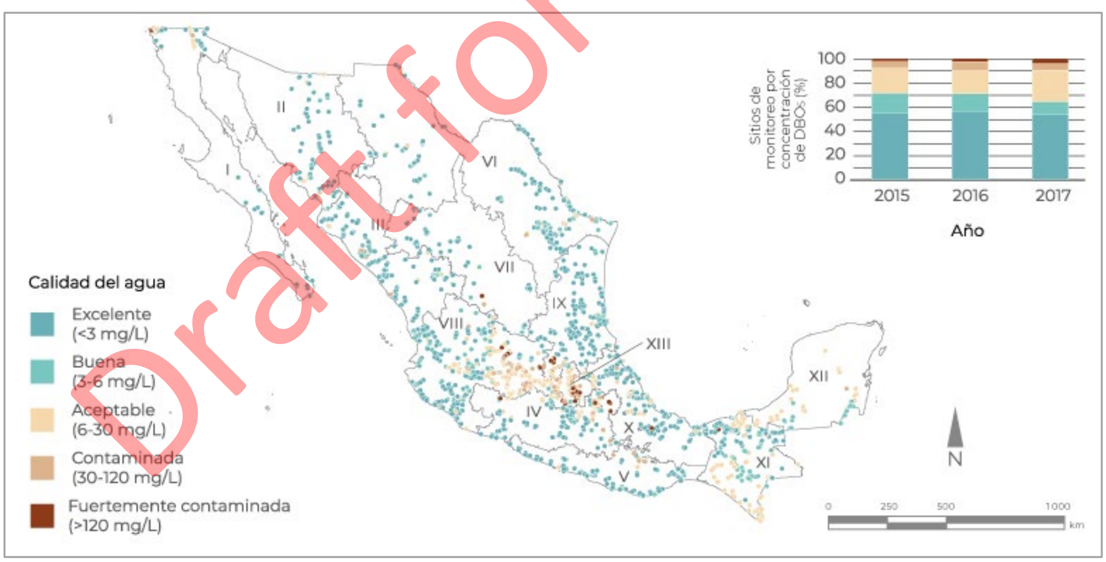

Figure 4. Monitoring sites distribution of biochemical demand of oxygen in superficial water bodies in 2017 (From CONAGUA, accessed June 2023).

Considering the significant tilapia production in Chiapas, particularly in the Malpaso water reservoir, an analysis conducted in this water body can offer valuable insights into the potential impact of nutrient inputs on other regions in Mexico that produce tilapia under similar conditions. The findings from two

[10] https://www.youtube.com/watch?v=qGaQzmCg6ak

water quality sampling sites located in the southernmost region of the reservoir, where aquaculture nutrient inputs would not influence water quality, were compared with the results obtained from a sampling site situated just outside the northernmost region of the reservoir dam (i.e., “downstream” of the aquaculture sites). An analysis of variance (ANOVA) was performed using each sites’ annual averages from 2012 to 2020 for six parameters: total biological and chemical oxygen demand, ammonia, nitrite, and phosphorus concentrations, and total suspended solids. The goal was to determine if significant differences existed in the water quality outcomes among these sites.

The ANOVA results indicated that there were no statistically significant differences in ammonia and total suspended solids results ($p < 0.05$). Furthermore, the p-values for the other four parameters ranged from 0.05 to 0.1, suggesting a low degree of variability in the reported data across the parameters for the three groups. These findings imply the lack of evident differences between the two southern stations (representing conditions prior to aquaculture inputs) and the northern station (after aquaculture inputs). The low variability and absence of clear distinctions among the three groups are depicted in Figure 5 a-d.

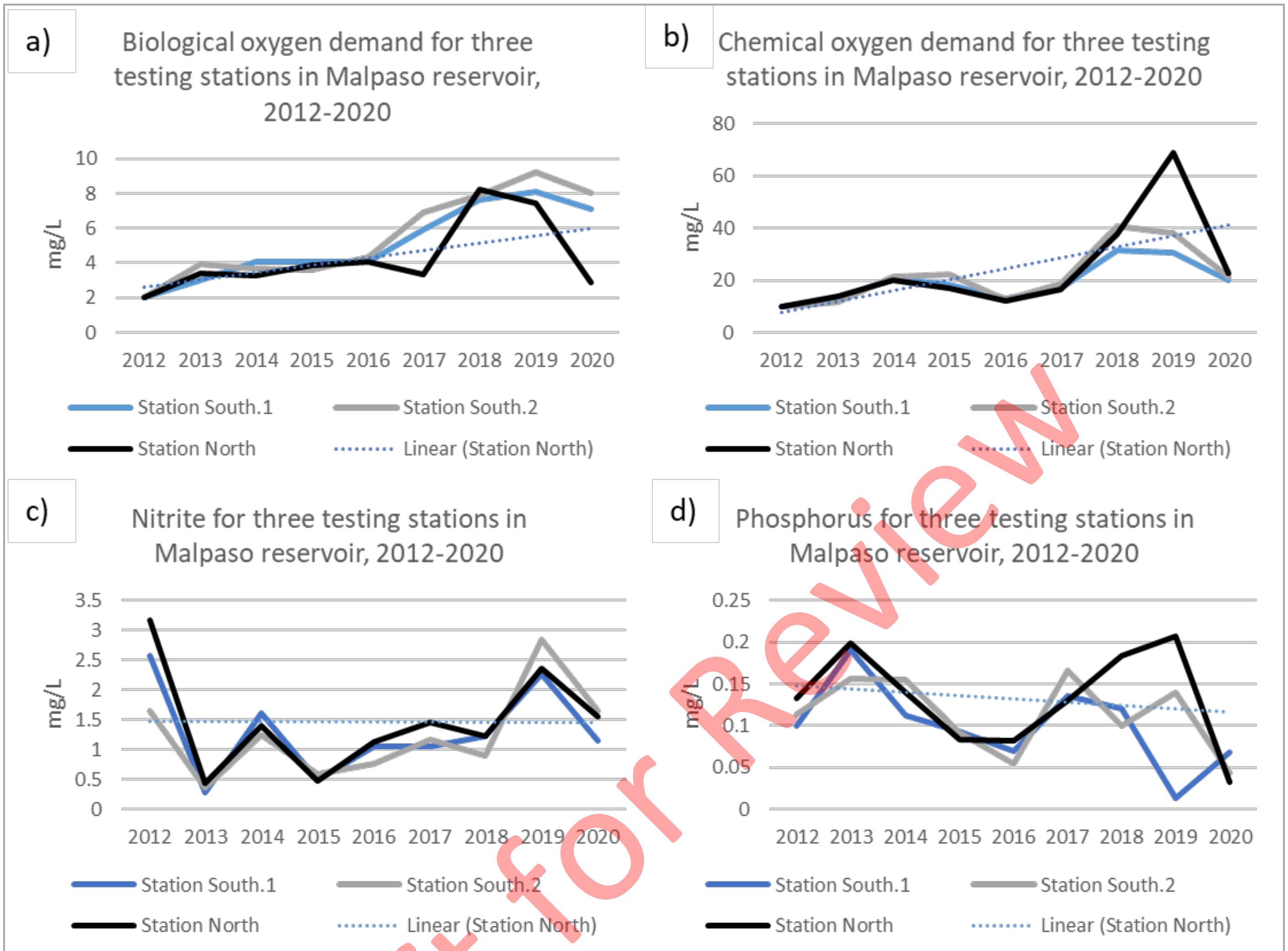

Figure 5. Results of four water quality parameters measured at three sampling stations in the Malpaso reservoir. Station South.1 and Station South.2 are situated at the entrance of the Grijalva River to the reservoir, while Station North is located at the reservoir's exit, downstream of the dam. The parameters include biological oxygen demand (Figure 5a), chemical oxygen demand (Figure 5b), nitrite concentration (Figure 5c), and phosphorus concentration (Figure 5d).

The findings depicted in Figure 5 indicate that water quality (WQ) at the entrance of the Grijalva River, the primary freshwater input of the Malpaso reservoir, and at the main water exit, where the water is discharged back into the Grijalva River, exhibit similar WQ characteristics over the nine-year period examined. Notably, there has been an observable increase in biological and chemical oxygen demand as well as phosphorus concentration during this timeframe. Furthermore, Figures 5a, 5b, and 5d illustrate a decline in the recorded values for 2019 and 2020. These declines may potentially be attributed to the decrease in anthropogenic inputs to this water body, which occurred as a result of the COVID-19 pandemic. The pandemic likely led to changes in human activities, including aquaculture practices, such as the departure of an unknown number of tilapia producers (pers. comm., Mauricio Orellana, Neoaqua, April 2023).

CONAGUA employs a classification system wherein various water quality parameters are categorized as Excellent, Good, Acceptable, Contaminated, or Highly Contaminated, based on specific threshold values for each parameter (Table 4). To assess the frequency of occurrence for three parameters (BOD, COD, and SST) reported in 2020 across the 59 sampling sites within the four discussed reservoirs, a frequency analysis was conducted. The objective of this analysis was to detect any indications of nutrient accumulation from the southernmost reservoir (La Angostura) to the northernmost reservoir (Peñitas), considering the cascade geographical arrangement of these reservoirs. The results, presented in Figure 7, depict the proportion of samples falling within each classification for each reservoir. A similar analysis was conducted for total phosphorus and nitrogen concentrations. However, in this case, the classifications were based on the trophic level classification presented in Table 3 for tropical freshwater bodies (Romero-Beltran et al., 2021). The frequency analysis for phosphorus and nitrogen is illustrated in Figure 7.

Table 4. CONAGUA's classification of three water quality parameters and their respective thresholds in mg/L (CONAGUA, 2021).

Classification	BOD thresholds	COD thresholds	SST thresholds
Excellent	< 10.0	< 3.0	< 25.0
Good	10.1 – 20.0	3.1 – 6.0	25.1 – 75.0
Acceptable	20.1 – 40.0	6.1 – 30.0	75.1 – 150.0
Contaminated	40.1 – 200.0	30.1 – 120.0	150.1 – 400.0
Highly contaminated	> 200.1	> 120.1	> 400.1

Given the interconnected nature of the reservoirs and the varying levels of tilapia production in each, one would expect anthropogenic nutrient and contaminant concentrations to increase as the altitude decreases and tilapia production levels rise. As mentioned previously, as of 2017 approximately 660 net pens were operational in La Angostura, although this number may have substantially decreased due to the impact of COVID-19, and the exact volume of production remains unknown (April 2023; pers. comm., Mauricio Orellana, Neoaqua, April 2023). However, most of the tilapia production in Chiapas occurs in Malpaso and Peñitas.

Upon analyzing Figures 6 and 7, no clear trends or correlations emerge indicating that higher levels of tilapia production in Malpaso and Peñitas result in poorer water quality compared to La Angostura and Chicoasen, nor does pollution appear to increase as altitude decreases. Among the four reservoirs examined, Chicoasen exhibits the most concerning water quality across all analyzed parameters. This can likely be attributed to anthropogenic nutrient inputs originating from Tuxtla Gutiérrez, the capital of Chiapas, which has a population of approximately 600,000 and is located only about 13 kilometers from Chicoasen's dam (Common Action Forum[11], accessed June 2023). However, when considering all the water quality indicators presented in Figure 6, the majority of samples across the four reservoirs were classified as acceptable, good, or excellent. Only Chicoasen exhibited a small proportion (less than 10% of total samples) of "highly contaminated" samples for the three indicators, and Malpaso was the only other reservoir with "contaminated" BOD samples (approximately 40% of total samples). It is worth highlighting that the BOD results shown in Figure 6 for these two reservoirs (Chicoasen and Malpaso),

[11] https://caf.unach.mx/destinos-turisticos

appear to have performed considerably worse than the state average water quality (for 2012 to 2021), shown ahead in Figure 8.

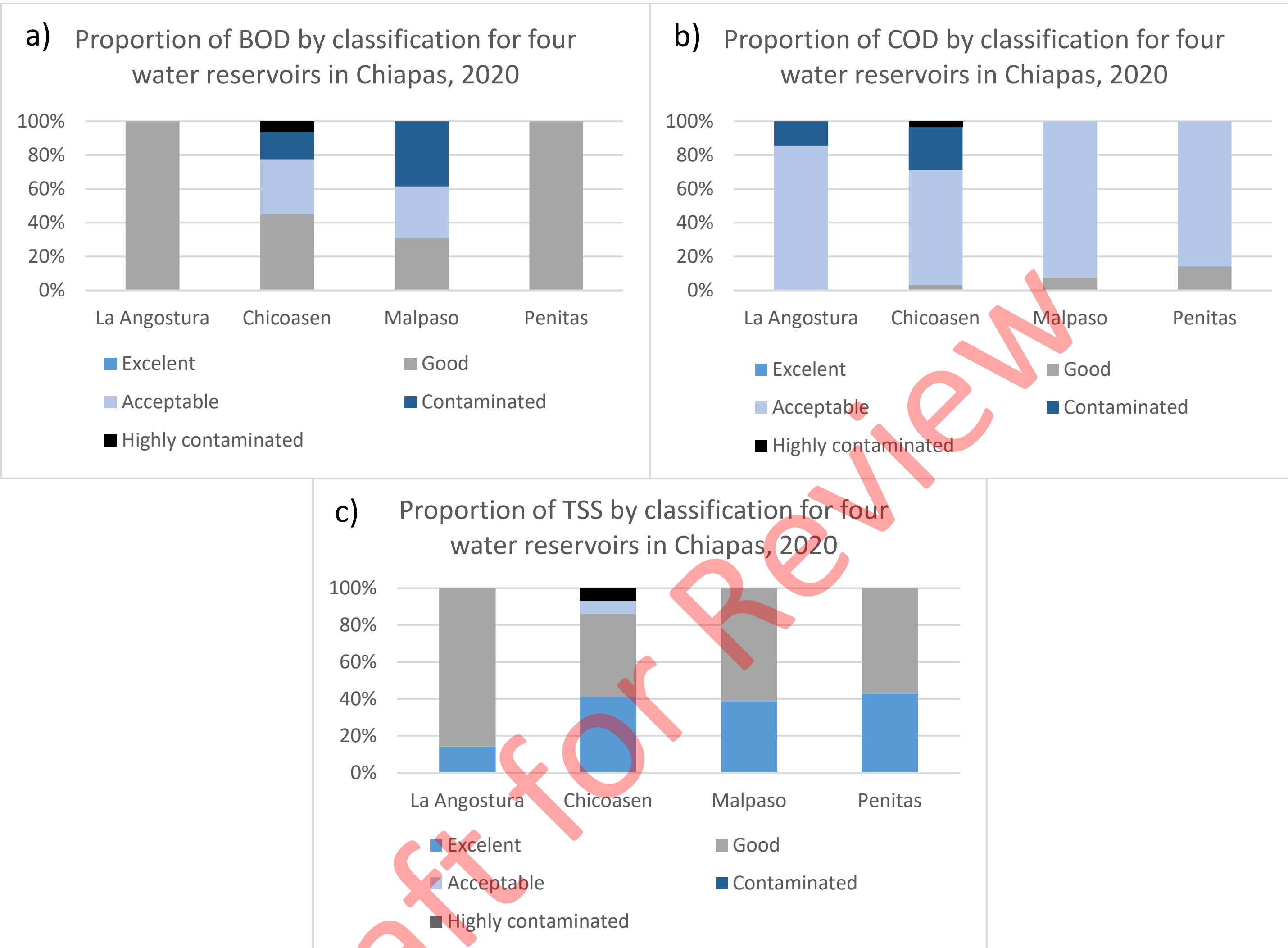

Figure 6. Proportion of 2020 samples of biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS), falling within each water quality classification in four reservoirs in Chiapas (CONAGUA, 2021).

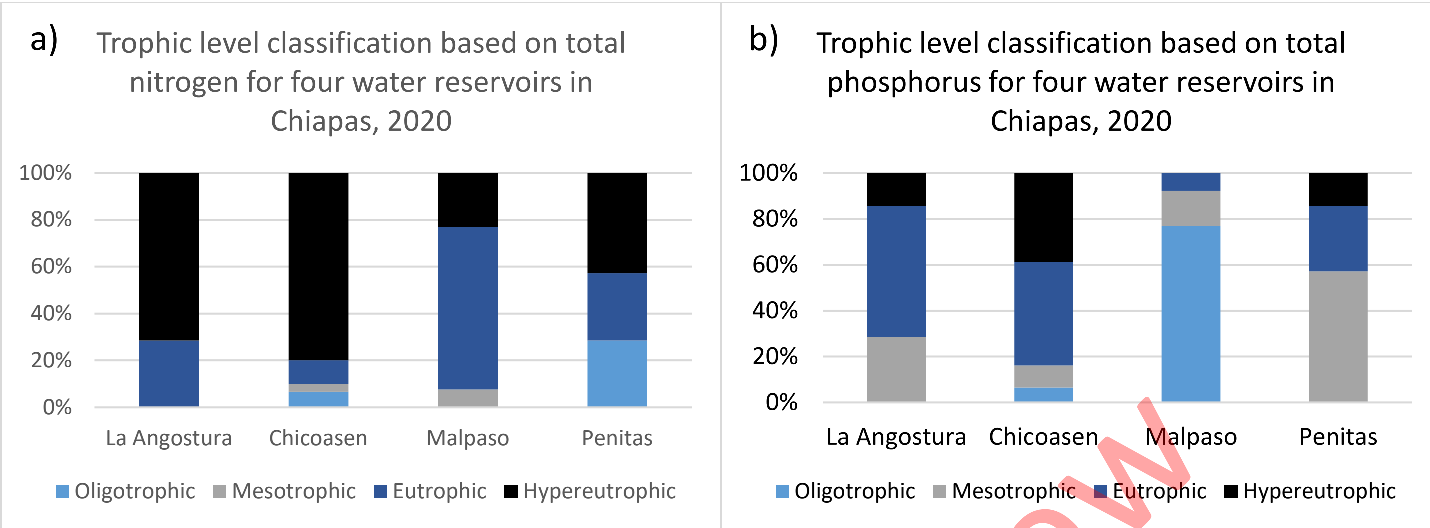

Figure 7. Proportion of 2020 samples of total nitrogen (N), and total phosphorus (P), falling within each trophic level classification in four reservoirs in Chiapas (CONAGUA, 2021). Note the different ranges of trophic status' (and colors) in each graph.

None of the four water reservoirs examined exceeded the monthly maximum permissible limits in freshwater bodies, which have been set at 25 mg/L for total nitrogen and 15 mg/L for total phosphorus (CONAGUA, 2021; NOM-001-ECOL-1996). However, when classifying these two water quality indicators for the four reservoirs, it becomes apparent that the majority of results fall within the eutrophic and hypereutrophic classifications. It is worth noting that the permissible limits set under the federal norm, NOM-001-ECOL-1996, are considerably higher (25 and 15 mg/L for nitrogen and phosphorus, respectively) than the worst trophic level classifications (hypereutrophic) listed in Table 3 (>1.51 and >0.211 mg/L for nitrogen and phosphorus, respectively). Additionally, this finding contradicts the oligotrophic classification reported by Romero-Beltran et al. (2021; 2020a; and 2020b) for Malpaso, Peñitas, and La Angostura, where the trophic level was determined using total phosphorus. It is important to note that the analysis shown in Figures 6 and 7 considered only seven samples for La Angostura in 2020, and the limited sample size does not provide a robust basis for drawing strong conclusions.

In a broader context, examining water quality at the state level can provide insights into the overall status of water quality and shed light on the potential contribution of tilapia aquaculture industry effluents to the anthropogenic impacts on freshwater resources nationwide. To explore this aspect, a similar qualitative analysis was conducted for the eight states with the highest levels of tilapia production, as determined by reported production data from 2013 to 2020. These states, ranked by production levels, include Chiapas, Veracruz, Jalisco, Campeche, Michoacan, Nayarit, Tabasco, and Sinaloa (CONAPESCA, 2020). The analysis focused on four water quality indicators: biological and chemical oxygen demand, total suspended solids, and Escherichia coli.

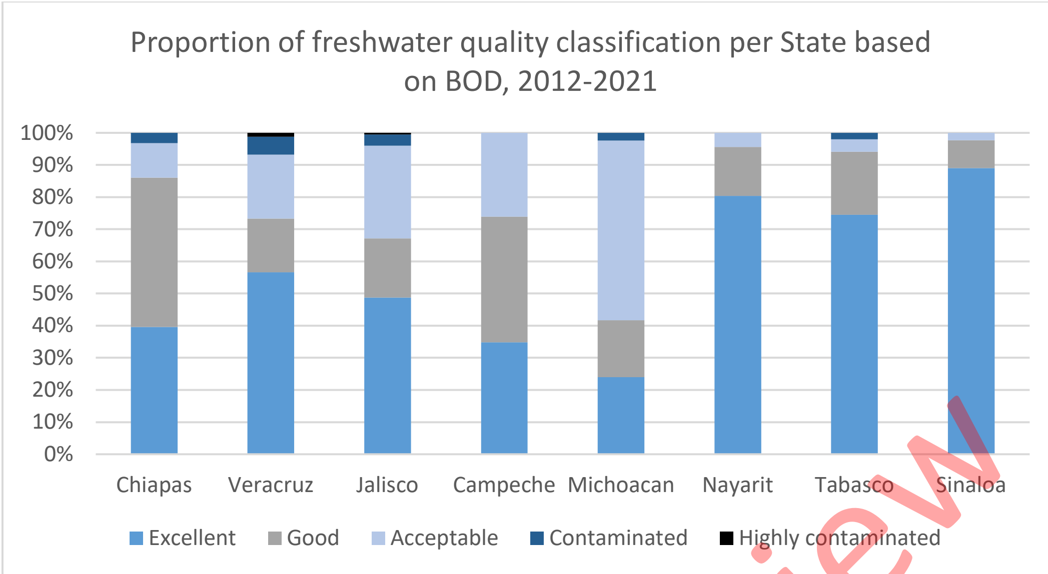

Figure 8. Proportion of biological oxygen demand results falling under each freshwater quality classification for the eight States in Mexico with highest levels of tilapia production, 2012 to 2021 (CONAGUA, 2021; CONAPESCA, 2020).

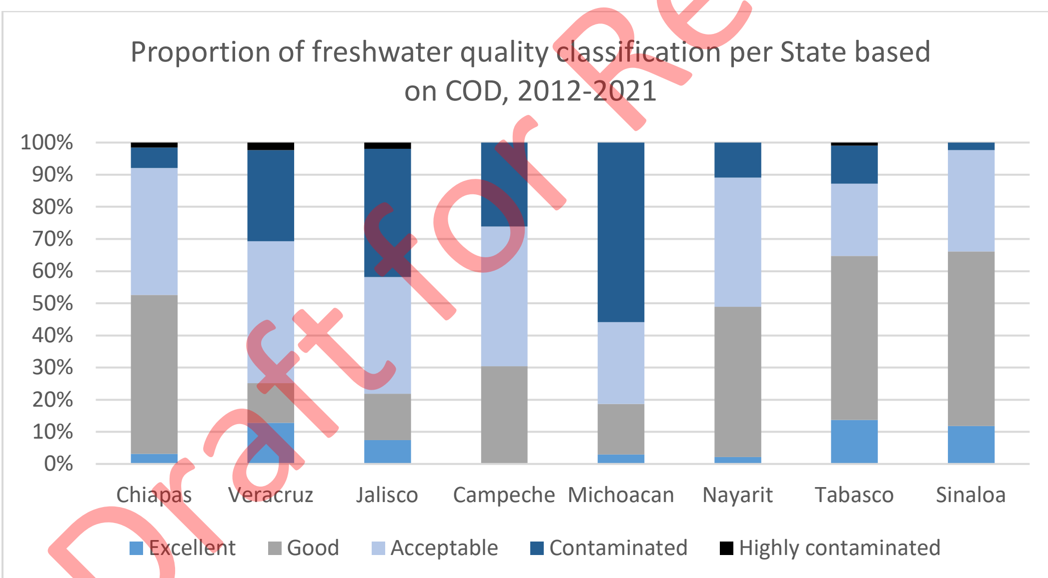

Figure 9. Proportion of chemical oxygen demand results falling under each freshwater quality classification for the eight States in Mexico with highest levels of tilapia production, 2012 to 2021 (CONAGUA, 2021; CONAPESCA, 2020).

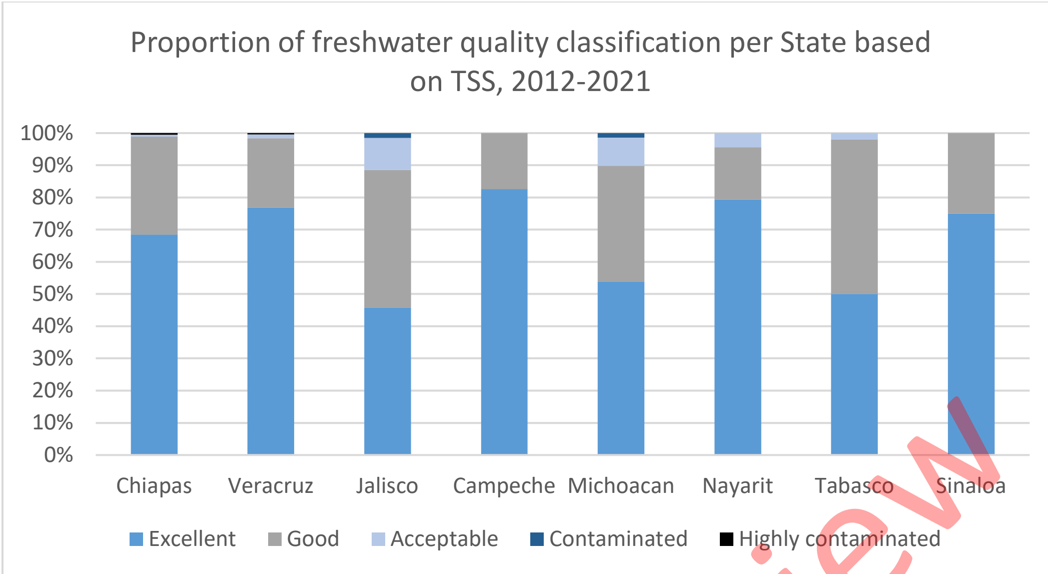

Figure 10. Proportion of total suspended solids results falling under each freshwater quality classification for the eight States in Mexico with highest levels of tilapia production, 2012 to 2021 (CONAGUA, 2021; CONAPESCA, 2020).

In relation to BOD, the proportion analysis of averaged classifications from 2012 to 2021 revealed that the majority of results for all states fell within the categories of excellent, good, or acceptable (Figure 8). The occurrence of contaminated or highly contaminated classifications was limited to 5% or less in the states of Chiapas, Veracruz, Jalisco, Michoacan, and Tabasco. A similar trend can be observed in Figure 10 for the classification of Total Suspended Solids (SST), where the majority of results were classified as excellent or good. However, when considering the parameter of Chemical Oxygen Demand (COD), all eight states assessed displayed at least one sample classified as "contaminated" (Figure 9). Jalisco and Michoacan exhibited the highest proportions of "contaminated" samples, with over 40% and 50% of the samples falling into this category, respectively.

Although various water quality indicators assessed in this study warrant attention from local authorities and residents of these states, no clear trend or correlation between the level of tilapia production and the state-level water quality was evident based on these analyses.

Furthermore, the third largest reservoir in Mexico is "El Infiernillo," which is shared by the states of Michoacan and Guerrero. According to a carrying capacity assessment conducted in 2018 by Hernandez-Acuayte et al. (2018), the estimated maximum sustainable aquaculture production for the reservoir was 2,475 mt per year. However, the combined reported aquaculture production for Michoacan and Guerrero in 2020 was only 1,034 metric tons (CONAPESCA, 2021), indicating that the aquaculture sector in El Infiernillo is currently operating below its carrying capacity. In the case of Lake Patzcuaro in Michoacan, there were previous intentions to establish tilapia aquaculture, but a carrying capacity assessment conducted in 2012 by Rojas-Carrillo and Aguilar-Ibarra (2012) revealed that the lake's carrying capacity had already been exceeded, suggesting the presence of ecological hysteresis. As of the present, online searches indicate that no aquaculture activities have been implemented in this lake. It is noteworthy to mention that Rojas-Carrillo and Aguilar-Ibarra (2012) also highlighted the pollution levels in most freshwater bodies in Mexico as a limiting factor for the development of cage-cultured aquaculture production in the country.

Similarly, Romero-Beltran et al. (2020) assessed the carrying capacity for aquaculture production in the Zimapan reservoir, which is shared by the states of Queretaro and Hidalgo. Their findings indicated that the reservoir was eutrophic and the carrying capacity had been exceeded by more than 200%. Although no aquaculture activities are currently taking place in Zimapan, there is an intensive stocking program led by the local governments of these states, primarily involving tilapia and carp (Ciprinus carpio) (Hernandez-Montaño and Melendez-Galicia, 2010). Romero-Beltran et al. (2020) suggest that even this stocking activity should be reduced due to the existing carrying capacity constraints.

As previously discussed, there exists contradictory information around water quality in Chiapas' reservoirs and at the state level. Nonetheless, the issue of eutrophication has emerged as a significant problem in certain dams in Chiapas where cage tilapia farming is practiced (Martinez-Cordero et al., 2021). Hence, it is crucial for the Mexican government to undertake effective planning and management measures for cage tilapia farming, such as implementing zoning strategies based on the carrying capacity of waterbodies and promoting the adoption of best aquaculture practices to mitigate adverse environmental effects. It is particularly important to address these concerns at an early stage to prevent the development of unsustainable practices. However, considering the historical enforcement context of this region, the prospect of effectively strategizing for the industry's comprehensive development appears dim. This is elucidated in Criterion 3 – Habitat, wherein it is revealed that 83% of UPAs holders in the Malpaso reservoir failed to adhere to all registration prerequisites, and half of the active producers surveyed lacked a pre-approved Environmental Impact Assessment (EIA) from SEMARNAT (ATT Innova, 2015).

Conclusions and Final Score: Net Pens

In conclusion, the analyses presented here found no clear relationship between the level of tilapia production and the water quality indicators at the reservoir and state levels. While there are contradictory findings with respect to water quality and trophic level analysis, the INAPESCA's carrying capacity studies suggest that the largest tilapia-producing reservoirs in Mexico (Malpaso and Peñitas) operate below their estimated carrying capacities, as do other reservoirs such as La Angostura, and El Infiernillo. INAPESCA's studies also conclude that Malpaso, Peñitas, and La Angostura reservoirs classify as oligotrophic to mesotrophic based on the modified Toledo index. There is evidence that aquaculture production is not permitted in reservoirs that exceed their carrying capacity for reasons unrelated to aquaculture. The largest producer operating in both Malpaso and Peñitas reservoirs (the existing mega farm), complies with all of ASC's water quality requirements, which is also indicative of the level of impacts generated by the tilapia industry in Chiapas, as many active producers share these two water bodies. There are no discernible trends indicating that higher tilapia production in certain reservoirs leads to poorer water quality compared to others, perhaps due to the many other nutrient inputs and nutrient dynamics in the lakes, particularly agriculture and municipal wastes. The cascading arrangement of reservoirs does not result in pollution accumulation or worsening water quality as anthropogenic inputs increase. However, there is an increasing trend in the biological and chemical oxygen demand for the Malpaso reservoir (from 2012 to 2020), and official data derived from CONAGUA's BOD and COD samples in 2020, underscore the recurrent classification of "contaminated" for La Angostura, Chicoasen, and Malpaso reservoirs on multiple occasions; with the Malpaso reservoir exhibiting contamination in as much as 38% of the BOD samples. Moreover, nutrient inputs in tilapia production reservoirs in Chiapas, and the analyzed data for total nitrogen and phosphorus suggest higher trophic levels than those previously reported. For instance, in 2020 there was a high proportion of total nitrogen samples classified as eutrophic (as high as 30 and 70% for La Angostura and Malpaso, respectively) and hypereutrophic (as high as 70 and 80% for La Angostura and Chicoasen, respectively) for the four reservoirs in Chiapas. Similarly, the four reservoirs resulted in considerable proportions of total phosphorus samples classified as eutrophic (as high as 45 and 57% for Chicoasen and La Angostura, respectively) and three reservoirs as hypereutrophic (as high as 38% for Chicoasen). Therefore, it is determined that tilapia aquaculture results in temporary contributions to regional cumulative impacts. These temporary impacts generated by tilapia production in net pens may extend to other regions in the country. Overall, the score for Criterion 2—Effluent for net pens is a moderate score of 4 out of 10.

Effluent: Ponds

As effluent data quality and availability is moderate/low (i.e., the score for the Effluent category in Criterion 1 – Data is 5 out of 10 or lower), the Seafood Watch Risk-based Assessment methodology has been used. This method involves assessing the amount of waste produced by the fish and then the amount of that waste that is discharged from the farm. The content and effectiveness of the regulatory system in managing wastes from multiple farms is used to assess the potential cumulative impacts from the industry as a whole.

Factor 2.1—Waste Discharged per ton of Fish

Factor 2.1a: Biological waste production per ton of fish

This assessment is based on nitrogen, because this is the most data-rich proxy indicator for aquaculture nutrient inputs and waste outputs (using protein in feeds and harvested fish). It is noted that phosphorous may be a more important limiting nutrient in freshwater systems.

As discussed in Criterion 5—Feed, the average economic feed conversion ratio (eFCR) for tilapia in Mexico, as reported in the literature, is 1.6; and the estimated average feed protein content for ponds is 30.0%. In addition to feed, fertilizers are commonly used to enhance the natural productivity of ponds. While specific information on fertilizer use in tilapia farms in Mexico is limited, observations from the Product System Committee of Tilapia in Mexico, indicate that extensive and semi-intensive farms in certain regions, particularly in the south and south-eastern areas, utilize fertilization in their ponds during the nursery stage of production, which lasts 80 days (SAGARPA, 2012). The recommended application rate of fertilizer is 1.25 to 1.75 grams per square meter per week, equivalent to 12.5 to 17.5 kilograms per hectare per week (SAGARPA, 2012; FAO[12], 2009). Given the lack of a country average for this ratio, the precautionary principle suggests using the higher end of the range, which is 17.5 kilograms of nitrogen per hectare per week. A common fertilizer applied in Mexico for new ponds and at earlier production stages is urea with a concentration of 46% nitrogen (Boyd, 2018; SAGARPA, 2012; Flores-Nava, 2007).

Combining a weekly fertilizer use of 17.5 kilograms per hectare over 80 days, with a 46% nitrogen concentration, and with a typical yield obtained from extensive and semi-intensive tilapia farms (2 metric tons per hectare), the nitrogen input from fertilizer per ton of fish produced is estimated to be 46 kilograms of nitrogen. Therefore, the total nitrogen input, including both feed (multiplied by the eFCR) and fertilizer, amounts to 122.8 kilograms of nitrogen per metric ton of production. This estimate is slightly higher than the range of 105.15 to 110.56 kilograms of nitrogen per metric ton reported for a net pen farm audited by ASC (ASC, 2022). Regarding nitrogen outputs, the protein content of a whole harvested farmed tilapia is 14% (Boyd, 2007), equivalent to 22.4 kilograms of nitrogen per metric ton

[12] https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/es/es_niletilapia.htm

(considering that protein contains 16% nitrogen). Consequently, the nitrogen waste produced by the fish is calculated to be 100.4 kilograms per metric ton.

Factor 2.1b: Production System Discharge

The amount of this waste that is discharged is affected by a variety of natural processes in the ponds, in addition to any water treatment, and particularly the water exchange rate. The average water flow rate in tilapia farms in Mexico exhibits variation based on the stage of production and the specific cultivation system employed. Water exchange percentages in Mexico typically range from 5% to 20%, but intensive systems may employ water exchanges rates of the pond water per day ranging from 100 to 250% turnover (Guzman-Luna et al., 2021; INAPESCA, 2018). For instance, in San Luis Potosi a farm producing tilapia in circular concrete tanks uses spring water at a biomass density of 8 kg/m^3, reports a daily water exchange rate of 100% (Ortega et al., 2018). Another farm in Queretaro culturing tilapia in geomembrane tanks at a similar density of 7 kg/m^3 and supplied with well water from a greenhouse system, reports a daily water turnover of 30%, which is consistent with observations in tilapia farms in Mexico using semi-intensive systems (Ortega et al., 2018). It is noteworthy that a common practice among micro farmers (AREL) is the reutilization of effluents for supplementary agricultural purposes, encompassing the cultivation of crops such as coffee, bananas, corn, beans, and others (pers. comm., Soledad Delgadillo, FAO, September 2023). While these specific observations provide some insights into daily water exchange practices, it is challenging to extrapolate these findings to the broader industry due to the considerable variation in factors such as farm sizes, types of production systems, geographic locations, and other relevant variables. Therefore, caution should be exercised when attempting to generalize water exchange rates based on these limited observations.

Nevertheless, Guzman-Luna et al. (2021) conducted a comprehensive water footprint analysis of three tilapia production systems in Mexico (Figure 11), revealing a substantial direct water footprint primarily attributed to the "blue" component, which accounts for surface or groundwater consumed directly in production, lost through evaporation, or incorporation into the product. The "grey" water component, representing the volume of water needed to dilute effluent waste, was also significant for semi-intensive and intensive systems at 1,873 m3/ton (Guzman-Luna et al., 2021). These blue and grey components can be considered as indicators of water exchange practices in Mexico's tilapia production.

Among the three production systems analyzed, the extensive system demonstrated the lowest water exchange rates, mainly due to replacing evaporation, while the intensive system exhibited the highest blue water footprint, being 14 times that of the extensive system and 4.5 times that of the semi-intensive system. The green water footprint, associated with aquafeed production, was higher for the semi-intensive and intensive systems but was not considered in this report as it represents indirect water use originating from sources like stored rainwater in soil (Guzman-Luna et al., 2021).

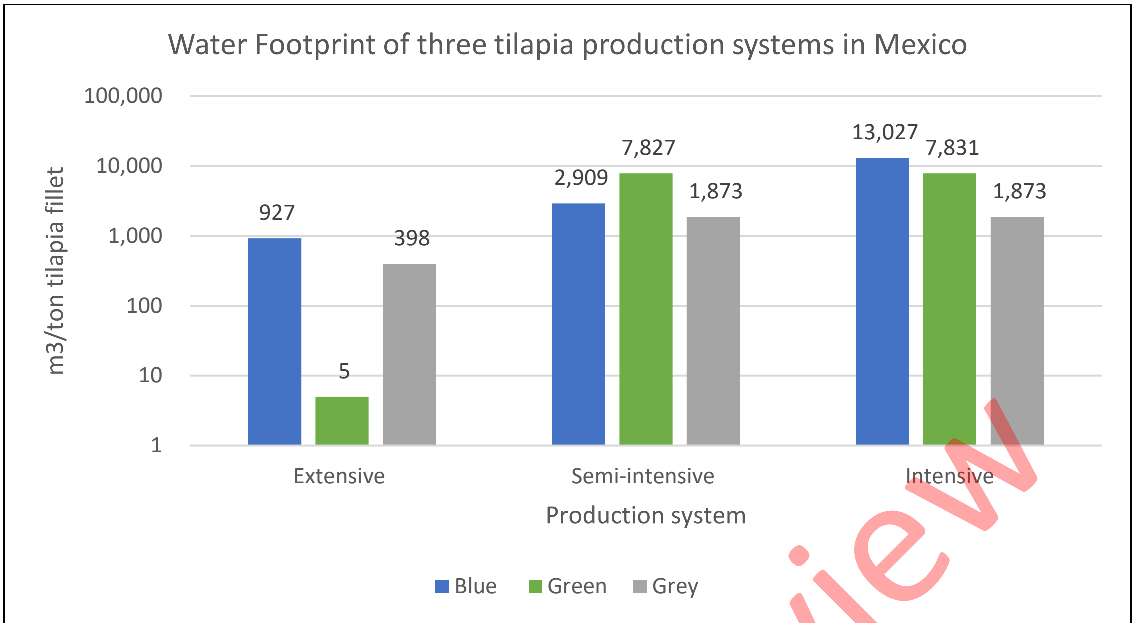

Figure 11. The blue, green and grey water footprint per ton of tilapia fillet for the extensive, semi-intensive and intensive production system in Mexico (logarithmic scale). Blue bars represent the volume of fresh water collected from surface or underground sources that evaporates in the production or is incorporated in the product, and the grey bars represent the volume of water required to dilute the effluent loads, both are an indicator of water exchanges. The green bars represent the water footprint associated with indirect water use originating from sources like stored rainwater in soil. Graph reproduced from data in Guzman-Luna et al. (2017).

Although the specific numbers mentioned above do not directly correspond to daily water exchange percentages, the study conducted by Guzman-Luna et al. (2021) provides support for the assumption that water exchange rates in tilapia ponds in Mexico can be significant. Taking into account the scoring thresholds outlined in the Seafood Watch standard (>3% or <3%) and the estimated range of 5% to 20% provided by INAPESCA (2018), the typical daily exchange rate used in this assessment is considered to be greater than 3%.

Regarding water treatment prior to discharge, both the technical recommendations provided by SAGARPA (2012) and the best practice manual for tilapia production (Garcia-Ortega and Calvario-Martinez, 2008) advocate for the implementation of water treatment when producing tilapia. However, the implementation of wastewater treatment systems in aquaculture production in Mexico has generally been poor (Sosa-Villalobos et al., 2016; DeWalt et al., 2002). In ponds, it has been observed that only 30% of the supplied nutrients are effectively converted into product, while the remaining portion is either accumulated in sediments or released as effluents, often flowing into rivers (Sosa-Villalobos et al., 2016). Consequently, in the absence of strong evidence suggesting otherwise, no adjustments have been made to account for the routine use of settling ponds. Likewise, there is limited information available regarding common practices for the disposal of settled particulate wastes, such as pond sludge. According to Guzman-Luna (2021), most farms do not treat their wastewater, although some reuse it for agricultural purposes. Therefore, the basic adjustment of 0.51 for ponds exchanging an average of >3% per day is used here (which means that 51% of the waste produced by the fish is considered to be discharged). With the biological waste production of 100.4 kg N/mt from Factor 2.1a above, this means that 51.2 kg N/mt is considered to be discharged from the ponds. This equals a score of 4 out of 10 for Factor 2.1.

Factor 2.2—Management of Farm-Level and Cumulative Impacts

Factor 2.2a: Content of effluent management measures

Mexico's Official Standard, NOM-001-ECOL-1996, establishes the maximum permissible limits for the discharge of effluents from various industries. The norm includes comprehensive lists of limits for key pollutants and heavy metals, which are outlined in Table 5 and 6. To ensure compliance with these limits, the National Water Commission (CONAGUA) is responsible for administering permits related to effluent discharge (Aguilar-Manjarrez et al., 2017; Garcia-Ortega and Calvario-Martinez, 2008; NOM-001-ECOL-1996). It is important to note that while the 1996 regulation addresses water discharges from various industries, including aquaculture, specific requirements dedicated to wastewater discharges from aquaculture are currently lacking (Hermoso, 2016).

Table 5. Monthly and daily averages, and instant value of maximum permissible limits for basic pollutants as it relates to rivers, and natural and artificial reservoirs (Taken from NOM-001-ECOL-1996).

Parameters (mg L-1, except when specified)	Rivers, streams, channels, and drains			Reservoirs, lakes, and lagoons			Marine zones		
	M. A	D.A	I.V	M. A	D.A	I.V	M. A	D.A	I.V
Temperature (°C)	35	35	35	35	35	35	35	35	35
Fats and oils	15	18	21	15	18	21	15	18	21
Total suspended solids	60	72	84	20	24	28	20	24	28
Chemical Oxygen Demand	150	180	210	100	120	140	85	100	120
Total Organic Carbon	38	45	53	25	30	35	21	25	30
Total nitrogen	25	30	35	15	25	30	25	30	35
Total phosphorus	15	18	21	5	10	15	15	18	21
Escherichia coli, (MPN/100 ml)	250	500	600	250	500	600	250	500	600
Fecal Enterococcus (MPN/100 ml)	250	400	500	250	400	500	250	400	500
pH	6-9								

* M.A: Monthly average. D.A: Daily average. I.V: Instant value. MPN: Most probable number.

Table 6. Monthly and daily averages, and instant value of maximum permissible limits for heavy metals as it relates to rivers, and natural and artificial reservoirs (Taken from NOM-001-ECOL-1996).

Parameters (mg L-1)	Rivers, streams, channels, and drains			Reservoirs, lakes, and lagoons			Marine zones		
	M. A	D.A	I.V	M. A	D.A	I.V	M. A	D.A	I.V
Arsenic	0.2	0.3	0.4	0.1	0.15	0.2	0.2	0.3	0.4
Cadmium	0.2	0.3	0.4	0.1	0.15	0.2	0.2	0.3	0.4
Cyanide	1	2	3	1	1.5	2	2	2.5	3
Copper	4	5	6	4	5	6	4	5	6
Chromium	1	1.25	1.5	0.5	0.75	1	1	1.25	1.5
Mercury	0.01	0.015	0.02	0.005	0.008	0.01	0.01	0.015	0.02
Nickel	2	3	4	2	3	4	2	3	4
Lead	0.2	0.3	0.4	0.2	0.3	0.4	0.5	0.75	1
Zinc	10	15	20	10	15	20	10	15	20

* M.A: Monthly average. D.A: Daily average. I.V: Instant value. MPN: Most probable number.

CONAGUA's[13] process for obtaining a discharge permit is a thorough and comprehensive procedure. It is primarily based on the National Water Law of 2016, specifically referring to the provisions outlined in Articles 87, 88, and 89. The issuance of permits involves the coordination of two key federal environmental authorities: CONAGUA and SEMARNAT. The overarching objective of this process is to assess the potential environmental impacts of fish farming water discharges on the receiving water body. Aquaculture producers are required to complete and submit three applications as part of this process.

1. CONAGUA-01-001: Water effluents discharge permit
2. CONAGUA-02-002: Permit to develop hydraulic infrastructure.
3. CONAGUA-01-006: Concession for the occupation of Federal land as it concerns the administration of CONAGUA.

The application process for obtaining a discharge permit requires the collective submission of the aforementioned documents. Consequently, aquaculture farmers must possess an approved environmental impact assessment (EIA) by SEMARNAT that addresses the entirety of the production project, including an evaluation of the receiving waterbodies (Criterion 3 – Habitat). Within CONAGUA-01-001, applicants are obliged to provide specific information such as the volume, frequency, and nature (continuous/intermittent) of the discharges. They must also disclose any substances classified as "dangerous" or having the potential to cause contamination beyond the scope of NOM-001-SEMARNAT-1996. Furthermore, a comprehensive physical, chemical, and bacteriological characterization of potential discharges is required, encompassing parameters like biochemical oxygen demand and total suspended solids. Detailed descriptions of the water treatment systems and processes to be employed prior to discharge, as well as measures for water re-use, must be provided.

For both CONAGUA-02-002 and CONAGUA-01-006, a technical description of the project's construction and the corresponding site is needed. This entails a professional topographic survey examining the physical, geographical, and geological characteristics of the farm site in relation to the EIA. Additionally,

[13] https://catalogonacional.gob.mx/FichaTramite/CONAGUA-01-001.html

construction plans, including a thorough description, timing of execution, and infrastructure characteristics, must be included. These requirements are pertinent to assessing potential impacts arising from specific discharges into the water body and necessitate the specification of contingency measures to prevent such impacts.

As previously discussed, (see example in Figure 4), CONAGUA operates a water quality monitoring system throughout Mexico known as the National Network for Water Quality Measuring. This network comprises 289 monitoring discharge points, analyzing approximately 40 water quality indicators. The comprehensive nature of the application process, coupled with the coordination among multiple agencies, and the feedback provided by CONAGUA's monitoring efforts, suggests that cumulative impacts from aquaculture producers, as well as other industries and municipal waste, are considered during the permit approval process. However, the transparency of this process is not readily apparent. Overall, although the adoption of this system by the numerous tilapia farmers in Mexico may be limited (as discussed in Factor 2.2b below), the management measures outlined by CONAGUA are perceived as well-intentioned and comprehensive. With some uncertainties regarding the incorporation of cumulative impacts from other industries, the score for Factor 2.2a: Content of effluent management measures is 4 out of 5 for ponds.

<u>Factor 2.2b: Enforcement of effluent management measures</u>

The comprehensive nature of the application process for water concessions and effluent discharge permits presents a significant challenge in terms of uptake and enforcement, primarily due to the associated costs. These costs extend beyond the permit fees and include the preparation of application materials. The limited number of registered farms holding the necessary permits, concessions, and evaluations serves as a stark indicator of inadequate enforcement in this regard. It appears that the legal requirements are attainable only for high-income aquaculture producers, constituting just 21% of all producers within Mexico's aquaculture industry (Cuellar-Lugo et al., 2018). Additionally, it is estimated that a substantial proportion of resource-limited aquaculture (AREL) operations or micro-operations, responsible for approximately 60% of tilapia production units across almost all Mexican states, remains mostly unregistered. It is estimated that fewer than 50% of producers have completed registration with the National Registry of Fisheries and Aquaculture (RNPA), a prerequisite for conducting production activities in a formal capacity (Ortega-Mejia et al., 2023). These unauthorized operations, which are typically excluded from official statistics, operate without the required permits (Pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; Martinez-Cordero, 2021).

Furthermore, farms seeking compliance would need to obtain a discharge permit, install a water meter, establish a contract with a laboratory for water analysis, and pay a monthly fee based on the cubic meter of effluents. The lack of certified laboratories offering affordable water analysis poses a significant constraint for small and medium-sized operations (Martinez-Cordero, 2021). Perevochtchikova and Andre (2013) and FAO (2009) (although somewhat outdated) highlight the lack of follow-up in enforcement actions due to insufficiently trained staff and limited resources. The FAO report from 2009 previously described a "high tolerance of non-compliance" within regulatory mechanisms, while Aguilar-Manjarrez (2017) still notes extensive non-compliance with aquaculture regulations, including those related to wastewater discharge. Similarly, Lebel et al. (2009) suggest that many stakeholders they encountered during their studies acknowledged the infrequent enforcement of laws pertaining to water use and discharge.

The federal Environmental Protection Attorney's office (PROFEPA) implemented an initiative in 2015 with the objective of ensuring compliance with environmental regulations among shrimp farms in Sinaloa. The primary focus of the program is to address the low rate of adherence to requirements related to environmental impact permits, which was at 8% in Sinaloa in 2015 (SFW, 2019). It emphasizes the enforcement of regulations pertaining to land use authorization and effluent discharge (PROFEPA, 2015, 2016, 2017). In 2019, a total of 332 farms were inspected as part of this program, representing 80% of all shrimp farms in Sinaloa. Out of these inspections, 90% were successfully resolved through fines or corrective measures (PROFEPA, 2019). However, as of the time of writing this report, no indications have arisen to suggest that this initiative is presently being pursued. Although this initiative exclusively targets shrimp farms and does not encompass tilapia farms, it demonstrates the proactive approach of the enforcement agency and its commitment to improving regulation within the aquaculture industry.

In 2019, PROFEPA conducted 241 inspections on companies (inclusive of all industry with wastewater discharges) holding approved water discharge permits. The purpose of these inspections was to verify compliance with permissible limits for water quality. Out of the inspected companies, 79 demonstrated compliance with the discharge limits, 154 exhibited minor irregularities, and 8 were found to have severe irregularities, leading to the temporary partial closure of two sites and the temporary total closure of six sites. Additionally, during the same year, PROFEPA conducted a broader inspection encompassing 1,363 “site visits” located in significant hydrological basins or watersheds throughout Mexico. However, the specific context of these visits, such as their objectives and the types of sites inspected, remains unclear. It is uncertain whether the agency was primarily assessing water quality or the type of waste being discharged. Nonetheless, PROFEPA's report indicates that out of the visited sites, 523 were found to be in compliance, 805 exhibited minor irregularities, and 35 sites had severe irregularities, resulting in the temporary partial closure of 19 sites and the temporary total closure of 16 sites. Additionally, fines totaling 42.98 million pesos were imposed (PROFEPA, 2019).

As previously mentioned, CONAGUA has established a water monitoring network comprising approximately 3,800 surface water sites (2,685 total) and 1,096 groundwater sites (Figure 4 provides an example of sampling sites, reporting on the biochemical oxygen demand indicator). However, the number of monitoring sites specifically located at discharge points is significantly lower, with only 281 surface water sites and 8 groundwater sites (CONAGUA[14], 2017). CONAGUA has also developed a publicly accessible online platform called the Public Registry for Water Rights[15], which provides registries of commercial entities categorized by industry type and state, indicating whether they have applied for surface or groundwater use permits or water discharge permits. However, a preliminary analysis of the reported permits suggests either a lack of permit allocation to aquaculture producers or potential unreliability of the data reported through this platform. For instance, Guzman-Cesar (2014) estimates the number of aquaculture farmers in Veracruz (not species-specific) to range from 800 to 1,500. Regardless of the wide range in this estimation, the number of reported registries in the Public Registry of Water Rights since 1995 for aquaculture producers is as follows: 38 for surface water use, 26 for groundwater use, and 65 for water discharges. Thus, this considerable discrepancy may indicate inaccurately reported permits or reflect the fact that only about 5% of Veracruz's tilapia operations are considered commercial farmers (producing 10 or more metric tons annually), representing the only producers capable of affording the expenses associated with obtaining permits.

[14] https://apps1.semarnat.gob.mx:8443/dgeia/informe18/tema/cap6.html
[15] https://app.conagua.gob.mx/ConsultaRepda.aspx

In addition, there are reports indicating that state committees for aquaculture health conduct further water testing within their respective states. According to CENASAY (2019a and 2019b), 26 aquaculture sites were tested for microbiological agents, 20 sites were tested for heavy metals, 20 sites were tested for pesticides, and a total of 208 water quality samples were analyzed in 2019 in the state of Nayarit. Similarly in Veracruz, tests aiming to assess pollutant concentrations in groundwater, including surface wells and water wells in aquatic farms situated along rivers, as well as lagoon systems; revealed that concentrations of nitrates, total coliforms, *Vibrio* sp., temperature, salinity, dissolved oxygen, and pH exceeded the permissible limits established by Mexican standards (Sosa-Villalobos et al., 2016). In 2020, COSAES monitored two UPAs in Sonora, finding traces of heavy metals such as arsenic (0.3 ppm in UPA 1 and 0.09 ppm in UPA 2), mercury (0.05 ppm in UPA 1), and lead (0.08 ppm in UPA 1) (COSAES, 2020). The extensive network of water quality testing sites at the federal level, along with the monitoring efforts conducted at the state level, indicate a certain level of enforcement. However, it is evident that the majority of tilapia producers in Mexico do not possess the necessary permits to utilize public waters or discharge wastewater into public water bodies. Furthermore, the available literature strongly suggests that enforcement measures concerning aquaculture effluents are not effectively implemented. Therefore, enforcement measures are considered to be limited, with limited monitoring and compliance data. The score for Factor 2.2b: Enforcement of effluent management measures is 2 out of 5 for ponds. Factors 2.2a and 2.2b combine to give a low final score for Factor 2.2—Management of Farm-Level and Cumulative Impacts of 3.2 out of 10.

Conclusions and Final Score: Ponds

Without sufficient data to understand the effluent impacts (or lack thereof) of pond farms, the risk-based assessment was used. Considering the available information on typical feed and fertilizer use, it is estimated that there is a total nitrogen input of 122.8 kg N/mt of tilapia (a value slightly higher to that stated in an independent certification audit of a net pen producer). After the removal of nitrogen in harvested tilapia, the total waste nitrogen produced is 100.4 kg N per mt. Approximately half of this is considered to be discharged from the ponds to the environment (51.2 kg N/mt, and a score of 4 out of 10 for Factor 2.1). The application process for aquaculture discharge permits in Mexico is thorough and involves coordination among multiple agencies. The comprehensive nature of this process, combined with monitoring efforts by CONAGUA, indicates that the cumulative impacts of aquaculture producers, as well as other industries and municipal waste, are taken into account during the permit approval process. However, the uptake of the necessary permits remains low, and the majority of tilapia farms continue to operate without complying with the legal requirements. The costs associated with achieving compliance continue to pose a significant challenge for most tilapia producers. Thus, with low effective enforcement, the effluent management score (Factor 2.2) is 3.2 out of 10 for ponds. The scores combine to give a final score for Criterion 2—Effluent of 4 out of 10 for ponds.

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.
- *Unit of sustainability:* 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	Value	Score
	Net Pens		Ponds	
F3.1 Habitat conversion and function		9		4
F3.2a Content of habitat regulations	3		3	
F3.2b Enforcement of habitat regulations	3		3	
F3.2 Regulatory or management effectiveness score		3.60		3.60
C3 Habitat Final Score 0-10)		**7.20**		**3.87**
Critical?	NO	**Green**	NO	**Yellow**

Brief Summary

Tilapia aquaculture in Mexico is primarily conducted in net pens located in reservoirs, and in ponds near freshwater sources. Although net pens contribute to the majority of the volume produced, ponds represent the majority of aquaculture production units spread across the country.

The habitat impacts associated with floating net pens in artificial environments, such as reservoirs, are generally considered to be limited. However, considering their number and distribution, it is still likely that these net pens have some degree of impact on the remaining ecosystem services provided by these waterbodies, but it is considered here to be minimal. The Habitat Conversion and Function score (Factor 3.1) for net pens is 9 out of 10. For pond farms, the available evidence indicates that the majority of farms in Mexico have been built in low value habitats (e.g., former agricultural land or scrubland), and there are unlikely to be substantial cumulative habitat impacts such as fragmentation due to the generally dispersed nature of the farms. However, habitat impacts have also been observed to riparian forests and other forest areas, which are considered moderate-value habitat, and overall, this results in a final score of 4 out of 10 for Factor 3.1 - habitat conversion and function score concerning ponds.

The management of tilapia production in reservoirs and ponds is governed by interconnected legislations such as the General Law of Sustainable Aquaculture and the Fisheries General Law of Ecological Balance and Environmental Protection. There appears to be coordination between agencies involved in the permitting process. However, it is evident that the existing regulations are not adequately designed to address the loss of ecosystem services, and they have limitations in terms of their effectiveness. Furthermore, while enforcement efforts aimed at protecting habitat exist and the responsible institutions are identifiable and contactable, the issue of cumulative impacts is not adequately addressed. The Farm Siting Regulation and Management score (Factor 3.2) is 3.6 out of 10 for net pens and ponds.

The final score for Criterion 3 — Habitat for net pens is 7.2 out of 10, and for ponds is 3.9 out of 10.

Justification for Ranking
The national development plan[16] of the federal government, spanning from 2019 to 2024, emphasizes two priority areas: food self-sufficiency and the restoration of agricultural fields. In line with these priorities, the aquaculture sector in Mexico is undergoing structural reforms aimed at establishing an industry capable of generating significant quantities of high-quality food. This industry is envisioned as a fundamental pillar in ensuring food security for the country while simultaneously facilitating job creation and economic benefits (Reyes-Delgadillo et al., 2015). It is considered to be crucial that these objectives are achieved within a sustainable framework that optimizes the utilization of Mexico's natural resources (Reyes-Delgadillo et al., 2015).

Furthermore, the SEMARNAT Sectorial Program, published in 2020, places its primary objective on promoting the conservation, protection, restoration, and sustainable utilization of ecosystems and their biodiversity. This approach incorporates considerations of territorial and human rights aspects, with the overarching aim of maintaining functional ecosystems that form the foundation for the well-being of the population (DOF[17], accessed June 2023).

These federal initiatives and regulatory agencies appear to be aligned in fostering the development of the country's food production sector while simultaneously planning for the sustainable use of land, natural resources, and ecosystem functionality. However, determining the actual outcomes and impact of these national goals can be a complex undertaking. The role of tilapia aquaculture production in net pens and ponds and their implications in the natural environment will be discussed separately in the following sections.

Factor 3.1. Habitat conversion and function

<u>Net Pens</u>
The construction of water dams represents a significant threat to the conservation of global freshwater ecosystems, causing hydrological alterations that have far-reaching consequences (Johnson et al., 2008). While dams have undeniably contributed to human development and yielded notable benefits, their construction, operation, and maintenance come at a high cost to the environment, economy, and society (Martinez-Yrizar et al., 2012). Ecologically, the land-use transformation caused by dams can result in the loss of substantial vegetation cover and the disturbance of riparian ecosystems due to reservoir flooding. This, in turn, negatively affects downstream river processes, such as modifications to deltas and coastal dynamics (Martinez-Yrizar et al., 2012). Moreover, apart from regulating flow, dams fragment aquatic habitats, impede species movement, and disrupt the downstream transport of nutrients. The flooding required for reservoir creation hampers access to natural resources, leading to degradation of agricultural and grazing lands, diminished fishery potential in estuaries due to reduced freshwater input, and the cultural displacement of individuals, ethnic groups, or marginalized communities (Martinez-Yrizar et al., 2012).

[16] https://www.dof.gob.mx/nota_detalle.php?codigo=5565599&fecha=12/07/2019#gsc.tab=0
[17] https://www.dof.gob.mx/nota_detalle.php?codigo=5596232&fecha=07/07/2020#gsc.tab=0

Despite the prevalent socio-ecological challenges arising from dam construction, certain regions such as Chiapas, where freshwater resources are abundant, may exhibit distinct outcomes in relation to the reported effects of building dams along flowing rivers. For instance, water reservoirs in Chiapas play a crucial role in maintaining biogeochemical cycles, hydrological processes such as water flow and aquifer recharges, and supporting biodiversity in the region's ecosystems (ATT Innova, 2015). These reservoirs also contribute to climate regulation, enhance resilience against extreme weather events, control erosion and sediment retention, facilitate nutrient recycling, and provide refuge to wild fauna (ATT Innova, 2015). Notably, the Grijalva-Usumacinta waterbody network accounts for 30% of Mexico's total river flow, amounting to 147 km^3 per year, and provides habitat for 67% of all species found within the country (ATT Innova, 2015). Preserving the functionality of these habitats ensures the provision of ecosystem services, such as habitable areas for local communities, hydroelectric power generation (1,080 megawatts per year), viable areas for food production, and various socio-economic activities to support the well-being of the local population (ATT Innova, 2015).

Reservoirs are highly modified artificial environments, and thus, the impacts produced by aquaculture net pen production are not directly on the natural environment. Net-pen systems, as compared to other aquaculture methods like ponds, occupy a smaller area. Water usage in net-pen cultures is also relatively lower than in land-based cultures, as reported by Boyd et al. (2007), who found that net-pen systems consumed the least amount of water (0.75 m^3/mt) among all aquaculture systems.

Nevertheless, research conducted in temperate coastal water bodies has demonstrated that net-pens and their associated structures, such as floats, weights, mooring ropes, buoys, and anchors, contribute substantial physical structures to nearshore habitats. These structures modify light penetration, currents, wave action, and provide surfaces for the development of diverse biotic assemblages, further enhancing habitat complexity (McKindsey, 2011). Additionally, the increased nutrient inputs from aquaculture activities can exacerbate anthropogenic impacts in these water bodies and potentially affect adjacent rivers and streams. Please refer to Criterion 2 – Effluents for a more comprehensive description of these impacts. A poorly managed aquaculture industry poses a risk to the ecosystem services offered by large tropical rivers, like the Grijalva River connecting the four reservoirs that support tilapia production in Chiapas. These vital services, including food production, irrigation, hydropower generation, transportation, and trade routes, among others, could be compromised if appropriate management practices are not implemented (Bianchi, 2016). It is essential to ensure responsible and sustainable management of the aquaculture industry to safeguard the invaluable ecosystem services provided by these bodies of water.

Mexico features a substantial number of large inland waterbodies suitable for net-pen tilapia culture, encompassing approximately 180 dams with a combined capacity exceeding 127 billion cubic meters of freshwater (Martinez-Cordero, 2021; CONAGUA, 2017). These reservoirs are dispersed across the country, as illustrated in Figure 12. While the specific reservoirs currently involved in tilapia production remain unclear, ascertaining the precise production levels in each reservoir from official statistics is a challenge. However, it is worth noting that two reservoirs in Chiapas, namely La Angostura and Malpaso, rank as the largest and second-largest reservoirs in Mexico by water capacity, respectively (CONAGUA, 2017). Additionally, as stated in Criterion 2 – Effluent, Chiapas stands as the foremost state in net-pen tilapia production in Mexico, contributing to 66% of the total aquaculture production in both 2019 and 2020 (Martinez-Cordero, 2021; CONAPESCA, 2020). Consequently, for the purpose of this report, the findings from Chiapas can be considered representative of the net pen habitat impacts within the industry.

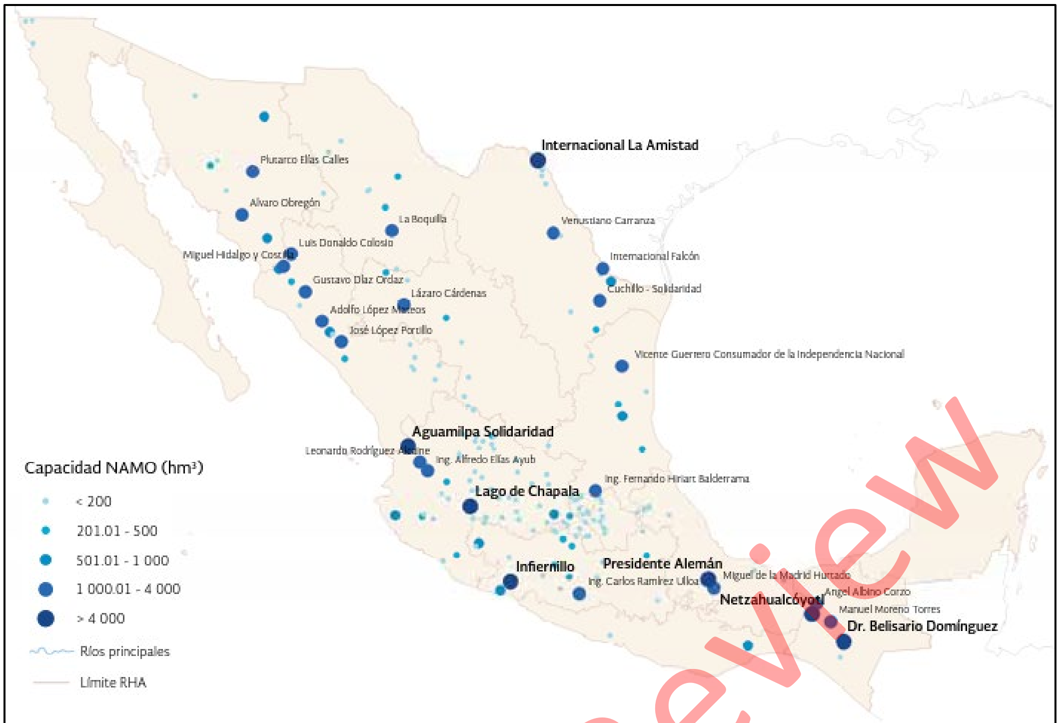

Figure 12. Main water reservoirs in Mexico as of 2016 (CONAGUA, 2017)

The land cover in the vicinity of the Malpaso reservoir comprises 75% cultivated pasture for cattle raising, 19% "temporary agriculture" (e.g., corn and beans), 3% perennial evergreen woods (including vulnerable species such as the Spanish cedar, according to IUCN), and 2% shrub-like deciduous forest (ATT Innova, 2015). While there are no natural protected areas immediately adjacent to Malpaso, the "Selva El Ocote" serves as a national reserve, and the "Parque Educativo Laguna Belgica" is designated as a zone under ecological conservation. Now, in La Angostura reservoir, vegetation cover reaches approximately 60%, predominantly characterized as lower-deciduous jungle vegetation, with additional pond-type vegetation such as arrowroot or water lilies observed in the lower-depth areas (Romero-Beltran et al., 2020b). These areas of the reservoir also provide essential resting and feeding grounds for migratory birds.

As mentioned previously (Criterion 2 – Effluent), INAPESCA conducted studies to identify suitable areas for aquaculture production in Malpaso, Peñitas, and La Angosturareservoirs and to estimate its physical carrying capacity (). Viable aquaculture sites require a depth ranging from a minimum of 15 meters to a maximum of 40 meters, with a sandy bottom serving as an indicator of appropriate water flow (ranging from 25.5 cm/s to 51 cm/s) (ATT Innova, 2015). Water quality parameters, covered in Criterion 2 - Effluent, were also taken into account when assessing site viability. The physical carrying capacity considers various physio-chemical properties of the area of interest (i.e., floor substrate, depth, hydrodynamics, temperature, salinity, and dissolved oxygen), excluding those strictly used to calculate the ecological carrying capacity, such as organic carbon concentration and chlorophyll. The studies determined that 4,195 ha for Malpaso, 153 ha for Peñitas, and 10,372 ha for La Angostura reservoirs were viable for aquaculture. It is worth noting that tilapia production in Malpaso, as of 2015, occurred in 1,253 cages, covering a total area of 572 hectares, which is significantly below the cumulative viable areas for aquaculture. This is not the case for Peñitas, where aquaculture is already taking place in 202.24 ha, surpassing the proposed 153 ha recommended by INAPESCA (CONAPESCA, accessed June

2023; Romero-Beltran, et al., 2020a). Furthermore, it is important to acknowledge that tilapia aquaculture in Chiapas experienced an approximate increase of 10,000 mt from 2015 to 2020 (CONAPESCA, 2020). Furthermore, the production in these reservoirs is expected to continue growing, as indicated by the presence of 11 aquaculture concessions awaiting approval, as depicted in Figures 21 and 22 (red polygons), all of which are smaller than four hectares in area each.

The artificial reservoirs under consideration offer a range of ecosystem services that yield significant economic, social, and to some extent, ecological benefits. Although the impacts associated with the construction of these reservoirs are subject to debate, it is important to recognize that these waterbodies are highly modified artificial environments. Consequently, considering the artificial nature of the reservoirs, the presence of a substantial number of floating net pen tilapia farms is reasoned to have only minimal impact on the ecosystem services provided by the lakes. Thus, the score for Factor 3.1 - Habitat Conversion and Function for net pens is determined to be 9 out of 10.

<u>Ponds</u>

Tilapia farmers utilizing earthen ponds and plastic tanks can be found across Mexico, strategically located in areas with convenient access to water sources such as rivers, lakes, or springs (Martinez-Cordero, 2021). The aquaculture production units (UPAs) map of Mexico, obtained from SENASICA in 2020, illustrates the widespread distribution of tilapia production throughout the country, with higher concentrations of farms observed in the southern region (see Figure 13). Unfortunately, detailed data regarding farm sizes, construction dates, or former habitat types are currently unavailable. Nonetheless, Figure 13 provides a general overview of the tilapia farming intensity across the country, suggesting that the majority of farms fall under the semi-intensive category, followed by hyper-intensive to intensive, and then extensive. Upon inspecting the area using satellite images from Google Earth, the red dots classified as "Growout" represent small producers employing extensive to semi-intensive pond systems. INAPESCA (2018) reported a total of 2,445 commercial tilapia farms and 1,960 self-subsistence farms based on local sub-delegation information from 2016. These farms collectively cover an area of approximately 21,580.25 ha. It is worth highlighting that the plastic tanks, which are frequently employed by a significant proportion of AREL and small farms (representing a minimum of 25% of UPAs), are designed in a manner that allows them to be relocated from the farm site. This suggests the potential for minimal to no impact on the surrounding habitat (pers. comm., Soledad Delgadillo, FAO, September 2023).

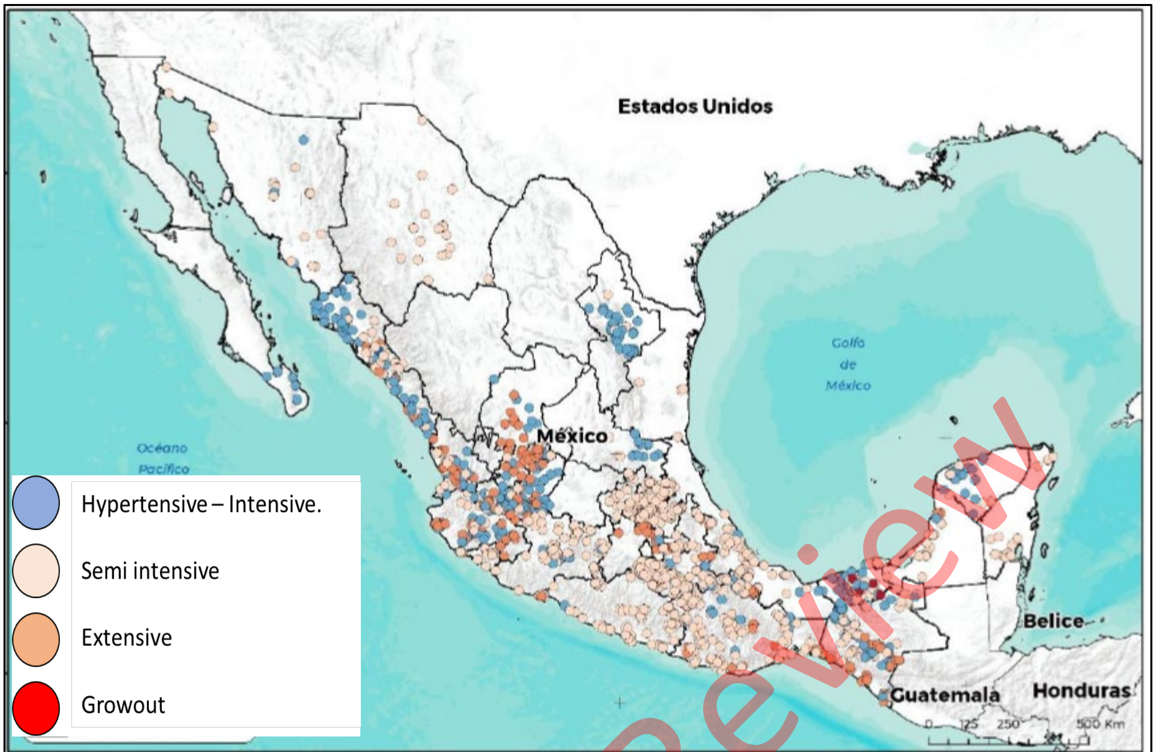

Figure 13. Distribution of tilapia aquaculture production units (UPAs) in Mexico in 2018 by type of production method. "Growout" refers to small extensive to semi-intensive producers (SENASICA, 2020).

CONAPESCA has developed a mapping tool that incorporates the locations of both approved and pending aquaculture concessions, as well as the officially registered aquaculture production units (UPAs). However, it is important to note that the exact date of the map's last update is unclear, and it is possible that updates may vary by state. Nevertheless, some concessions in the map's database appear to have information as recent as 2022, suggesting that recent updates have been made to the map's database. Upon visually exploring the mapping tool, it becomes evident that there is a diverse range of farm sizes involved in tilapia production across Mexico. For instance, Figure 14 displays a large tilapia pond farm located in Jalisco, Mexico, while Figure 15 shows an agricultural farm featuring three small tilapia ponds. By observing the farms represented in the CONAPESCA map layer, it becomes apparent that the majority of listed UPAs are characterized by their small or very small scale, often consisting of just one or two small ponds or a few circular tanks. These observations align with the findings of Martinez-Cordero et al. (2021), who reported that approximately 85% of UPAs in Mexico are categorized as micro or small-scale farms.

Figure 14. An example of a large tilapia farm in Jalisco, with many large ponds. The yellow line shows a scale of 0.1 mile. Image reproduced from Google Earth.

Figure 15. An example of a small tilapia farm in Tabasco, with two ponds. The yellow line shows a scale of 0.1 mile. Image reproduced from Google Earth.

Due to the absence of official records or comprehensive data on the specific types of former habitats where tilapia ponds have been established in Mexico, it becomes necessary to make an approximation based on the available information. In this case, the locational data provided by CONAPESCA can be utilized alongside satellite imagery, specifically using the historic image function of Google Earth Pro, in order to analyze a representative sample of tilapia UPAs and infer their former habitats.

A random selection process was employed at a broad level from the CONAPESCA map layer across Mexico (e.g., randomly selecting markers from 15 states in the map). For the selected farms identified by CONAPESCA as tilapia producers and where the resolution of Google Earth images permitted adequate visualization, the former habitats of 50 farms were documented. These former habitats were categorized into the following types: a) agricultural, b) sparse scrub, c) dense scrub or dry forest, and d) wetland or riparian forests. For categories c) and d), Google Earth Pro was utilized to determine if the forested area was adjacent to a marked river or stream. An illustrative example can be observed in Figure 16, where a riparian forest bordering a stream has been modified by a small-scale tilapia producer in Puebla. The results from the sample analysis revealed that 42% of the farms were situated in former agricultural lands, with 18% located in areas characterized by dry scrub, 24% in dry forests, and 16% in wetlands or riparian forests.

Figure 16. Riparian habitat modification due to the construction of a Tilapia farm in Puebla. Google Earth image from 2005 and from 2021.

During the visual examination of the UPAs documented by CONAPESCA, it became evident that the majority of farms were situated in low-value habitats, such as agricultural lands, sparse or dense scrub areas, and dry forests. Moreover, in cases where farms were located adjacent to water bodies, their land footprint appeared relatively small, typically occupying less than one hectare (as depicted in Figure 16). However, it should be noted that modifications to high-value habitats were observed in 16% of the sampled UPAs.

When evaluating the distribution of vegetation cover in Mexico in terms of high-value versus low-value habitats (as illustrated in Figure 17 and 18), it becomes apparent that a substantial overlap exists between these two habitat types, particularly in the central region of the country (INEGI[18], accessed June 2023). As previously indicated in Figure 13, tilapia farms are dispersed throughout Mexico, with a higher concentration observed in the central areas. The diverse range of habitats in Mexico, paired with variations in production scales, and with the large number of unregistered producers and consequently unknown habitat impacts where these unregistered producers operate (which will be discussed further in the section on enforcement of management measures) contribute to significant uncertainty in determining the precise extent of impact caused by tilapia ponds.

Figure 17. Vegetation cover for high-value habitats as classified by the Seafood Watch aquaculture standard. Purple indicates the evergreen forest distribution, and the green tones indicate other heavy vegetated forests (INEGI, accessed June 2023).

[18] https://www.inegi.org.mx/temas/usosuelo/

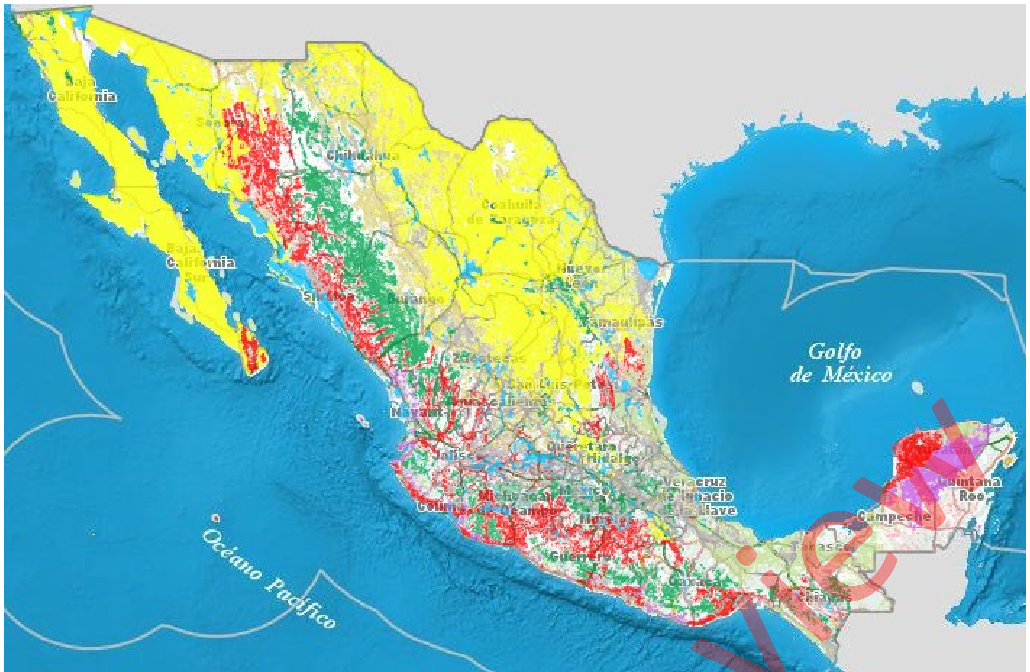

Figure 18. Vegetation cover for low-value habitats as classified by the Seafood Watch aquaculture standard. Purple and reds indicate the deciduous forest distribution, dark green represents coniferous forests, light green and gold represent cultivated and natural pasturelands, yellow represent dry shrubland, and blue and grey represent agricultural land (INEGI, accessed June 2023).

The CONAPESCA map also highlights the dispersed nature of tilapia farms (as well as UPAs for other species) across Mexico. While there may be clusters of farms within specific areas or regions, the absence of large contiguous farm areas can be observed (in contrast to what is commonly observed in Google Earth for shrimp farms in Southern Vietnam, for instance). Although this observation does not dismiss concerns regarding the cumulative impact of the total pond area or its potential contribution to habitat fragmentation, it further supports the conclusion that the construction of dispersed ponds, mostly within already modified agricultural landscapes, is unlikely to have a substantial cumulative impact.

Another important factor to consider when examining the cumulative impacts arising from land-use change within a given territory is to compare the land use across different productive sectors, as illustrated in Figure 19 for Mexico. The comparison reveals a stark contrast, demonstrating that the land utilized for aquaculture production (across all species) constitutes a minute fraction of the land dedicated to other primary productive activities within the country. Specifically, aquaculture operations occupy slightly over 118 thousand hectares, whereas temporary agriculture covers an extensive area of nearly 23 million hectares (INEGI[19], accessed June 2023).

[19] https://www.inegi.org.mx/temas/usosuelo/

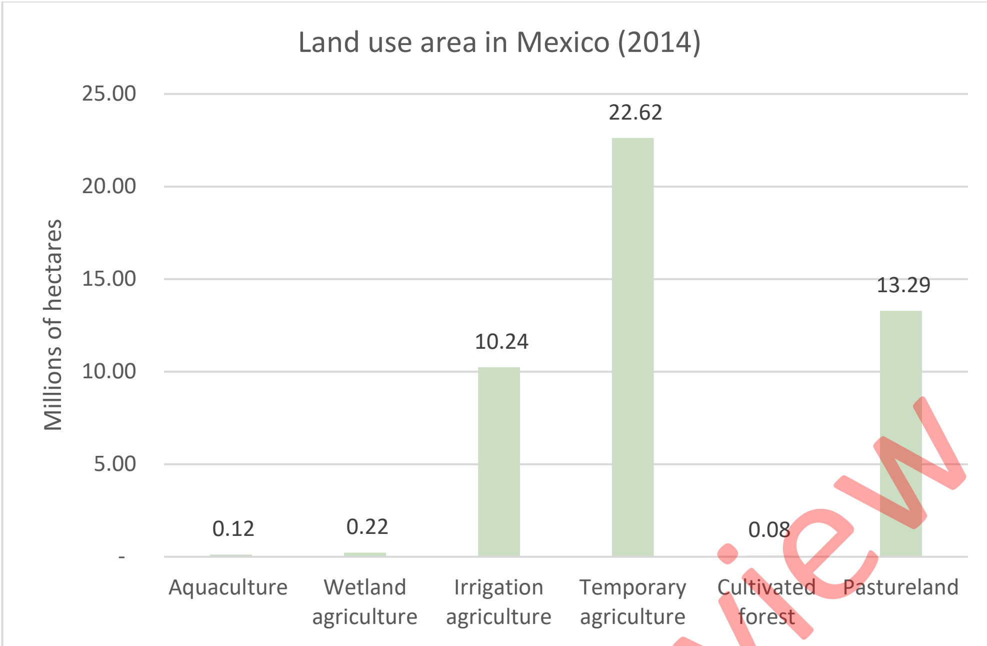

Figure 19. Surface area in hectares by type of land-use in Mexico in 2014 (INEGI, accessed June 2023).

The allocation and utilization of water resources are increasingly becoming subjects of contention, primarily due to escalating demands from industrial, agricultural, and domestic sectors (Sosa-Villalobos et al., 2016). In light of this, thorough planning is essential for land and resource utilization, particularly in coastal and adjacent areas to water bodies and watercourses. Such planning is crucial to avert conflicts with other stakeholders, whose numbers are surging as a consequence of population growth (Sosa-Villalobos et al., 2016). It is worth noting that the prevailing surface water sources are extensively contaminated, necessitating heavy reliance on groundwater as the primary freshwater source for aquaculture activities. Consequently, excessive extraction of groundwater has led to land subsidence in various regions, which can be considered an extension of habitat impacts caused by the operation of aquaculture farms (Sosa-Villalobos et al., 2016).

From the analysis of randomly selected farms through satellite imagery, it is observed that the typical tilapia farms in Mexico are often established on former agricultural land or in habitats of low ecological value, such as shrubland or dry forests. Considering that the agricultural land had previously undergone modification from its original natural state to become farmland, the subsequent conversion to aquaculture ponds is not considered to have led to a decline in ecosystem functionality. In other words, the ecosystem services provided by the agricultural land have generally been preserved, and the conversion to aquaculture has not resulted in a loss of overall functionality in the area.

However, it should be noted that in certain instances, the establishment of farms has had some negative effects on riparian forests or other forested areas since 1999, resulting in losses of moderate-value habitat. This would warrant a score of 2 out of 10 for Factor 3.1. Nonetheless, the ability to survey farms using Google Earth is limited due to time constraints and the availability of sufficiently high-resolution images from earlier periods. Moreover, taking into account the land-use distribution data reported by INEGI (as of June 2023) and the predominantly scattered distribution of farms, which primarily consist of micro and small producers, significant cumulative impacts on habitat fragmentation are not evident. Additionally, the majority of pond farms are considered to have been constructed in former agricultural land or other low value habitats, and to be maintaining the functionality of the ecosystems in which they were constructed, albeit with some moderate impacts, which would result in a score of 7 out of 10 for Factor 3.1. Thus, an intermediate score between 7 and 2 is appropriate, resulting in a final score of 4 out of 10 for Factor 3.1 - Habitat Conversion and Function, concerning ponds.

Factor 3.2. Farm siting regulation and management

There are notable intersections in the legal framework and regulatory provisions pertaining to the establishment of tilapia farms in Mexico and the subsequent impacts on the habitats where they are situated. This holds true for both pond systems and net pen production in water reservoirs. Consequently, the scoring for Factor 3.2 considers ponds and net pens collectively, and their scores are integrated with the respective scores obtained for Factor 3.1, specific to each production system.

Factor 3.2a: Content of habitat management measures
The following content relates to the current regulatory system in place for tilapia 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, which can be traced back to the 1980s (Vazquez-Vera y Chavez-Carreño, 2022).

The legislative instruments currently governing the regulation, promotion, and management of the exploitation of fisheries and aquaculture resources are the General Law of Sustainable Aquaculture and Fisheries (LGPAS[20]) of 2007 and the Law of Sustainable Rural Development of 2001, and its respective rulings[21]. These rulings refer to the laws' complementary Mexican official norms (NOM and NMX), which support the implementation of the law by specifying the requirements for the execution of aquaculture activities. Furthermore, the activity is also governed by other federal regulations outlined in the General Law of Ecological Balance and Environmental Protection, National Water Law, Regulations of the National Water Act, and the Federal Law of Rights. These regulations mandate the requirement of conducting an environmental impact assessment before undertaking the project, obtaining permits for water use, and implementing water treatment measures to ensure that discharged water does not contaminate the receiving bodies of water (Sosa-Villalobos et al., 2016). The required EIA holds utmost importance as the primary regulatory component when SEMARNAT and CONAPESCA authorize a particular site as a unit of aquaculture production (UPA), as explained ahead.

The LGPAS addresses aquaculture siting by giving Federal entities the power to agree upon actions that promote the territorial planning of aquaculture developments located in inland waters (Article 81 § IV); as well as to promote the establishment of protected areas and initiatives for the restoration, rehabilitation, and conservation of coastal, lagoon, and inland water ecosystems, in accordance with the provisions set forth in the General Law of Ecological Balance and Environmental Protection (Article 9 § III).

The General Law of Ecological Balance and Environmental Protection (LGEEPA) is intended to regulate ecological considerations. For instance, it stipulates the need to determine the ecological regionalization of the national territory, as well as the areas falling under the nation's sovereignty and jurisdiction, at the federal, regional, and local levels. This determination is based on a comprehensive assessment of various factors, including the characteristics, availability, and demand of natural resources, the

[20] https://www.diputados.gob.mx/LeyesBiblio/pdf/LGPAS.pdf
[21] https://www.dof.gob.mx/nota_detalle.php?codigo=5617393&fecha=03/05/2021#gsc.tab=0

productive activities conducted within these areas, and the distribution and status of existing human settlements (Article 20 § I).

The relevant provisions established by General Law of Ecological Balance and Environmental Protection (LGEEPA) include determining at the federal, regional, and local level, the ecological regionalization of the national territory and the areas over which the nation exercises sovereignty and jurisdiction, based on the diagnosis of the characteristics, availability, and demand of natural resources, as well as the productive activities carried out within them, and the location and status of existing human settlements (Article 20 § I). Additionally, it mandates the Federation to establish guidelines and ecological strategies for the preservation, protection, restoration, and sustainable utilization of natural resources, as well as for the location of productive activities and human settlements (Article 20 § I). Within the context of natural protected areas, Article 51 of this law specifies that the authorization, restriction, or prohibition of activities or resource utilization must align with the provisions outlined in the LGEEPA and the General Law of Sustainable Fishing and Aquaculture. Moreover, the law encompasses criteria for the sustainable use of water as a natural resource and aquatic ecosystems, including provisions related to aquaculture water concessions (Article 89 § IX).

In Mexico, 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 (I) 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.

<u>Environmental Impact assessment and management</u>

In 1996, LGEEPA 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). The EIA process starts with submission of a preventive report, which identifies whether there are Official Mexican Standards (NOMs) or other regulatory provisions governing emissions, discharges, natural resource exploitation, and overall environmental impacts resulting from the relevant works or activities (FAO, 2023). The specific contents of the preventive report are outlined in the Regulation. Following the submission and analysis of the preventive report, SEMARNAT determines, within a period of twenty days, whether an EIA should be conducted or if the preventive report is deemed sufficient.

As mentioned previously, an EIA is a prerequisite for obtaining a UPA permit through CONAPESCA[22], enabling the production of tilapia in any water body. This EIA must be conducted by a specialist in coordination with SEMARNAT, which holds the responsibility of assessing the validity of the EIA.

Typically, EIAs provide a comprehensive assessment of the anticipated impacts of a proposed project and propose mitigation strategies within the technical characterization of the project (Perevochtchikova and André, 2013; Aguilar-Manjarrez et al., 2017; SEMARNAT, 2012). These mitigation measures encompass both operational and decommissioning stages (Aguilar-Manjarrez et al., 2017), which include activities such as infrastructure abandonment, dismantling, and restoration (SEMARNAT, 2012). While the restoration component of proposed projects is mentioned in the laws previously discussed (LGPAS and LGEEPA), there is a lack of specific guidelines or requirements established by these laws, aside from NOM-022-SEMARNAT-2003, which provides some specifications for mangrove restoration. This issue was also raised by Ileana Villalobos in SEMARNAT's (2012) report, highlighting the lack of progress in habitat restoration in relation to EIA implementation.

In summary, FAO (2023), indicates that an EIA must provide information regarding:

- Particulars of the project, the applicant and the person responsible for the EIA.
- Description of the project.
- Linkage to applicable environmental provisions, and, where applicable, to land use regulations.
- Description of the environmental system and an indication of environmental problems in the project area.
- Identification, description and assessment of environmental impacts.
- Preventive and mitigating measures.
- Environmental forecasts and the identification of alternatives.
- Identification of methodological instruments and technical elements that support the information provided.

Under certain circumstances, the requirement for an EIA may be waived for an aquaculture farm situated on land that has undergone prior transformation, such as for crop cultivation or livestock rearing. However, the ultimate decision rests with SEMARNAT's judgement (Martinez-Cordero, 2021). Furthermore, mitigation strategies are enforced as conditions for aquaculture concession holders, as mandated by SAGARPA, to actively contribute to environmental preservation and the conservation and reproduction of species, including the implementation of repopulation programs (FAO, 2023).

<u>Effectiveness of regulation</u>

In the 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, and the pace of growth has often exceeded government capacity to regulate for environmental protections (FAO, 2009; Aguilar-Manjarrez *et al.*, 2017), a sentiment also expressed by industry itself (pers. comm., Soledad Delgadillo, FAO, September 2023; SEMARNAT, 2012). 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 EIA required for the

[22] https://www.dof.gob.mx/nota_detalle.php?codigo=5617393&fecha=03/05/2021#gsc.tab=0

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 (SFW, 2019).

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 (Ortega-Mejia et al., 2023; 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. This concern was recently conveyed by aquaculture industry stakeholders, by underscoring the presence of a bottleneck in information flow and the lack of communication between governmental entities like CONAGUA, CONAPESCA, INAPESCA, SENASICA, academic institutions, and the aquaculture producers (pers. comm., Soledad Delgadillo, FAO, September 2023). One stakeholder interviewed for this assessment referred to ongoing corruption and even the production of "fake" environmental impact assessments; another stated that Environmental Impact Assessments are often written by private consultants to "favor" a shrimp company (SFW, 2019).

Article 85 of the LGPAS emphasizes the importance of adopting an ecosystem-based management approach in aquaculture through the establishment of Aquaculture Management Units (UMA). The UMA is defined as a delimited zone that integrates multiple production units with shared infrastructure and facilities, operating collectively (LGPAS, 2010). Each UMA is required to have a comprehensive management plan in place, addressing the following aspects (relevant to habitat impacts):

1. Producer's action plans in the short and long term.
2. The carrying capacity of the water bodies from which the aquaculture production units intend to use for production.
3. The geographic characteristics of the area or region.
4. The existing infrastructure and planned development works, as well as their corresponding administrative program.
5. The description of the physical and biological characteristics of the aquaculture production unit.
6. Actions for the protection and sustainable utilization of natural resources, along with a compliance schedule for relevant legal provisions.

However, Reyes-Felgadillo et al. (2015) have pointed out the lack of clarity regarding the concept, objectives, and functionality of UMAs. This lack of clarity is further reflected in the absence of any mention of UMAs in the National Program of Fisheries and Aquaculture 2020-2024, indicating a persistent ambiguity surrounding their implementation. Moreover, a thorough investigation conducted within the relevant governmental agencies, such as SADER and CONAPESCA, yielded no evidence of UMAs being established in the country.

Although they may not be officially classified as UMAs, there are tilapia aquaculture cooperatives, such as the ones operating in La Angostura reservoir in Chiapas, that manage production collectively while holding UPA permits. However, it is important to recognize that net pen production in dams or reservoirs takes place in waterbodies that were not originally designated or developed for aquaculture purposes. As a result, the governing authorities responsible for these waterbodies typically prioritize other uses over net pen farming activities (Martinez-Cordero et al., 2021).

However, 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 EIA (SEMARNAT, 2012).

In summary, Mexico's regulations for aquaculture siting demonstrate commendable conservation elements, such as the interconnectedness between the LGPAS and the LGEEPA, as well as the coordination between enforcement agencies during the permitting process. An example of this coordination is the requirement for CONAPESCA to obtain a pre-approved EIA from SEMARNAT in order to authorize a UPA permit. However, it is evident that the existing regulations are not adequately designed to address the loss of ecosystem services and have limitations in terms of 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

The regulatory and enforcement agencies responsible for overseeing aquaculture in Mexico, such as PROFEPA, SEMARNAT, and CONAPESCA, are identifiable and accessible. Information regarding enforcement activities can be found on government websites, although it has certain limitations. CONAPESCA, for instance, offers downloadable data on annual enforcement actions, albeit at a general level with limited detail. Table 7 presents the results of their activities from 2019 to May 2023, providing an overview of the quantity of actions performed on a state level. While the reported number of activities by CONAPESCA may seem significant, it is important to consider the scale of the aquaculture and fisheries industries in Mexico (both regulated by CONAPESCA), with over 9,320 aquaculture sites encompassing more than 118,000 hectares and more than 115,000 active fishery permits (CONAPESCA, 2023a; CONAPESCA, 2023b, Vazques-vera y Chavez-Carreño, 2022). Therefore, the total of 10,579 enforcement activities in 2020 indicates that the available resources may not be adequate for effectively overseeing these industries. Furthermore, CONAPESCA does not provide sufficient additional information regarding the specific enforcement activities related to tilapia aquaculture operations, particularly in terms of surveillance, nor do they elaborate on the outcomes of these reported activities (CONAPESCA, 2023a).

Table 7. CONAPESCA's number of enforcement activities from 2019 to May 2023 (CONAPESCA, 2023a).

Activities	2019	2020	2021	2022	2023
Surveillance	8160	9344	8973	7293	1930
Inspections	305	255	288	379	150
Prevention workshops	32	11	156	217	83
Revision sites	409	26	25	68	62
Aquatic patrols	51	10	50	135	119
Terrestrial patrols	973	933	140	326	264
Total	**9930**	**10579**	**9632**	**8418**	**2608**

PROFEPA, the agency responsible for enforcing environmental regulations, offers access to annual activity data categorized by state, as well as a bit more detailed information in their annual reports. However, similar to CONAPESCA, the data provided by PROFEPA lacks context and generally specific details. For example, their 2019 data reports a total of 23 inspections related to environmental impacts and 21 inspections and 2 raids related to wildlife, but it does not provide further information on the nature of these impacts or the specifics of the inspections conducted (PROFEPA[23], 2019). In 2018, PROFEPA[24] published a news release announcing the closure of two aquaculture farms operating without the required permits (specifically, the SEMARNAT-EIA) in the Marismas Nacionales Biosphere Reserve, a Natural Protected Area. One of the farms was involved in shrimp production on a 20-hectare site, while the other was engaged in tilapia production on 8 hectares of coastal wetlands. The farm owners faced charges that could result in a federal prison sentence ranging from 2 to 10 years, as well as financial penalties ranging from 300 to 3,000 days of income based on their estimated daily earnings.

As previously discussed, the majority of tilapia net pen production in Mexico is concentrated in reservoirs where the carrying capacity and aquaculture viability have been studied to some extent. These studies are conducted as part of the EIA required during the aquaculture permitting process. Therefore, conducting a comparison between the viable aquaculture areas identified in INAPESCA's 2021 study (Figure 20) and the water concessions and UPA permits approved by CONAPESCA in the Malpaso reservoir (Figure 21) can provide insights into the extent to which these studies are taken into consideration (Romero-Beltran et al., 2021; CONAPESCA, 2023). Upon examining Figures 20 and 21, it is evident that there is a significant portion of aquaculture production occurring outside the designated viable aquaculture areas established by INAPESCA. This disparity between the authorized concessions (depicted by blue polygons in Figure 21), approved UPAs (represented by orange polygons and blue map pins in Figure 21), and the viable areas as outlined by INAPESCA (white areas in Figure 20), suggests that there may be a lack of adherence to these viability studies. Importantly, the red polygon delineated in Figures 20 signifies the eastern segment of the Malpaso reservoir, as also incorporated in Figure 21. Notably, the western section of the reservoir, with merely nine active producers in that particular zone, is consequently omitted from Figure 21.

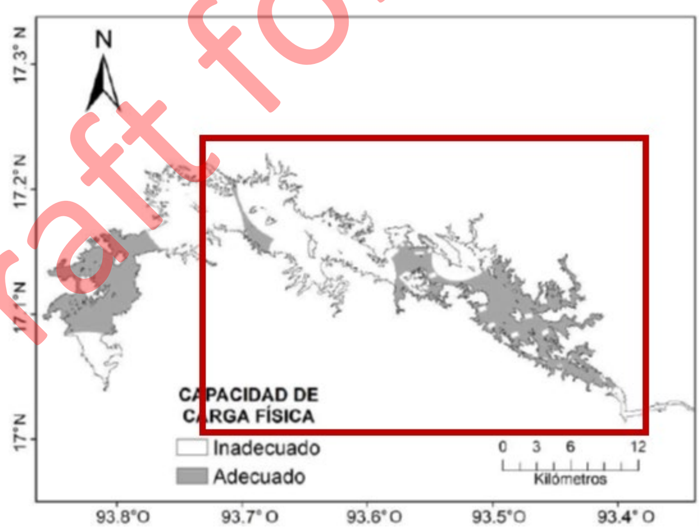

Figure 20. Malpaso reservoir map indicating the viable (dark areas) and not viable (white areas) areas for aquaculture production according to its physical carrying capacity (Romero-Beltran et al., 2021). The red polygon indicates the area of the reservoir shown in the following Figure 21.

[23] http://www.profepa.gob.mx/innovaportal/v/7635/1/mx.wap/datos_abiertos.html
[24] https://www.gob.mx/profepa/prensa/clausura-profepa-dos-granjas-acuicolas-en-anp-reserva-de-la-biosfera-marismas-nacionales-nayarit

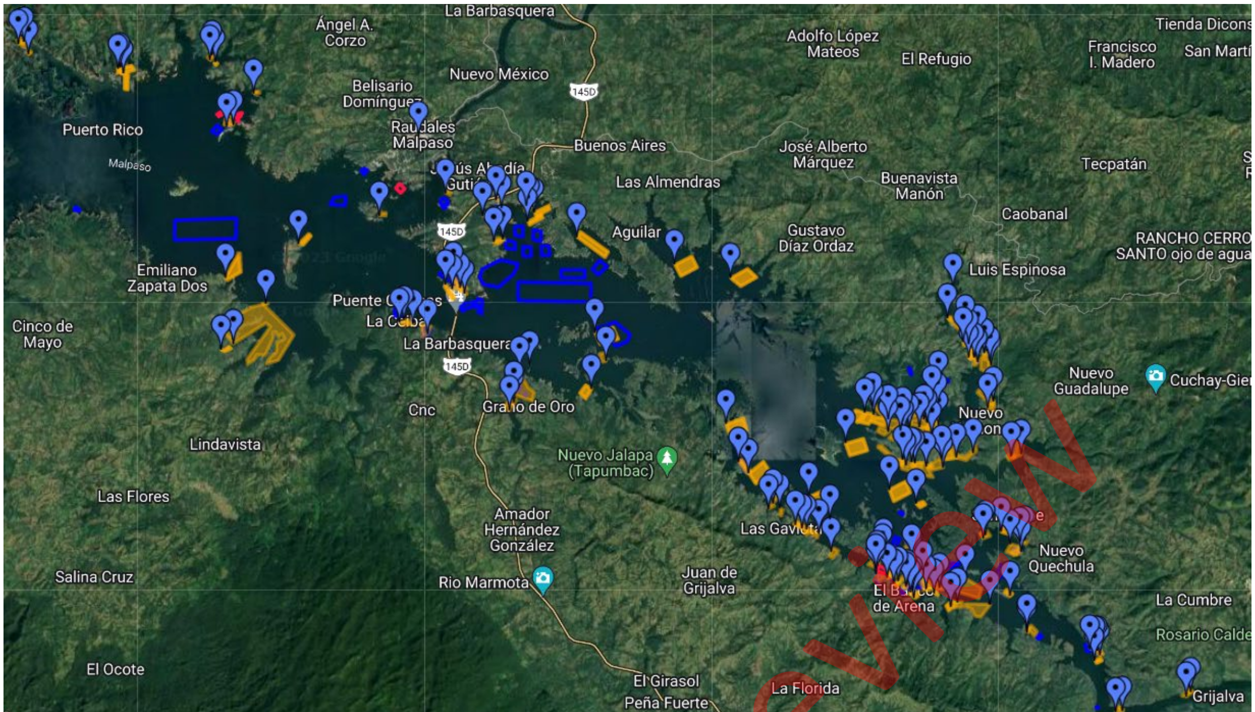

Figure 21. CONAPESCA's mapping tool showing the approved (blue polygons) and waiting for approval (red polygons) aquaculture concessions and registered UPAs (orange polygons and blue map pins) in Malpaso reservoir, in Chiapas, Mexico. (CONAPESCA, accessed June 2023).

Additionally, it is worth noting that the compliance with required permits and official farm registrations in the Malpaso reservoir was significantly lacking even though the industry at this reservoir has been active for decades. According to ATT Innova's report, up until 2015, 83% of UPAs holders either did not possess all the necessary permits or had not officially registered their operations with the relevant authorities; and 50% of the surveyed active producers did not possess a pre-approved EIA by SEMARNAT (ATT Innova, 2015).

Furthermore, Romero-Beltran et al. (2020b), suggest that among the four cooperatives operating UPAs in the La Angostura reservoir, only two adhere to their assigned water concession boundaries, while the other two significantly exceed their authorized areas. For instance, one producer was found to be operating within their authorized 6.46 ha, but also occupying an additional unauthorized area of 6.83 ha, effectively more than doubling the authorized area (Romero-Beltran et al., 2020b). Similarly, the second non-compliant producer operates in an area that is ten times larger than their authorized water concession, with an authorized area of 0.60 ha compared to the actual occupied area of 6.5 ha (Romero-Beltran et al., 2020b).

However, it is evident that there are efforts being made in the region by the enforcement agency, CONAPESCA, to assist small-scale local producers in operating within the legal framework. For example, in 2014, CONAPESCA adopted an open-door approach to inform producers about the legal requirements and provided assistance in submitting the necessary paperwork (ATT Innova, 2015). As a result of this initiative, 58 producers were able to complete the required documentation and operate legally in the reservoir. Though, no evidence was found signaling to the effectiveness of this effort, and the overall level of informality among tilapia producers in Chiapas and Mexico as a whole remains a significant concern (pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; pers. comm., Mauricio Orellana, Neoaqua, April 2023).

It is also worth noting that approximately 40% (equivalent to approximately 15,000 mt) of Chiapas' total aquaculture production occurs in the Peñitas reservoir (ASC, 2022; CONAPESCA 2020). As previously mentioned, the current tilapia production in the Peñitas reservoir is below INAPESCA's estimated carrying capacity of 18,207 metric tons. However, when we compare the areas currently utilized for tilapia production within the water concessions delineated in Figure 22 (blue polygons) with the suitable areas identified by INAPESCA in 2020, as presented in Figure 23, it becomes evident that the largest authorized concessions (Figure 22) have been operating in areas that substantially overlap with those areas more recently deemed unsuitable for aquaculture by INAPESCA (Figure 23). Furthermore, the approved water concessions in Peñitas, already allocated for 202.24 ha, surpassing the proposed 153 ha recommended by INAPESCA (CONAPESCA, accessed June 2023; Romero-Beltran, et al., 2020a). According to CONAPESCA's mapping tool, there is an additional 2.5 ha currently pending approval. In 2019, CONAPESCA allocated 460 thousand pesos (~$27,000 USD) to develop a management plan for the Peñitas reservoir, although as of the writing of this report, the plan was not publicly accessible (CONAPESCA, 2021). It is worth highlighting that a significant portion of the production in this reservoir is attributed to a single producer, the existing mega farm, which is certified by the ASC and adheres to their required production practices that are audited by a third party (ASC, 2022).

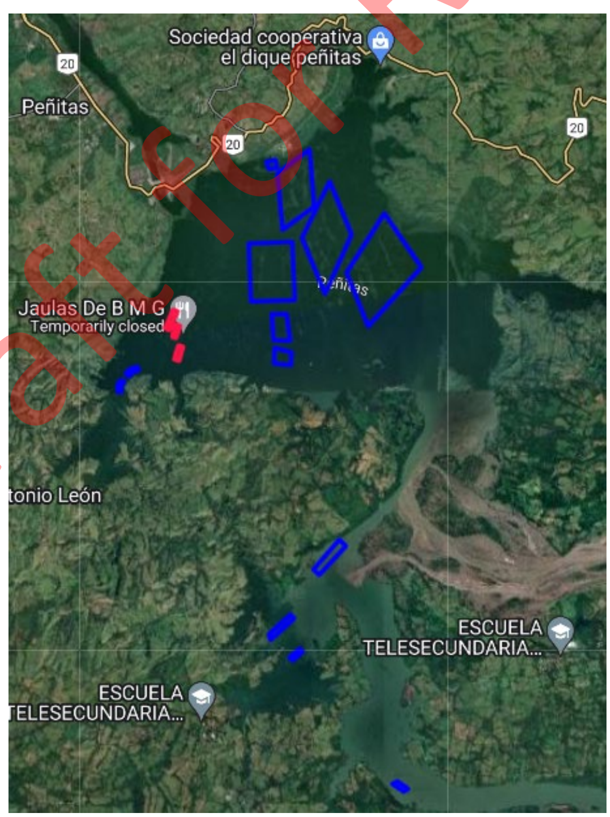

Figure 22. CONAPESCA's mapping tool showing the approved (blue polygons) and waiting for approval (red polygons) aquaculture concessions in Peñitas reservoir, in Chiapas, Mexico. (CONAPESCA, accessed June 2023).

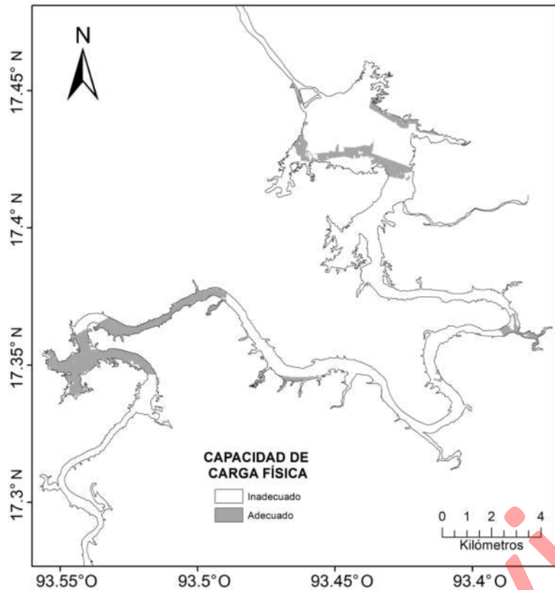

Figure 23. Physical Carrying capacity: Suitable areas (dark areas) and unsuitable areas (white areas) for the development of aquaculture projects in the Peñitas reservoir, Chiapas.

Similar disparities between the areas authorized by CONAPESCA and the actual areas utilized for tilapia farming are also evident in ponds production across the country. For instance, the Nayarit region illustrated in Figure 24, depicts the officially registered aquaculture land concessions designated by CONAPESCA (orange polygons and blue map pins), as well as the extent to which aquaculture production is occurring beyond these authorized boundaries (highlighted as red polygons). It is important to note that while tilapia is included as one of the species being cultivated within all of these orange polygons, the majority of these UPAs encompass the rearing of multiple species, such as catfish and ornamental fish.

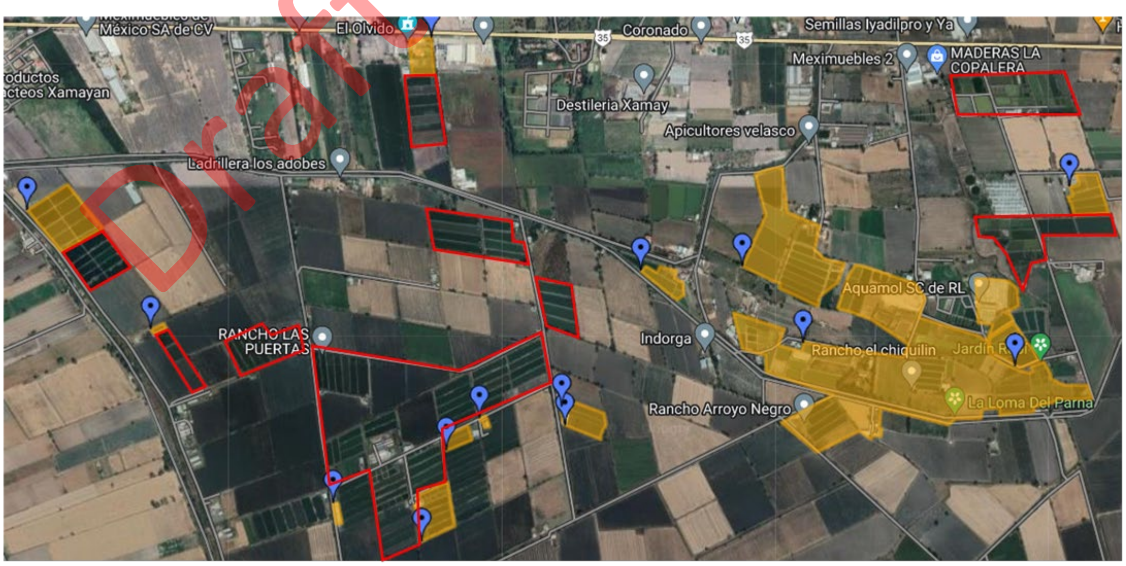

Figure 24. CONAPESCA's mapping tool showing the approved aquaculture concessions (orange polygons and blue pins) and un-registered areas of aquaculture production (red polygons) in Nayarit, Mexico. (CONAPESCA, accessed June 2023).

The non-compliance with authorized aquaculture areas in ponds and water reservoirs is evident throughout Mexico. However, researchers have also highlighted the challenges stemming from the lack of traditional practices and experience in tilapia culture and freshwater fish farming in general. This, coupled with limited land tenure across the country, insufficient rapprochement between authorities and producers to make surveillance, advisory, or extension visits, poses significant constraints on the development of tilapia culture in earthen ponds and in reservoirs (Ortega-Mejia et al., 2023; Martinez-Cordero, 2021). Furthermore, the current National Development Plan (NDP) for the period 2019-2024, which places emphasis on the restoration of agricultural fields, may discourage the government from allocating land resources for tilapia earthen pond culture (Martinez-Cordero, 2021). These factors collectively contribute to the slow progress of the aquaculture industry in Mexico.

In summary, there is evidence that enforcement of regulations aimed at protecting habitat exists and these institutions are identifiable and contactable. Watchdog organizations have adopted a complaint-driven approach to enforcement, leading to some enforcement actions being taken. PROFEPA, as the federal body entrusted with enforcing environmental regulations, has successfully closed down two aquaculture farms operating within natural protected areas, resulting in the imposition of penalties. However, there is evidence suggesting that the issue of cumulative impacts is not adequately addressed, as evidenced by the presence of active operations without the required EIAs and the granting of water concessions in regions within reservoirs that INAPESCA's carrying capacity studies have since identified as unsuitable for aquaculture (refer to Figures 20 to 23). Moreover, the lack of adherence to CONAPESCA's authorized production areas in ponds and reservoirs highlights significant gaps in compliance with regulatory requirements. Therefore, 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 for net pens and ponds is 3.6 out of 10.

Conclusions and final score

Tilapia aquaculture in Mexico is primarily conducted in net pens located in water reservoirs, and in ponds near freshwater sources. Although net pens contribute to the majority of the volume produced, ponds represent the majority of aquaculture production units spread across the country.

The habitat impacts associated with floating net pens in artificial environments, such as reservoirs, are generally considered to be limited. However, considering their number and distribution, it is still likely that these net pens have some degree of impact on the remaining ecosystem services provided by these waterbodies, but it is considered here to be minimal. The Habitat Conversion and Function score (Factor 3.1) for net pens is 9 out of 10. For pond farms, the available evidence indicates that the majority of farms in Mexico have been built in low value habitats (e.g., former agricultural land or scrubland), and there are unlikely to be substantial cumulative habitat impacts such as fragmentation due to the generally dispersed nature of the farms. However, habitat impacts have also been observed to riparian forests and other forest areas, which are considered moderate-value habitat, and overall, this results in a score of 4 out of 10 for Factor 3.1 - habitat conversion and function score concerning ponds.

The management of tilapia production in reservoirs and ponds is governed by interconnected legislations such as the General Law of Sustainable Aquaculture and the Fisheries General Law of Ecological Balance and Environmental Protection. There appears to be coordination between agencies involved in the permitting process. However, it is evident that the existing regulations are not adequately designed to address the loss of ecosystem services, and they have limitations in terms of their effectiveness. Furthermore, while enforcement efforts aimed at protecting habitat exist and the responsible institutions are identifiable and contactable, the issue of cumulative impacts is not adequately addressed. The Farm Siting Regulation and Management score (Factor 3.2) is 3.6 out of 10 for net pens and ponds.

The final score for Criterion 3 — Habitat for net pens is 7.2 out of 10, and for ponds is 3.9 out of 10.

Criterion 4: Chemical Use

Impact, unit of sustainability and principle

- *Impact:* The use of chemical treatments can impact non-target organisms and lead to ecological and human health concerns due to the acute or chronic toxicity of chemicals and the development of chemical-resistant organisms.
- *Unit of sustainability:* Non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to treatments.
- *Principle:* Limit 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

Mega farm

Chemical Use parameters			Score
C4 Chemical Use Score (0-10)			**8**
	Critical?	NO	**Green**

Net pens and ponds

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

Brief Summary

The increasing scale and intensity of production have led to the emergence of diseases as a common and severe problem in global tilapia aquaculture, including in Mexico, introducing the potential for veterinary medicines and treatments. Ten products are specifically listed for use in fish in Mexico: four antimicrobials, one antiparasitic treatment, four vaccines, and one hormone, but there are no readily available data with which to understand their use in Mexico's tilapia farms. Despite a lack of readily available data, experts suggest that pharmaceutical treatments are utilized to control diseases, and academic studies suggest it is common. For example, a recent survey of 40 farms in the Malpaso reservoir indicated more than three-quarters used antimicrobials. In addition, one of the state-level Aquaculture Health Committees reported the use of streptomycin, which is not authorized in Mexico, and raises concerns about their illegal use. Therefore, although regulations and best management practices are apparent, they may not be followed in practice, which poses both environmental risks and economic losses for producers. While there is no evidence of prophylactic antimicrobial use in Mexico, the metaphylactic use of antimicrobials to treat entire populations remains prevalent. The rejection of imported shrimp from Mexico by the United States Food and Drug Administration due to drug residue violations indicates potential illegal antimicrobial use in the shrimp industry in Mexico, but no rejections have been reported for tilapia products.

Additionally, Mexico, like other low- and middle-income countries, has been linked to higher levels of antimicrobial-resistant bacteria, including in tilapia farming. Antimicrobial-resistant genes have been isolated in tilapia, and the presence of these genes is associated with the use of specific antimicrobials.

The use of antimicrobials in aquaculture poses environmental challenges, as residues can accumulate in sediments and contribute to the selection of antimicrobial-resistant species and genes, impacting natural ecosystems. However, a definitive link between antimicrobial use in aquaculture and the development of resistance in bacterial populations has yet to be established.

Although there is considerable circumstantial information available, the frequency and scale of chemical use in Mexico's tilapia farms is essentially unknown regarding the specific data (or lack thereof) from the thousands of farms. Circumstantial evidence indicates that antimicrobials highly and critically important for human medicine are being used in unknown quantities, resulting in a final score for Criterion 4—Chemical Use of 0 out of 10, for ponds and net pens (excluding the existing mega farm). In contrast, the existing mega farm does have good data availability through third-party audits from the Aquaculture Stewardship Council, and has only used one antimicrobial treatment since 2015 (in 2022). Therefore, chemical use is considered to be less than once per production cycle, and the final score for the existing mega farm for Criterion 4—Chemical Use is 8 out of 10.

Justification of Rating

There has historically been a low need for chemical use on tilapia farms because of the disease-resistant nature of these species (Boyd 2004) (Fitzsimmons 2007); for example, Boyd (2004) stated that antimicrobial (AM) use in tilapia culture is extremely rare. But, with increasing scale and intensity of production, diseases became an increasingly common and severe global problem, including in Mexico (Velasquez, 2022; El-Sayed, 2019).

Unfortunately, there do not appear to be any readily available data on chemical use in aquaculture in Mexico, and no academic studies could be found that robustly defined their use (or non-use). An information request was made to the National Service for Health, Safety, and Quality of Agro-foods (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria, SENASICA), the federal entity regulating the use of antimicrobials or veterinary drugs, which provided a list of registered chemicals for aquaculture (discussed further below). However, no data were available on the volume or frequency of their use (pers. comm., SENASICA representatives, May 2022). Although SENASICA did not provide specific information regarding the extent of pharmaceutical use in tilapia production, experts in the industry suggest that pharmaceutical treatments are employed in Mexico to control diseases and raised concerns about their unregulated use among a significant portion of producers (pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; pers. comm., Anonymous, Asia-Pacific Economic Cooperation, April 2023; Todo Tilapia, 2021). The only specific data points available from tilapia farms in Mexico are the audit reports of the existing mega farm certified to the Aquaculture Stewardship Council (ASC, 2022), which operates in the two water reservoirs in Chiapas mentioned previously (Malpaso and Peñitas).

Specific Feedback Request from Expert Review
Further information is requested with regard to the volume and frequency of antimicrobial and pesticide use in Mexico's tilapia aquaculture production (or in Mexico's aquaculture industry).
Response:

Regulatory Measures for Veterinary Medicines

The regulatory framework for veterinary treatments in Mexico consists of various laws and norms, including the Specifications for the Regulation of Chemical, Pharmaceuticals, Biological and Feed

Products for Animal Use or Consumption (NOM-012-ZOO-1993[25]). This norm sets forth requirements for the production and quality control of products intended for use and consumption in animals and applies to chemical producers, importers, distributors, and retailers that may pose a zoo-sanitary risk. Another important regulation is the Guidelines for the Classification and Prescription of Veterinary Pharmaceuticals Based on the Risk Level of Active Ingredients (NOM-064-ZOO-2000[26]). This norm establishes technical and scientific criteria for the classification, prescription, sale, and use of active ingredients used in the formulation of veterinary pharmaceutical products, taking into account their potential risks to animal and public health. It applies to veterinary pharmaceutical producers, manufacturers, importers, distributors, retailers, and any entity involved in the prescription or application of such substances.

According to SENASICA[27], there are approximately 9,400 registered veterinary products in Mexico as of March 22nd, 2023. Among these, 10 products are specifically authorized for use in tilapia aquaculture or fish in general. These authorized products include four antimicrobials (oxytetracycline, florfenicol, enrofloxacin, and the sulfadimethoxine-ormetoprim mix), one antiparasitic treatment (ethylenediamine dihydroiodide), four vaccines (for Streptococcus), and at least one hormone (17-α-methyl testosterone for sex reversal in fry) (Pers comm. SENASICA representatives, May 2022; SENASICA, 2023; SENASICA, 2008). SENASICA issues a Certificate of Aquaculture and Fisheries Welfare for the Use and Application of Antibiotics (CSAUA) for each of the authorized chemicals. These certificates specify the correct doses for producers to use. The pharmaceuticals mentioned above align with those listed in the best practice tilapia manual, with the exception of enrofloxacin, which is classified as a critically important antibiotic for human medicine by the World Health Organization (WHO, 2019). The different groups of treatments are discussed briefly in the following sections.

SENASICA manages aquaculture health through state-level Aquaculture Health Committees. Aquaculture Health Committees 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, along with promoting best practices—including using antimicrobials as a last resort (COSAES[28]; CESASIN[29]; CESAJ [30]; CESANAY[31]; accessed May 2023; 2014b, 2019a). In a few tilapia-producing states, aquaculture health committees periodically release reports on disease surveillance, as outlined in Criterion 7—Disease. However, accessing these reports can be challenging as the websites of these committees are often unavailable, either due to being disabled or non-existent. Furthermore, the limited information provided through the available websites appears to be unreliable due to the lack of detailed and contextual information regarding the reported data. As an example, in 2020, COSAES[32] reported the absence of antimicrobials (specifically classified as sulphonamides and others) in fish samples tested from two UPAs in the state of Sonora. However, the report did not specify the monitoring methods employed, the locations where the samples were collected, the species of fish

[25] https://www.gob.mx/cms/uploads/attachment/file/202293/Modificaci_n_C_NOM-012-ZOO-1993_270104.pdf
[26] https://www.gob.mx/cms/uploads/attachment/file/203504/NOM-064-ZOO-2000_270103.pdf
[27] https://www.gob.mx/senasica/documentos/productos-registrados-autorizados-regulacion-de-productos-veterinarios?state=draft
[28] https://www.cosaes.org/nosotros
[29] https://cesasin.mx/conocenos/
[30] https://osiap.org.mx/senasica/sector-estado/jalisco/Acuicola
[31] https://cesanay.org/cesanay/nosotros/
[32] https://www.cosaes.org/_files/ugd/e56b21_0ea4caafad7f4d95a566c4fa618e742a.pdf

tested, or the type of production system used. It is also worth highlighting that most of these Health Committees often do not have veterinary professionals among their staff, and they show deficiencies related to job security and technical-scientific training (Ortega-Mejia et al., 2023).

In terms of pesticide regulation, SEMARNAT has included an initiative in the Sector Program of Environmental and Natural Resources 2020-2024 to evaluate the contribution of pesticides to water pollution. However, this program lacks specific actions to oversee and reduce pesticide use across industries (OECD, 2021). Similarly, the Sector Program of Human Health 2020-2024 does not prioritize the assessment of pesticides and their effects on human health (OECD, 2021). Nevertheless, it is noteworthy that Mexico is among the few countries, including Denmark, France, Italy, Norway, and Sweden, that have implemented tax measures to reduce pesticide usage. The Federal Administration for Taxes (SAT) is responsible for implementing these taxes on pesticide users, based on the pesticide categories established in NOM-232-SSA1-2009. This norm not only categorizes pesticides according to their toxicity level in case of ingestion but also sets requirements for packaging and labeling of pesticides used in various industries.

<u>Antimicrobial use – prevalence and types</u>
An increase in the severity of bacterial diseases raises the potential for treatment with antimicrobials. There have been several documented disease outbreaks in Mexican tilapia farms, sometimes resulting in severe losses (Velazquez, 2022; Fajer-Avila, 2017; SENASICA, 2020; Ortega et al., 2018 and 2016; Soto-Rodriguez et al., 2013). Although antimicrobial use may be common in tilapia aquaculture in other countries, (e.g., China) this cannot be extrapolated to other countries (Zang et al., 2021; Zou et al., 2021). Still, understanding the actual use in practice is challenging due to the limited information available in the literature and in official statistics. No evidence was found to suggest the prophylactic use of antimicrobials in Mexico. The tilapia industry's best practice manual explicitly states that antimicrobials should not be used as a preventive or prophylactic measure, and stakeholders in the field did not express concerns that AM were used in this way. (Pers. comm., Anonymous, Universidad Michoacana de San Nicolás de Hidalgo, April 2023; Pers. comm., Anonymous, Asia-Pacific Economic Cooperation, April 2023; Todo Tilapia, 2021; Watts et al., 2017; Garcia-Ortega and Calvario-Martinez, 2008). Furthermore, it is a prevalent practice among producers to administer cost-effective local treatments, such as salt, peroxide, or iodine, before resorting to any form of antibiotic use (pers. comm., Soledad Delgadillo, FAO, September 2023). However, due to the inherent production processes of aquaculture, the metaphylactic[33] use of antimicrobials to treat entire populations is still prevalent (Todo Tilapia, 2021; Watts et al., 2017).

A survey conducted by Velasquez (2022) in the Malpaso reservoir from August 2020 to September 2021, involving 40 aquaculture production units (UPAs), revealed that 77.5% of the surveyed producers reported using antimicrobial treatments. Among those who declared using antimicrobials, 77.5% applied oxytetracyclines, 17.5% used sulfadimethoxins, and the remaining 5% utilized enrofloxacin. Furthermore, 22.5% of these producers indicated that they did not receive any technical guidance regarding the application, dosage, and monitoring of antimicrobial treatments (Velazquez, 2022). Additionally, the anecdotal evidence and the surveys carried out by Velazquez (2022) suggest that a good portion of Mexican tilapia producers do not use best management practices as it relates to antimicrobial treatments and apply them as necessary to control disease outbreaks during different

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https://www.ncbi.nlm.nih.gov/books/NBK487950/table/annexa_1.3.t1/#:~:text=prophylaxis%2C%20and%20metaphylaxis.-,Metaphylaxis,have%20evidence%20of%20infectious%20disease.

stages of production, including the grow-out stage. For instance, Ortega et al. (2018), explained that facility records from November 2013 indicated that symptomatic tilapia from a farm in Queretaro received treatment with oxytetracycline, resulting in a reduction in daily mortality rates. However, this therapeutic intervention was administered late, with 50% of the fish already deceased and the remaining individuals severely affected by the infection.

There have been no import rejections reported by the United States Food and Drug Administration (U.S. FDA) for any tilapia products (U.S. FDA accessed May 2023), and there are therefore no indications from this information source that antimicrobials (legal or otherwise) are used in Mexican tilapia farms. It is worth reiterating that the primary exporter of tilapia to the U.S. is the existing mega farm, and their reported practices are indicative of this landscape. Specifically, the existing mega farm only reports the application of one treatment of Florfenicol for 13 of their floating cages located in Malpaso reservoir in 2022, which resulted in a total use of 177.2 kg of the antimicrobial (ASC, 2022). The producer confirmed that this has been the sole treatment applied since 2015, consistent with ASC audit reports spanning from 2013 to 2022 (ASC, 2013, 2017, 2020,2021, and 2022; pers. comm., Regal Springs representative, September 2023). The report did not specify the biomass volume subjected to this antimicrobial treatment, and the producer did not provide further information upon request; however, given the scale of this producer, it can be assumed that the treatment represents a small portion of their total production. The U.S. FDA has occasionally rejected imports of shrimp from Mexico for exceeding drug residue standards (8 times from 2019-2023), including nitrofurans (antimicrobials), indicating that other types of antimicrobial may be used, and that illegal antimicrobial use might be occurring to come level in the aquaculture industry (U.S. FDA[34], 2023).

Three of the antimicrobials approved by SENASICA are also common aquaculture drugs and authorized by the Food and Drug Administration (FDA)[35]; for example, oxytetracycline, florfenicol, and sulfadimethoxine-ormetoprim mix are all approved for aquaculture use in the United States. Enrofloxacin is approved by SENASICA for aquaculture use specifically but the FDA approves it for animal use more generally. Streptomycin is not approved by SENASICA or the FDA to be used in aquaculture, but the FDA approves it for animal use more generally.

The World Health Organization's list of Highly and Critically Important Antimicrobials, considers three of the five treatments currently used in Mexico for tilapia aquaculture (oxytetracycline, florfenicol, and sulfadimethoxine) 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 other two treatments known to be used in Mexico's aquaculture industry (enrofloxacin and streptomycin) are listed as *Critically Important* to human medicine, meaning it meets both criteria a) and b).

[34] https://www.accessdata.fda.gov/cms_ia/importalert_27.html
[35] https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs

Florfenicol is noted as Highly Important (even though it is used only in veterinary medicine) because of the potential for human pathogens to acquire resistance genes from florfenicol-treated nonhuman sources (e.g., livestock or fish) (WHO, 2019). For veterinary applications, the World Organization for Animal Health (WOAH, formerly OIE) has also prepared the List of Antimicrobial Agents of Veterinary Importance, where both florfenicol and oxytetracycline are listed as "Veterinary Critically Important Antimicrobial Agents" (OIE, 2019). The OIE (2019) states: "The wide range of applications and the nature of the diseases treated make phenicols [and tetracyclines] extremely important for veterinary medicine. This class is of particular importance in treating some fish diseases, in which there are currently no or very few treatment alternatives." This emphasizes the need for responsible and prudent use (OIE, 2019). Of note, CESANAY[36] (accessed May 2023) reports the use of streptomycin (an unauthorized antimicrobial), florfenicol, and sulphonamides administered through feed to treat bacterial hemorrhagic septicemia, caused by *Aeromonas hydrophilia*; but the extent to which these treatments are used is not specified.

<u>Antimicrobial Resistance</u>

The use of antimicrobials in aquaculture links it to global concerns regarding the development of bacterial resistance to one or more antimicrobials, and to the passage of resistance genes from aquatic to terrestrial pathogens (Lulijwa et al., 2020; Santos and Ramos, 2018;). Aquaculture has even been considered a "genetic hotspot" for resistance gene transfer as multiple antimicrobial-resistance strains have been frequently detected in fish, shellfish, and aquatic environments (Hossain et al., 2022; Watts et al., 2017). Additionally, low- and middle-income countries like Mexico have been associated with contributing higher levels of antimicrobial-resistance bacteria (Reverter et al., 2020). The pathogenic bacteria most commonly affecting tilapia that overlap with the frequently isolated antimicrobial-resistance bacteria reported by Hossain et al (2022) are: *Vibrio* spp., *Aeromonas* spp., *Pseudomonas* spp., and *Streptococcus* spp. (Hossain et al., 2022; Velazquez, 2022; Soto-Rodriguez, 2013).

Mexico shares these concerns and as a result established in 2018 an Official Agreement – National Strategy Against the Antimicrobial Resistance[37] with the following four objectives, which includes considerations of their use in aquaculture:

1. Improve awareness and understanding of AMR, through effective communications, education, and training.
2. Reinforce knowledge and evidence of AMR through surveillance and research in human and animal health (including epidemiological, health, and use of antimicrobials surveillance).
3. Reduce the incidence of infections, through effective preventive, hygiene and sanitary measures, for human and animal health.
4. Optimal and rational use of antimicrobial agents for human and animal health.

It is worth noting that the best practices manual for tilapia, published by SENASICA in 2008, already included the risks associated with antimicrobial resistance in the context of human and environmental health, therefore promoting the responsible use of pharmaceuticals when treating disease (Garcia-Ortega and Calvario-Martinez, 2008).

[36] https://cesanay.org/cesanay/peces-enfermedades/
[37] https://www.dof.gob.mx/nota_detalle.php?codigo=5525043&fecha=05/06/2018#gsc.tab=0

Several antimicrobial-resistance genes have been isolated in tilapia. For instance, in Egypt, Algammal et al (2021) sampled 165 *Oreochromis niloticus* and 120 *Clarias gariepinus* isolated bla_{TEM}, bla_{CTX-M}, and *tetA* genes with a total prevalence of 83.3%, 77.7%, and 75.6%, respectively. Bla_{TEM}, and *tetA* (plus *floR* and other genes) were also classified as some of the most frequently detected antimicrobial resistance genes by Hossain (2022) in Chile, South Korea, USA, Turkey, and Vietnam along with their respective resistant antimicrobial, which happen to include those approved in Mexico: Sulfonamide, tetracycline, enrofloxacin, florfenicol and more. Oviedo-Bolanos (2021), detected the presence of genes resistant to tetracycline (genes with their respective prevalence percentage from total samples: tetO (29.1%), tetM (12.7%), and ermB (1.8%)) in ponds in Costa Rica growing tilapia that had been treated with oxytetracycline and florfenicol. In the case of florfenicol, the resistance gene is known as the floR gene, and due to the widely recognized phenomenon of horizontal gene transfer (HGT), florfenicol has the potential to co-select for a diversity of resistances (Kim and Aoki, 1996).

As it is explained ahead (Criterion 7 – Disease), *Aeromonas dhakensis* (Ad) is one of the most prevalent pathogenic Aeromonas species to humans and fish. While *Ad* showed susceptibility to enrofloxacin (a fluoroquinolone) in samples cultured from fish grown in Sinaloa, Mexico, this study showed that *Ad* samples from both cultured hybrid tilapia and wild fish were resistant to erythromycin, amoxicillin, and ampicillin (Soto-Rodriguez, 2018). The study also found β-lactamase, tetracycline, and multiple antimicrobial resistance genes in the genome of *Ad* (CAIM 1873) (Soto-Rodriguez, 2018).

Lulijwa et al.'s (2020) review of antimicrobial use in aquaculture indicates antimicrobial residues accumulate in sediments and may drive change in microbial communities through selection for antimicrobial-resistant species and/or strains of species (and antimicrobial resistance genes may persist in the environment for several years after actual use of the drugs). This highlights an additional environmental challenge linked to the utilization of antimicrobials and their fate within natural ecosystems.

Overall, the subject of antimicrobial susceptibility and resistance is extremely complex and the focus of a voluminous and rapidly growing body of literature; thus, understanding the complex potential impacts to food safety, occupational health, and (marine and nonmarine) antimicrobial resistance continues to be challenging to fully comprehend (Lulijwa et al., 2020). Therefore, a conclusive link between antimicrobial use in aquaculture with developed resistance in the bacterial populations observed to date does not exist.

<u>Pesticides</u>

Parasites are one of the biggest problems affecting fish health, and *Trichodina sp.* is one of the most common in the early life stages of tilapia culture in Mexico (Serna-Ardila et al., 2022). The one antiparasitic treatment registered for use in tilapia in Mexico (as listed by SENASICA) is ethylenediamine dihydroiodide (EDA, trade name Dermo-Gard Aqua). It can be applied either in feed or as a bath treatment. The chemical is recognized by the U.S. Food and Drug Administration as Generally Recognized as Safe (GRAS78), but this relates to human safety as a food additive, and there are no readily available data or other information on the potential environmental impacts of using or discharging water that has been treated with this chemical. However, the U.S. Environmental Protection Agency (2001) states that EDA is not anticipated to accumulate in living organisms due to its physical and chemical characteristics. It is highly likely to undergo rapid biodegradation in the environment, with over 80% of the compound being degraded within a period of 28 days. Moreover, the estimated half-life for photodegradation of EDA is approximately 8.9 hours (U.S. EPA, 2001). Tests performed by Raymo (2021), suggest that this compound has a specific ectoparasiticidal effect (i.e., it kills external parasites) and is specified to control protozoa (including *Trichodina* spp. and *Ichthyophthirius* spp.) and arthropods (including the crustacean parasites *Argulus* spp. and *Caligus* spp.). It could be assumed that this substance may therefore have an impact if discharged in an active form, but no information on the frequency, scale, or manner of its use in Mexican tilapia farms could readily be found.

The Organization for Economic Co-operation and Development (2021) noted that, in Mexico, as in most countries, there is massive and indiscriminate use of pesticides (mainly referring to their use in agriculture), and from 2000 to 2014 the consumption of pesticides in Mexico increased 59.2%. This use generated high toxic contaminant levels (i.e., heavy metals and pesticides) in the soil, water, plants, and animals resulting in adverse human health effects, mainly in children (OECD, 2021). Mexico ranks as one of the countries with the highest consumption (based on national sales) of pesticides in the world (OECD, 2021), but the data described imply that these are primarily agricultural pesticides (i.e., insecticides, fungicides, herbicides), and there is no information from which to understand pesticide use in aquaculture. Nonetheless, COSAES tested two UPAs in the state of Sonora during 2020 for pesticides resides (including organochlorines, organophosphates, carbamates, and pyrethroids) in the water where fish were cultivated, reporting no traces of any of these pesticides.

<u>Hormones</u>

It is considered common practice for methyl testosterone (MT) to be added to hatchery feeds for approximately 28 days (fish starting size of approximately 8 mm) for the production of all-male populations via sex reversal (Trejo-Quezada et al., 2021; Jimenez-Badillo and Arredondo-Figueroa, 2000). The use of large volumes of sex steroids to obtain monosex populations has raised increasing concerns among environmental groups. This is because the accumulation of steroids in the bodies of water near the farms can disrupt the sex ratios of wild animals that inhabit those areas (Trejo-Quezada et al., 2021). In a review of the use of hormones in fish, Hoga et al. (2018) note that, on a large scale, sexual reversal may pollute the environment because almost all (more than 99%) of the hormones are not metabolized and released into the water. While hatcheries usually operate through a close recirculation system, fate and transport of MT from a tilapia masculinization pond to the nearby environment involves many processes such as adsorption and desorption processes, deposition, photodegradation, biotransformation processes (microbial or phytoremediation), leakage, leaching and runoff (Thanasupsin et al., 2021).

Hoga et al. (2018) also note that municipal wastewaters are the main source of these types of hormones in the aquatic environment. But, according to Barry et al. (2011), MT and its metabolites become tightly associated with the sediment, with half-lives for MT dissipation and mineralization in the sediment systems ranging from 2 to 9 days, depending on the sediment type and the presence or absence of oxygen. According to Macintosh (2008), and Megbowon and Mojekwu (2013), there are no known risks to the environment (or human health) from the use of MT in aquaculture.

Methyl testosterone (MT) is imported from the Philippines to Mexico, requiring a sanitary license during the process. However, the availability of this hormone in the country was historically limited (Jimenez-Badillo and Arredondo-Figueroa, 2000). Due to increased costs and availability issues, alternative hormones such as Fluoxymesterone have been used. However, the environmental impact of Fluoxymesterone has not been extensively studied compared to MT, and the extent of its use in Mexico remains unclear. Additionally, there is no evidence indicating a difference in the environmental risks between these two types of testosterone, as both have the potential to disrupt the sex ratio of wild animals inhabiting these areas (Ramirez-Ochoa et al., 2023). Researchers suggest that these chemicals can be lost through various pathways, including leakage from poorly constructed ponds, leaching through the vadose zone, and runoff from farm production, thereby potentially impacting nearby environments (Mlalila et al., 2015), however as noted above with regard to MT, the specific risks relating to the use of hormones in general in aquaculture are uncertain.

Conclusion

The increasing scale and intensity of production have led to the emergence of diseases as a common and severe problem in global tilapia aquaculture, including in Mexico, introducing the potential for veterinary medicines and treatments. Ten products are specifically listed for use in fish in Mexico: four antimicrobials, one antiparasitic treatment, four vaccines, and one hormone, but there are no readily available data with which to understand their use in Mexico's tilapia farms. Despite a lack of readily available data, experts suggest that pharmaceutical treatments are utilized to control diseases, and academic studies suggest it is common. For example, a recent survey of 40 farms in the Malpaso reservoir indicated more than three-quarters used antimicrobials. In addition, one of the state-level Aquaculture Health Committees reported the use of streptomycin, which is not authorized in Mexico, and raises concerns about their illegal use. Therefore, although regulations and best management practices are apparent, they may not be followed in practice, which poses both environmental risks and economic losses for producers. While there is no evidence of prophylactic antimicrobial use in Mexico, the metaphylactic use of antimicrobials to treat entire populations remains prevalent. The rejection of imported shrimp from Mexico by the United States Food and Drug Administration due to drug residue violations indicates potential illegal antimicrobial use in the shrimp industry in Mexico, but no rejections have been reported for tilapia products.

Additionally, Mexico, like other low- and middle-income countries, has been linked to higher levels of antimicrobial-resistant bacteria, including in tilapia farming. Antimicrobial-resistant genes have been isolated in tilapia, and the presence of these genes is associated with the use of specific antimicrobials. The use of antimicrobials in aquaculture poses environmental challenges, as residues can accumulate in sediments and contribute to the selection of antimicrobial-resistant species and genes, impacting natural ecosystems. However, a definitive link between antimicrobial use in aquaculture and the development of resistance in bacterial populations has yet to be established.

Although there is considerable circumstantial information available, the frequency and scale of chemical use in Mexico's tilapia farms is essentially unknown regarding the specific data (or lack thereof) from the thousands of farms. Circumstantial evidence indicates that antimicrobials highly and critically important for human medicine are being used in unknown quantities, resulting in a final score for Criterion 4—Chemical Use of 0 out of 10, for ponds and net pens (excluding the existing mega farm). In contrast, the existing mega farm does have good data availability through third-party audits from the Aquaculture Stewardship Council, and has only used one antimicrobial treatment since 2015 (in 2022). Therefore, chemical use is considered to be less than once per production cycle, and the final score for the existing mega farm for Criterion 4—Chemical Use is 8 out of 10.

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 the efficiency of conversion can result in net food gains or dramatic net losses of nutrients.
- *Unit of sustainability*: 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

C5 Feed parameters	Value	Score	Value	Score	Value	Score
	Mega farm		Net pens		Ponds	
F5.1a Forage Fish Efficiency Ratio	0.80		0.64		0.86	
F5.1b Source fishery sustainability score (0-10)		6.00		3.00		3.00
F5.1: Wild fish use score (0-10)		6.90		4.77		3.72
F5.2a Protein INPUT (kg/100kg fish harvested)	60.00		48.00		48.00	
F5.2b Protein OUT (kg/100kg fish harvested)	14.00		14.00		14.00	
F5.2: Net Protein Gain or Loss (%)	-76.67	2.00	-70.83	2.00	-70.83	2.00
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	14.58	6.00	14.37	6.00	14.16	6.00
C5 Feed Final Score (0-10)		**5.45**		**4.39**		**3.86**
Critical?	No	**Yellow**	No	**Yellow**	**No**	**Yellow**

Brief Summary

Specific data on the composition of tilapia feeds are limited. Given the importance of robust data to the outcomes of this criterion, attempts were made to contact feed companies and access feed data through the Federal Committee of Animal Feeds and Nutrition (CONAFAB), but none of these efforts were successful. The available information indicates that fishmeal and fish oil levels are low and the feeds are dominated by crop ingredients across production systems. The fish meal and fish oil values were considered to be higher in pond feed based on the limited information available and a necessary precautionary approach. The feed conversion ratios may vary according to the production system, but without better data, the estimated eFCRs considered in this assessment are as follows: for the existing mega farm an eCFR of 2.0 was obtained through third party ASC-certification audit reports, but without specific details for the rest of producers in Mexico, an average value obtained through the literature of 1.6 was used. General aquaculture literature indicates that the use of by-product sources for fishmeal and fish oil might be substantial, but with the limited specific information available for Mexican tilapia feeds, a 20% inclusion was assigned to the existing mega farm (based on ASC audit reports), but no by-product inclusion was considered for the rest of producers. The Forage Fish Efficiency Ratio (FFER) is estimated at 0.80, 0.64, and 0.86 for the existing mega farm, net pen, and ponds producers, respectively. Using pond production as an example, this FFER value means that, from first principles, 0.86 mt of wild fish must be caught to supply the fish oil to grow 1 mt of tilapia. Again, this value varies across farms and production systems. The source fisheries for the marine ingredients used by the existing mega farm are listed in ASC audit reports, and can be seen to be moderately sustainable, and the Wild Fish Use score is 6.90 out of 10. Due to the unknown source of fisheries for the marine ingredients used by several feed manufacturers, the Wild Fish Use for rest of tilapia producers in Mexico, scores are 4.77 for net pens and 3.72 for pond producers. Based on four feed company websites and on four additional references reporting on Mexico tilapia feed protein levels, the averaged feed protein content over a production cycle used in this assessment is 30%. With a whole tilapia protein content of 14% (and the eFCRs considered in this assessment), there is a substantial net loss of protein (-76.67% for the existing mega farm and -70.83% for net pen and pond producers, resulting in a score of 2 out of 10 for all producers). The feed footprint calculated as the embedded climate change impact (kg CO2-eq) resulted in an estimated kg CO_2-eq per kg of farmed seafood protein 14.58, 14.37, and 14.16 for the existing mega farm, net pen, and pond producers, respectively. These values are equivalent to a score of 6 out of 10 for all production systems. The three scores combine to give final scores for Criterion 5—Feed of 5.45 out of 10 for the existing mega farm; 4.39 for net pens; and 3.86 for ponds (See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Ranking

Small-scale tilapia farmers utilizing extensive production systems may primarily rely on limited quantities of manufactured tilapia feed or employ fertilizers in their ponds (refer to Criterion 2—Effluent for a detailed discussion on fertilizer use). Nonetheless, it should be noted that they still constitute the second-largest group in terms of fed species for freshwater fish, with an increasing trend towards the use of commercial feeds (Martinez-Cordero et al., 2021; Tacon et al., 2011; Garcia-Ortega and Calvario-Martinez, 2008). As larger and/or more intensive farms are typically fully dependent on added feed, this report considers that all farmed tilapia in Mexico are to some extent dependent on manufactured feeds.

According to the Federal Committee of Animal Feeds and Nutrition (CONAFAB), the production of tilapia feed has shown a consistent increase from 31.5 thousand mt in 2010 to the latest available estimate of 136.0 thousand mt in 2020 (CONAFAB, 2020). CONAFAB indicates that their nine member-companies produce more than 95% of the feed used for shrimp and cultured fish in Mexico (CONAFAB[38], accessed April 2023; CONAFAB[39], 2021). These companies include ADM Aquaculture[40], Purina[41], El Pedregal[42],

[38] https://www.conafab.org/membresia/acuicola

[39] https://www.conafab.org/images/comunicados/19_04_2021_acuicultura_impulsa_el_auge_de_la_pesca_mexicana.pdf

[40] https://acuacultura.com.mx/

[41] https://www.nutrimentospurina.com/

[42] https://el-pedregal.com/alimento/omnivoros

Nicovita[43], Nutrimar[44], Provimi[45], Vimifos[46], El Nogal[47]. It should be noted that while Purina is listed as one of the aquaculture feed suppliers in Mexico, the specific products they offer for this industry are unclear from their website. Nutrimar is a significant shrimp feed supplier in the country but does not supply feed specifically for tilapia. Furthermore, Cargill[48] appears to be one of the main suppliers for the existing mega farm, however, the brands they distribute in Mexico are Provimi and Purina. Additionally, the existing mega farm also uses Campi Alimentos as one of its feed suppliers, which is not a member of CONAFAB (pers. comm., Regal Springs representative, September 2023).

Each feed company typically offers a selection of four or five tilapia feeds tailored for different stages of the production cycle. By analyzing the target start and end weights associated with each feed size (according to feeding schedules available from company websites), along with the corresponding weight gain achieved on each feed, it becomes evident that the majority of growth occurs during the larger grow-out phase. These grow-out feeds, as discussed further below, generally exhibit lower protein contents ranging from 25% to 35%, compared to starter or nursery feeds designed for smaller tilapia that may contain up to 45% protein (Martinez-Cordero et al., 2021; El-Sayed, 2019). While this pattern is consistent across all feed companies, it is important to highlight that feeds within the 25% to 35% protein range are predominantly utilized throughout the production process, beginning with fry as small as 10 grams. Consequently, the focus of this assessment is on feeds employed during the tilapia grow-out phase where the bulk of growth and therefore feed use occurs (Nicovita[49], accessed May 2023; FAO[50], accessed June 2023).

Feed Ingredients and Inclusion Levels

While previous studies by Tacon and Metian (2008) predicted improvements, particularly reductions, in the utilization of marine ingredients such as fishmeal and fish oil in aquaculture feed formulations over time, little recent data on feed composition in Mexico are available. Despite efforts to gather information from each of the feed suppliers affiliated with CONAFAB, none of the companies provided the requested data. As a result, the specific details regarding the composition of tilapia feeds were not accessible at the time of writing this report. Consequently, this assessment heavily relies on control diets documented in the academic literature (typically intended to mimic commercial diets) and employs the precautionary principle to establish single values used in the calculations. Furthermore, due to the unavailability of market share estimates for feed suppliers, most of the values utilized in this analysis are averaged from the data obtained through literature sources.

Regarding other ingredients, the UN FAO acknowledges that the ingredient composition and formulation of commercial tilapia feeds are typically proprietary. Thus, a comprehensive disclosure of ingredient formulation is often only provided for experimental tilapia diets published in academic journals. However, the FAO cautions that such experimental formulations may not accurately represent the typical commercial feeds used in intensive farming systems, or the feeds in any particular geographic region. However, such studies typically use a control diet that more closely reflects a "typical"

[43] https://nicovita.com/productos/
[44] https://www.nutrimar.mx/
[45] https://www.provimi.mx/
[46] https://www.vimifos.com/categoria/tilapia
[47] http://www.nogal.com.mx/productos/9/acuacultura
[48] https://www.cargill.com.mx/es/nuestra-oferta
[49] http://www.industriaacuicola.com/biblioteca/Tilapia/Manual%20de%20crianza%20de%20tilapia.pdf
[50] https://www.fao.org/fishery/affris/species-profiles/nile-tilapia/feed-formulation/en/ (Accessed June 2023)

commercial formulation, and in the absence of specific formulation data from the feed companies in Mexico, six such control diet formulations were obtained from recent studies (Ashour et al., 2020; Hasan et al., 2019; Terrones-España and Reyes Avalos, 2018; Jimenez-Ruiz, 2017; Khan et al., 2013; González-Félix et al., 2010). Moreover, it is most likely that comparable feed manufacturers and, consequently, similar dietary compositions, are employed by both net pen and pond producers. This is suggested by the apparent absence of distinct feed characteristics preferred by tilapia farmers employing different production systems (personal communication with Mauricio Orellana, Neoaqua, April 2023). To address this, in accordance with the precautionary principle, we employed feed formulations extracted from the available literature in an arbitrary manner to create an approximation of a representative tilapia grow-out feed. These formulations were then averaged with the diets reported by net pen producers for the purpose of this evaluation. The detailed composition of this formulation is presented in Table 8.

In comparison to many cultivated fed finfish species, the incorporation of fishmeal (FM) in tilapia feeds is relatively low, with inclusion levels varying between 0% and 15% (Hasan et al., 2019; Arcos-Mendez, 2015). Similarly, the required inclusion level of fish oil (FO) in tilapia feeds is also modest, with some cases excluding it as a feed ingredient, while in others, it has been reported to be as high as 6% (Hasan et al., 2019; Xu and Ming, 2018; Arcos-Mendez, 2015). In this context, one tilapia producer shared their specific inclusion levels of fishmeal and fish oil used in their feeds (FM=0% and FO=0.3%), and ASC audit reports also provided inclusion levels for the existing mega farm (FM=4% and FO=2%) (pers. comm., Mauricio Orellana, Neoaqua, April 2023; ASC, 2020). Both producers utilize net pen production systems. However, in the absence of market share data for feed suppliers, a precautionary approach is applied. As a result, the highest known values for fishmeal and fish oil inclusion in Mexican tilapia feed formulations (4% and 2%, respectively) are utilized to calculate the wild fish use for net pen producers. Considering pond producers in Mexico, there are no available estimates for the typical inclusion levels of FM and FO in tilapia feeds. Consequently, adhering to the precautionary principle, an approximation to the average of the upper levels within the ranges reported in the literature for these two ingredients (10% for fishmeal and 5% for fish oil) is employed to calculate the wild fish use in feeds for pond producers (Hasan et al., 2019; Arcos-Mendez, 2015). The variations in the inclusion levels of FM and FO between net pens and ponds play a significant role in shaping the divergent inclusion levels of other ingredients outlined in Table 8. It is important to recognize that each ingredient's inclusion level falls within the ranges established by existing literature.

Specific Feedback Request from Expert Review
Further information is requested with regard to the inclusion levels of fish meal and fish oil in tilapia feeds in Mexico. This is an important aspect in the scoring of this criterion.
Response:

Table 8: Tilapia feed formulation approximated from control feeds of five academic studies referenced in the text.

Ingredient	Inclusion %	
	Net pens	Ponds
Fish meal	4	8
Fish oil	2	2.7
Soybean meal	25	25
Wheat bran	25	25
Corn meal	24	22
Corn gluten	9	8
Vegetable oil	6	5
Vitamins/minerals, etc.	2	2
Rice bran	3	2.3
Vitamins/minerals, etc.	2	2
Total	**100**	**100**

Feed Conversion Ratio

The feed conversion ratio is the ratio of feed given to an animal per weight gained, measured in mass (e.g., FCR of 1.4:1 means that 1.4 kg of feed is required to produce 1 kg of fish). It can be reported as either biological FCR, which is the straightforward comparison of feed given to weight gained, or economic FCR (eFCR), which is the amount of feed given per weight harvested (i.e., accounting for mortalities, escapes, and other losses of otherwise harvestable fish). The eFCR is an important component of this assessment and used in the ensuing calculations. Determining a single eFCR value to represent an entire industry is challenging. The difficulty is rooted in the differences in tilapia genetics, feed formulations, farm practices, and more. For instance, in a review of Nile tilapia production yields, Mengistu et al. (2020) noted that many factors affect eFCR, notably survival, temperature, dissolved oxygen, pH, and the crude protein content of feed. It is also likely that yields will differ across different species (e.g., red tilapia and Nile tilapia), as will yields from production in net pens or ponds. For example, Mengistu et al. (2020, referencing Rana & Hassan, 2013) showed that reported FCR values for tilapia vary widely, ranging from 1.0 to 2.5 in different countries and production systems.

The most representative data available on Mexico's tilapia feed are derived from literature reviews and audits conducted by the ASC audits (interviewed by Panorama Acuicola[51], accessed February 2023; Tacon et al., 2022; Martinez-Cordero et al., 2021; ASC, 2020; Arana et al., 2020; Zafra et al., 2019; Hasan et al., 2019). By analyzing ASC audit reports for the existing mega farm, an average estimated eFCR from the latest ASC report available of 2.0 was obtained, and this value is applied in the relevant calculations for this producer (for reference, the average eFCR value from the previous 2020 to 2022 audit reports was also very similar at 1.97). Considering the literature data, eFCR values for tilapia production in Mexico ranged from 1.15 to 2.5, with an average of 1.6, which aligns with the latest global average of 1.6 reported by Hasan et al. (2019). Consequently, an eFCR value of 1.6 is utilized for calculations involving other net pen and pond producers in Mexico.

[51] https://panoramaacuicola.com/2019/05/18/entrevista-a-juan-loustanau-gerente-de-operaciones-de-acuicola-gemso/

Factor 5.1—Wild Fish Use

Factor 5.1a – Feed fish efficiency ratio (FFER)
As mentioned previously, Mexican tilapia feed formulations considered for this assessment correspond to 4% FM and 2% FO in the case of net pens; while a combination of 8% FM and 2.7% FO is utilized to calculate the consumption of wild fish in feeds for pond producers (see Table 8).

According to IFFO[52] (2022), approximately 29.8% of global fishmeal production is derived from by-products, while for fish oil, by-products account for 51% of the total production. In North America, the reported inclusion of by-products in fishmeal is 41%, and for fish oil, it is 22% (Jackson and Newton, 2016). However, the utilization of by-products in fishmeal and fish oil can vary significantly across different regions, ranging from 16% to 85% for fishmeal and from 14% to 89% for fish oil (Jackson and Newton, 2016). ASC audit reports provide information indicating that one of the species, Californian anchovy, included in the feeds used by the existing mega farm, is sourced as a by-product (trimmings). Since Californian anchovy waste is commonly processed into by-products, it will be considered as a by-product for FM (Giannetto et al., 2020). However, the specific inclusion level of this by-product was not disclosed by the existing mega farm. Therefore, considering the global and North America by-product inclusion levels and employing the precautionary principle, it is deemed appropriate to evenly distribute the inclusion levels among the five species reported in ASC audits for the existing mega farm (for an explanation of these species, see Factor 5.1b below). As a result, the inclusion level of by-products in FM for the existing mega farm is considered to be 20% in the subsequent calculations. For other net pen and pond producers, no information is available from the feed companies (online) regarding whether these ingredients are sourced from whole fish or fishery by-products. Consequently, the use of FM and FO by-products is not included in the calculations of wild fish use for these producers.

Specific Feedback Request from Expert Review
Further information is requested regarding use of fish meal and fish oil from by-products in tilapia feeds in Mexico.
Response:

Equation 4, derived from the Seafood Watch Aquaculture Standard – Appendix 3 (Single feed scenario), is used to calculate the FM and FO feed fish efficiency ratios ($FFER_{FM}$ and $FFER_{FO}$). These ratios take into account the estimated feed composition values that have been calculated thus far. The FFER is a measure of the dependency on wild fisheries for feed ingredients using the ratio of the amount of wild fish used in feeds relative to the harvested farmed fish. Each variable used in these calculations, as detailed below, is also summarized in Table 9. In order to capture the ecological cost of production associated with by-products, only 5% of the estimated FM and FO by-products inclusion levels are considered when calculating the FFER and are also noted in Table 9. The eFCR and the FM and FO yield values are also identified in Table 9 and used in equation 4.

[52] https://www.iffo.com/product

Table 9. Parameters used and their calculated values to determine the use of wild fish in feeding Mexico farmed tilapia.

Parameter	Data (%)		
	Mega farm	Net pens	Ponds
Fish meal inclusion level (total)	4.00	4.00	8.00
Fish meal inclusion level from whole fish	3.20	4.00	8.00
Fish meal inclusion level from by-product[53]	0.80	0.00	0.00
Fish meal yield	22.50		
Fish oil inclusion level (total)	2.00	2.00	2.70
Fish oil inclusion level from whole fish	2.00	2.00	2.70
Fish oil inclusion level from by-product[54]	0.00	0.00	0.00
Fish oil yield	5.00		
Economic Feed Conversion Ratio	2.00	1.60	1.60
FFER fish meal	0.36	0.28	0.57
FFER fish oil	0.80	0.64	0.86
Assessed FFER	**0.80**	**0.64**	**0.86**

The Feed Criterion considers the FFER from both FM and FO and uses the higher of the two to determine the score. As seen in Table 9, the resulting FFER for FO was higher than the FFER for FM across production systems. Therefore, the score for Factor 5.1a – FFER are determined as 0.80, 0.64, and 0.86 for the existing mega farm, net pen, and pond producers, respectively. Using pond production as an example and based on first principles, 0.86 tons of wild fish are required to produce the fish oil required to grow one ton of farmed Mexico tilapia.

<u>Factor 5.1b: Source fishery sustainability</u>

This factor evaluates the sustainability of the fisheries supplying FM and FO for Mexico tilapia grow-out feed. For the existing mega farms, ASC audits disclose that the species used in their feeds consist of Pacific thread herring, Pacific sardine, Peruvian anchovy, Pacific chub mackerel, and Californian anchovy. As per ASC certification requirements, the producer must utilize feeds in which all the species employed as raw ingredients have an average FishSource[55] score of six or higher, with no individual score falling below six. Upon verification, it was confirmed that all the listed species, except for Californian anchovy (Engraulis mordax), meet the sustainability criteria. Although Campi Alimentos, one of the feed suppliers for the existing mega farm, claims to procure sardine and anchovy from the Gulf of California and affirms that none of their feed ingredients originate from illegal, unreported, and unregulated fisheries, it is pertinent to acknowledge that authoritative sources such as FishSource, the IUCN Red List[56], and Fishbase[57] classify California anchovy as "data deficient." An assessment conducted by INAPESCA (2006) for a multi-species fishery indicated a decline in California anchovy catches in 2000 and suggested a declining trend in the Baja California management area. Although this fishery has been managed since 1993 through measures such as minimum catch size, special closing seasons, and fishing effort

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[53] Note that 5% of the by-product fish meal inclusion (i.e., inclusion level x 0.05) is included in the FFER calculations.
[54] Note that 5% of the by-product fish meal inclusion (i.e., inclusion level x 0.05) is included in the FFER calculations.
[55] https://www.fishsource.org/
[56] https://www.iucnredlist.org/species/183856/102904070
[57] https://www.fishbase.se/summary/Engraulis-mordax.html

limitations, the data deficiency status persists, and the most recent assessment available dates back to 2006. Consequently, the sustainability of Californian anchovy remains unknown, resulting in a score of 2 out of 10 under the Seafood Watch Aquaculture Standard. The sustainability scores for all the species used as raw material in the existing mega farm's feeds are presented in Table 10.

With regard to understanding the sources of marine ingredients used by producers other than the existing mega farm, out of the total fishing production of small pelagic fish in Mexico, approximately 15% is allocated for direct human consumption, while the remaining 75% is utilized for the production of FM and FO, indirectly contributing to human consumption (Panorama Acuicola[58], 2020). Among the species of small pelagic fish that are caught, five of them, namely Pacific thread herring, California pilchard (also known as Pacific sardine), Japanese sardine, Pacific jack mackerel, and Pacific mackerel, are suitable for direct human consumption. The other pelagic species fished in Mexico, such as Pacific herring, pine sardine, and Pacific anchovy are exclusively used in the production of FM, which serves as feed for other species (Panorama Acuicola, 2020). As previously discussed, the species utilized by feed manufacturers supplying the mega farm, and documented in the ASC audit reports, are regarded as representative of at least four feed manufacturers in Mexico, namely Campi Alimentos, Vimifos, Cargill (Purina and Promivi). Additionally, a medium net pen producer acquires its feed from El Pedregal, which indicated the inclusion of three additional marine species: Middling thread herring (Opisthonema medirastre), slender thread herring (Opisthonema bulleri), and Pacific anchoveta (Cetengraulis mysticetus). All the FishSource scores for Middling thread herring are greater than six, and the stock health score is 10. This results in an overall sustainability score of 8 under the SFW Aquaculture Standard. In the case of slender thread herring, while all the management quality scores designated by FishSource are greater than six, the stock health scores are designated as data-deficient due to the absence of a publicly available stock assessment. Nevertheless, owing to the species' apparent adept management within Mexico's harvest control protocols for the Ophistonema species complex, it receives an intermediate sustainability score of 5 under the SFW Aquaculture Standard. FishSource does not currently score Pacific anchovy (specifically *Cetengraulis mysticetus*) from the Mexican fishery in the Gulf of California . Nevertheless, FishSource indicates Pacific anchovy is managed as part of the small pelagic fishery in Sonora, which holds a MSC certification. Furthermore, Pacific anchovy is classified as "least concern" under the IUCN categorization. Hence, it seems appropriate to assign an intermediate sustainability score of 4, considering the uncertainty surrounding sustainability due to the absence of a stock assessment, while factoring in its management alongside other small pelagic species that are MSC certified.

Nonetheless, for producers apart from the existing mega farm, there is a notable absence of information regarding the specific fisheries supplying the FM and FO used in the formulation of tilapia feed across various feed suppliers in Mexico. It would be unwarranted to presume that all other feed manufacturers exclusively rely on pelagic species obtained from sustainable sources within Mexican waters. As mentioned previously, comprehensive data regarding the market share of each feed supplier were not available. Therefore, guided by the precautionary principle, we make the assumption that the known species, whose sustainability has been addressed, represent 50% of the market share among feed suppliers. Conversely, the remaining 50% of feed suppliers, associated with the net pen and pond

[58] https://panoramaacuicola.com/2020/06/22/produccion-de-harina-de-pescado-genera-mas-de-2000-empleos-especializados-en-mexico/

producers included in this study, are assigned a fishery sustainability score of 0 out of 10, based on the fact that the source fisheries for this latter group remain undisclosed (refer to Table 10).

Table 10: Source fisheries and resulting F5.1b scores. Note the five species listed are obtained from ASC audit reports of the existing mega farm. The "Unknown" category refers to other producers for which the sources of fish meal and fish oil in their feeds are not known.

Common Name (*Genus species*)	Country/fishing region of origin	Gear type	Relevant certifications/ratings	F5.1b Score
Middling thread herring (*Opisthonema medirastre*)	Gulf of California	Purse Seine	NA	8
Slender thread herring (*Opisthonema bulleri*)	Gulf of California	Purse Seine	NA	5
Pacific thread herring (*Opisthonema libertate*)	Gulf of California	Purse Seine	MSC – Withdrawn	8
Pacific Sardine (*Sardinops sagax*)	Mexico	Purse Seine	MSC	6
Peruvian anchovy (*Engraulis ringens*)	Peru	Purse Seine	FIPs	6
Pacific chub mackerel (*Scomber japonicus*)	Mexico	Purse Seine	NA	6
Californian anchovy (*Engraulis mordax*)	Mexico	Purse Seine	NA	2
Pacific anchoveta (*Cetengraulis mysticetus*)	Mexico	Purse Seine	MSC – multiple species	4
Unknown	NA	NA	NA	0

Upon establishing the sustainability scores for each species utilized in feeds and considering the even distribution of inclusion levels among the reported species, a single Factor 5.1b Source Fishery Sustainability score for each marine ingredient was determined. This calculation was conducted using equation 6 from the Seafood Watch Aquaculture Standard – Appendix 3, and the resulting scores for the source fishery sustainability of each marine ingredient are presented in Table 11.

Table 11: Marine ingredients inclusion levels and sustainability scores for the existing mega farm, net pens, and ponds.

Marine Ingredient	Inclusion (%)			Sustainability Score
	Existing mega farm	Net pens	Ponds	
Fishmeal from whole fish	**4**	**4**	**8**	
Pacific thread herring (*Opisthonema libertate*)	0.80	0.33	0.67	8
Middling thread herring (Opisthonema medirastre)	0.00	0.33	0.67	8
Slender thread herring (Opisthonema bulleri)	0.00	0.33	0.67	5
Pacific Sardine (*Sardinops sagax*)	0.80	0.33	0.67	6
Peruvian anchovy (*Engraulis ringens*)	0.80	0.33	0.67	6
Pacific chub mackerel (*Scomber japonicus*)	0.80	0.33	0.67	6
Unknown source fishery	0.00	2.00	4	0
Sustainability score for fishmeal whole fish	6.5	3.3	3.3	
Fishmeal from by-product	**0.80**	**0**	**0**	
Californian anchovy (*Engraulis mordax*)	0.80	0	0	2
Sustainability score for fishmeal by-product	2.0	NA	NA	
Fish oil from whole fish	**2.00**	**2.00**	**2.7**	
Pacific thread herring (*Opisthonema libertate*)	0.50	0.14	0.19	8
Middling thread herring (Opisthonema medirastre)	0.00	0.14	0.19	8
Slender thread herring (Opisthonema bulleri)	0.00	0.14	0.19	5
Pacific Sardine (*Sardinops sagax*)	0.50	0.14	0.19	6
Peruvian anchovy (*Engraulis ringens*)	0.50	0.14	0.19	6
Pacific chub mackerel (*Scomber japonicus*)	0.50	0.14	0.19	6
Pacific anchoveta (*Cetengraulis mysticetus*)	0.00	0.14	0.19	4
Unknown source fishery	0.00	1.00	1.35	0
Sustainability score for fish oil whole fish	6.5	3.1	3.1	

Equation 7 from the Seafood Watch Aquaculture Standard – Appendix 3 was employed to calculate the weighted overall sustainability scores for total FM and FO. Subsequently, Equation 8 was utilized to adjust the weighted overall sustainability scores for fishmeal for each production system: 6.28 for the existing mega farm, and 3.25 for net pens and ponds. The overall sustainability scores for fish oil for each production system is 6.50 for the existing mega farm, and 3.07 for net pens and ponds based on their respective Fish Feed Efficiency Ratios (FFER) calculated in Factor 5.1a ($FFER_{FM}$ = 0.36, 0.28, and

0.57 for the existing mega farm, net pens, and ponds, respectively; $FFER_{FO}$ = 0.80, 0.64, and 0.86 for the existing mega farm, net pens, and ponds, respectively). This is done to accurately attribute the sustainability of source fishery scores with the biomass utilized for tilapia feed. As a result, the Final 5.1b Source fishery sustainability score is 6 out of 10 for the existing mega farm, 3 out of 10 for net pens and ponds.

Therefore, considering the existing mega farm's FFER Factor 5.1a score of 0.80 is combined with Factor 5.1b Source fishery sustainability score of 6 out of 10 for a Factor 5.1—Wild Fish Use score of 6.90 out of 10. For net pens and ponds FFER Factor 5.1a score of 0.64 and 0.86, respectively, are combined with Factor 5.1b Source fishery sustainability score of 3 out of 10 for a Factor 5.1—Wild Fish Use score of: 4.8 out of 10 for net pens and 3.7 out of 10 for pond producers.

Specific Feedback Request from Expert Review
Further information is requested regarding the use of marine species used as ingredients in tilapia feeds in Mexico. Information on the inclusion levels, the use of by-product sources, and on the **source fisheries** is important to the scoring in this assessment.
Response:

Factor 5.2. Net Protein Gain or Loss

Factor 5.2 measures the net protein efficiency of the fish farming process based on the feed protein inputs and the harvested fish protein outputs. As indicated before, the protein content of feeds used during the tilapia growout stage in Mexico falls within the range of 25% to 35%. To determine an average value, protein content data from the websites of Mexican feed manufacturers (ADM Aquaculture, Purina, El Pedregal, Nicovita, Nutrimar, Provimi, Vimifos, El Nogal) and additional literature sources reporting on Mexican tilapia feed (USSEC[59], 2020; SAGARPA, 2021; ATT Innova, 2015) were considered. The calculated average protein content of feeds used during the growout stage of production was found to be 29.6%. For the purpose of this report, the average protein content was rounded to 30%, the net protein gain or loss is calculated according to equation 1, and the results for each production system are included in Table 12:

(Eq. 1)

$$\text{Net Protein} = \frac{[\text{Harvested fish protein content \%} - (\text{feed protein content \%} \times \text{eFCR})]}{(\text{feed protein content \%} \times \text{eFCR}) \times 100}$$

Regarding the protein output in harvested tilapia, the protein content of a whole harvested farmed tilapia is 14% (Boyd 2007), or 140 kg protein per mt of tilapia. By considering the inputs and outputs, the net protein loss can be calculated, and with moderately high feed protein contents and relatively low whole-tilapia protein contents, the loss is substantial.

[59] https://ussec.org/mexican-tilapia-farm-reaches-great-success-iprs-technology/

Table 12. The parameters used and their calculated values to determine the protein gain or loss in the production of farmed Mexico tilapia.

Parameter	Data	
	Mega farm	Net pens and ponds
Protein content of feed	30%	30%
Economic Feed Conversion Ratio	2.0	1.6
Total protein INPUT per ton of farmed tilapia	600 kg	480 kg
Protein content of whole harvested tilapia	14.0%	14.0%
Total protein OUTPUT per ton of farmed tilapia	140.0 kg	140.0 kg
Net protein loss	**-76.67%**	**-70.83%**
Seafood Watch Score (0-10)	2	2

Considering the eFCR of 2.0 for the existing mega farm and of 1.6 for other net pen and pond producers (see Factor 5.1a for details), alongside a whole-tilapia protein content of 14% (Boyd 2007), the net protein loss for the existing mega farm is -76.67% and for net pen and pond producers is -70.83%. This results in a score of 2 out of 10 for Factor 5.2 – Net protein gain or loss – for all producers.

Factor 5.3. Feed Footprint

Factor 5.3—Feed Footprint is an approximation of the embedded Climate Change Impact value (CCI) (kg CO_2-eq including land-use change [LUC]) of the feed ingredients required to grow 1 kilogram of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database[60] to estimate the CCI of 1 metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood. If an ingredient of unknown origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied; this approach is intended to encourage data transparency and provision. However, in cases where an ingredient is sourced from a known origin but does not have a direct or closely matched entry in the GFLI database, an average value is calculated based on the closest approximate ingredients available in the database. Detailed calculation methodology can be found in Appendix 4 of the Seafood Watch Aquaculture Standard. Because of the licensing agreement, the specific values for each ingredient from the GFLI database are not reproduced here, but the calculated value per mt of feed for each ingredient is shown.

For the existing mega farm, Table 13 shows the ingredient categories selected from the GFLI database according to the above methodology for ingredients of unknown origins or those with no exact match. Please note that the CCI average for Pacific sardine was calculated based on the available data for European pilchard (sardine) and South American pilchard (sardine) within the GFLI database. These two "sardine" ingredients were the only options present in the database, thus necessitating the use of their average value to approximate the CCI for Pacific sardine. Similarly, for Pacific chub mackerel, the average CCI value was derived from all the available entries for "Fish meal, at processing" within the GFLI database. Finally, the existing mega farm submitted the U.S. Soy Sustainability Certification for the U.S.-sourced soy used by one of their prominent feed suppliers, but this does not identify the source of soy used by other feed suppliers. Consequently, in order to establish a comprehensive climate change impact value for soybean meal, an average was calculated, taking into account both the U.S. and global values provided in the GFLI dataset.

[60] https://globalfeedlca.org/gfli-database/lcia-download/

Table 13. Estimated embedded climate change impact of one mt of the existing mega farm – Mexico tilapia feed.

Feed ingredients	Species or Ingredient	Climate Change Impact (incl. LUC) item	Ingredient inclusion %	kg CO_2-eq/mt feed
Fishmeal from whole fish	Pacific thread herring (*Opisthonema libertate*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.8	30.66
	Pacific sardine (*Sardinops sagax*)	Fish meal, from European pilchard (sardine), at processing/NO Economic S	0.8	
		Fish meal, from South American pilchard (sardine), at processing/US Economic S		
	Peruvian anchovy (*Engraulis ringens*)	Fish meal, from Anchoveta, at processing/PE Economic S	0.8	
	Pacific chub mackerel (*Scomber japonicus*)	Averaged – Fish meal, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	0.8	
Fishmeal from by-products	Californian anchovy (Engraulis mordax)	Averaged – Fish meal, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	0.8	8.88
Fish oil from whole fish	Pacific thread herring (*Opisthonema libertate*)	Fish oil, from Atlantic Herring, at processing/NO Economic S	0.5	19.75
	Pacific sardine (*Sardinops sagax*)	Fish oil, from European pilchard (sardine), at processing/NO Economic S	0.5	
		Fish meal, from South American pilchard (sardine) , at processing/US Economic S		
	Peruvian anchovy (*Engraulis ringens*)	Fish oil, from Anchoveta, at processing/PE Economic S	0.5	
	Pacific chub mackerel (*Scomber japonicus*)	Averaged – Fish oil, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	0.5	
Total vegetable meals	Wheat bran	Wheat bran, from dry milling, at processing/GLO Economic S	25	961.14
		Wheat bran, from wet milling, at processing/GLO Economic S		
	Soybean meal	Soybean expeller (pressing), at processing/GLO Economic S	25	
		Soybean expeller (pressing), at processing/US Economic S		
	Corn gluten meal	Maize gluten feed dried, at processing/GLO Economic S	9	
		Maize gluten meal dried, at processing/GLO Economic S		
	Corn meal	Maize flour, at processing/GLO Economic S	24	
	Rice bran	Rice bran (mixed), at processing/CN Economic S	3	
	Vegetable oil	Crude vegetable oil blend, from crushing, at processing/GLO Economic S	6	
Others	Vitamins/minerals, etc.	Total minerals, additives, vitamins, at plant/RER Economic S	2	0.35
Sum of total			**100%**	**1020.77**

For other net pen and pond tilapia producers in Mexico, Table 14 displays the selected ingredient categories derived from the GFLI database, following the methodology described above for ingredients with unknown origins. It is important to acknowledge that, there was no global value for FM or FO, and instead the average CCI value was derived from all the available entries for “Fish meal, at processing “ and “Fish oil, at processing”. This average was used instead of the global FM and FO CCI value, and was then averaged with the worst listed value for FM and FO (see Table 14).

Table 14. Estimated embedded climate change impact of one mt of net pen and pond – Mexico tilapia.

Feed ingredients	Species or Ingredient	Climate Change Impact (incl. LUC) item	Net pens		Ponds	
			Ingredient inclusion %	kg CO_2-eq/mt feed	Ingredient inclusion %	kg CO_2-eq/mt feed
Fishmeal from whole fish	Unknown source fishery	Averaged – Fish meal, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	2	41.52	4	83.07
		Fish meal, at processing/CN Economic S				
	Pacific thread herring (*Opisthonema libertate*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.33		0.67	
	Pacific sardine (*Sardinops sagax*)	Fish meal, from European pilchard (sardine), at processing/NO Economic S	0.33		0.67	
		Fish meal, from South American pilchard (sardine), at processing/US Economic S	0.33		0.67	
	Peruvian anchovy (*Engraulis ringens*)	Fish meal, from Anchoveta, at processing/PE Economic S	0.33		0.67	
	Middling thread herring (*Opisthonema medirastre*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.33		0.67	
	Slender thread herring (*Opisthonema bulleri*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.33		0.67	
Fish oil from whole fish	Unknown source fishery	Averaged – Fish oil, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	1.0	17.47	1.35	23.59
		Fish oil, at processing/CN Economic S				
	Pacific thread herring (*Opisthonema libertate*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.14		0.19	
	Pacific sardine (*Sardinops sagax*)	Fish meal, from European pilchard (sardine), at processing/NO Economic S	0.14		0.19	
		Fish meal, from South American pilchard (sardine), at processing/US Economic S	0.14		0.19	
	Peruvian anchovy (*Engraulis ringens*)	Fish meal, from Anchoveta, at processing/PE Economic S	0.14		0.19	
	Middling thread herring (*Opisthonema medirastre*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.14		0.19	
	Slender thread herring (*Opisthonema bulleri*)	Fish meal, from Atlantic Herring, at processing/NO Economic S	0.14		0.19	
	Pacific anchoveta (*Cetengraulis mysticetus*)	Averaged – Fish meal, at processing/CL, CN, DE, DK, GB, JP, NL, NO, PE, US Economic S	0.14		0.19	
Total vegetable meals	Wheat bran	Wheat bran, from dry milling, at processing/GLO Economic S	25	1197.98	25	1128.18
		Wheat bran, from wet milling, at processing/GLO Economic S				
	Soybean meal	Soybean expeller (pressing), at processing/GLO Economic S	25		25	

	Corn gluten meal	Maize gluten feed dried, at processing/GLO Economic S	9		8	
		Maize gluten meal dried, at processing/GLO Economic S				
	Corn meal	Maize flour, at processing/GLO Economic S	24		22	
	Rice bran	Rice bran (mixed), at processing/CN Economic S	3		2	
	Vegetable oil	Crude vegetable oil blend, from crushing, at processing/GLO Economic S	6		5	
Others	Vitamins/minerals, etc.	Total minerals, additives, vitamins, at plant/RER Economic S	2	0.35	2	0.35
Sum of total			**100%**	**1257.32**	**100%**	**1235.20**

Based on the available information, the estimated embedded CCI of 1 mt of the existing mega farm feed is 1020.77 kg CO_2-eq; of net pen producers feed is 1257.320 kg CO_2-eq; and of pond producers feed is 1259.96 kg CO_2-eq. Considering a whole harvest tilapia protein content of 14%, each production system's eFCR (2.0 for the existing mega farm and 1.6 for net pen and pond producers), and the total inclusion of all ingredients, the estimated kg CO_2-eq per kg of farmed seafood protein is 14.58, 14.37, and 14.16 for the existing mega farm, net pen, and pond producers, respectively; which were calculated using equation 2:

(Eq. 2)

$$Est.\,kg\,CO2-\frac{eq}{kg}\,of\ farmed\ seafood\ protein = \frac{eFCR}{whole\ harvested\ fish\ protein\ content} \times \left(\frac{Total\ CCI}{mt\ of\ Feed} \times \frac{10}{Total\ ingredient\ inclusion}\right)$$

As a result, the feed footprint of Mexico farmed tilapia is considered low to moderate, hence Factor 5.3—Feed Footprint results in a score of 6 out of 10 for all producers.

Conclusions and Final Score

Specific data on the composition of tilapia feeds are limited. Given the importance of robust data to the outcomes of this criterion, attempts were made to contact feed companies and access feed data through the Federal Committee of Animal Feeds and Nutrition (CONAFAB), but none of these efforts were successful. The available information indicates that fishmeal and fish oil levels are low and the feeds are dominated by crop ingredients across production systems. The fish meal and fish oil values were considered to be higher in pond feed based on the limited information available and a necessary precautionary approach. The feed conversion ratios may vary according to the production system, but without better data, the estimated eFCRs considered in this assessment are as follows: for the existing mega farm an eCFR of 2.0 was obtained through third party ASC-certification audit reports, but without specific details for the rest of producers in Mexico, an average value obtained through the literature of 1.6 was used. General aquaculture literature indicates that the use of by-product sources for fishmeal and fish oil might be substantial, but with the limited specific information available for Mexican tilapia feeds, a 20% inclusion was assigned to the existing mega farm (based on ASC audit reports), but no by-product inclusion was considered for the rest of producers. The Forage Fish Efficiency Ratio (FFER) is estimated at 0.80, 0.64, and 0.86 for the existing mega farm, net pen, and ponds producers, respectively. Using pond production as an example, this FFER value means that, from first principles, 0.86 mt of wild fish must be caught to supply the fish oil to grow 1 mt of tilapia. Again, this value varies across farms and production systems. The source fisheries for the marine ingredients used by the existing mega farm are listed in ASC audit reports, and can be seen to be moderately sustainable, and the Wild Fish Use score is 6.90 out of 10. Due to the unknown source of fisheries for the marine ingredients used by several feed manufacturers, the Wild Fish Use for rest of tilapia producers in Mexico, scores are 4.77 for net pens and 3.72 for pond producers. Based on four feed company websites and on four additional references reporting on Mexico tilapia feed protein levels, the averaged feed protein content over a production cycle used in this assessment is 30%. With a whole tilapia protein content of 14% (and the eFCRs considered in this assessment), there is a substantial net loss of protein (-76.67% for the existing mega farm and -70.83% for net pen and pond producers, resulting in a score of 2 out of 10 for all producers). The feed footprint calculated as the embedded climate change impact (kg CO2-eq) resulted in an estimated kg CO_2-eq per kg of farmed seafood protein 14.58, 14.37, and 14.16 for the existing mega farm, net pen, and pond producers, respectively. These values are equivalent to a score of 6 out of 10 for all production systems. The three scores combine to give final scores for Criterion 5—Feed of 5.45 out of 10 for the existing mega farm; 4.39 for net pens; and 3.86 for ponds (See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

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
- *Unit of sustainability:* 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	Value	Score	Value	Score
	Mega farm		Net pens		Ponds	
F6.1 System escape risk	4		2		4	
F6.1 Recapture adjustment	0		0		0	
F6.1 Final escape risk score		4		2		4
F6.2 Competitive and genetic interactions		10		10		9
C6 Escape Final Score (0-10)		10		10		6
Critical?	No	Green	No	Green	No	Yellow

Brief Summary

Net pen aquaculture systems for tilapia carry a high risk of escape, but best practices for escape management, including the use of all male or sterile fish, are considered widespread. Similarly, ponds are also likely to be at risk of flooding or other fish losses during production (e.g., if ponds are drained at harvest). While the existing mega farm's net pens still entail a high risk of escape, the producer has implemented an escape containment plan and a comprehensive net inspection program, which are monitored through ASC audits and reported publicly. While there are no data available on escapes events in Mexico or on post-escape recaptures; the potential impacts are reduced when the species has been historically introduced and continue to be actively stocked into the environment, especially for net pen producers which mainly operate in the same reservoirs that have been actively stocked up until recent years (2020). Tilapia were strategically introduced to Mexico by the government to enhance inland fisheries during the 1960s and 1970s, and since then, it appears several species became established in the wild across the country. Although this occurred before the large-scale development of the aquaculture industry took place, it is likely that aquaculture introductions (and subsequent escapes) increased the range of tilapia in Mexico. Hence, tilapia, including the dominant farmed Nile tilapia species, are considered fully established in Mexico for the purposes of this assessment, but partly due to aquaculture. The potential habitat effects and impacts on native biota resulting from aquaculture escapes are considered by SEMARNAT during the evaluation of project proposals and are integral to the EIA approval process. Nonetheless, it remains unclear if there is an ongoing potential for tilapia to be introduced to additional waterbodies in Mexico where they are not yet present. The final escape criterion score is based on the interaction of the risk of escape (Factor 6.1; scores of 4 of 10 for the existing mega farm and pond producers, and 2 out of 10 for the rest of net pen producers) and the risk of competitive and genetic interactions with wild species (Factor 6.2; score of 10 out of 10 for all net pen producers and 9 out of 10 for pond producers in Mexico). This results in a final score for Criterion 6—Escapes of 10 out of 10 for all net pen producers and 6 out of 10 for pond producers.

Justification of Ranking

Aquaculture related escapes into wild habitats can be of significant concern given the potential negative impacts associated with the introduction of species, especially as the majority of aquaculture relies on introduced species. These introductions can lead to issues in wild habitats, such as competition with native species for resources, predation on native species, and hybridization, which can result in the loss of genetic attributes in the native species (Gracida-Juarez, 2020; Sosa-Villalobos et al., 2016). On a global scale, Xiong et al. (2022) highlights numerous instances of tilapia escaping from culture facilities (net pens and ponds) and establishing feral populations in various tropical and subtropical countries.

Factor 6.1—Escape Risk

Escapes from aquaculture facilities pose a risk in all operations (Diana, 2009), although the level of risk varies depending on the type of production system and the effectiveness of management practices. Proper employee training and the implementation of emergency plans are crucial in mitigating escape incidents (Halwart et al., 2007; Jensen et al., 2010). Net-pen production systems, due to their open nature, are particularly susceptible to escapes (Naylor et al., 2005; Halwart et al., 2007), as can be ponds in the case of flooding (Vazquez-Vera and Chavez-Carreno, 2022).

As previously discussed, obtaining a pre-approved EIA from SEMARNAT is a mandatory requirement for aquaculture operations (both net pens and ponds) as part of the permitting process. This approval is necessary to obtain the aquaculture operation unit approval from CONAPESCA and the water discharge permit approval from CONAGUA. The potential habitat effects and impacts on native biota resulting from aquaculture escapes are considered by SEMARNAT during the evaluation of project proposals and are integral to the EIA approval process. The EIA requires the applicant to include the assessment of the "attributes and threats" associated with the cultivated species (DOF, 2014; SEMARNAT, 2002). The EIA must comprehensively address and provide predictions on the potential outcomes or issues that may arise from the translocation of exotic and/or hybrid species, which is the case for tilapia. Hence the EIA must include the following considerations (translated from SEMARNAT, 2002):

1. The mechanisms to prevent the likelihood of escapes and translocation, as well as to significantly reduce the potentially negative effects that could occur on native wild populations.
2. Based on the consultation of published and recent literature sources (not older than five years), provide a description of the biological characteristics of the species, particularly aspects such as the probable relationships that could be established with other wild populations, potential flows of predation, competition for food and space, likely spread of diseases, parasites, and vectors, and in general, the possible detrimental effects on the conservation of the biological diversity that characterizes the selected area for the project.

Moreover, the EIA also mandates the inclusion of a comprehensive description of the abiotic environmental system within the assessed location. This encompasses climate phenomena, such as storms and hurricanes, and explicitly emphasizes the need to link these phenomena with potential production or infrastructure issues that may arise as a consequence. For example, the EIA specifically addresses concerns such as the breaching of levees due to flooding and the escape of cultured organisms into the natural environment (SEMARNAT, 2002). Furthermore, as part of the geographical and geomorphological description of the site, the EIA requires an assessment of the area's susceptibility to seismic activity, landslides, collapses, floods, other ground or rock movements, and possible volcanic activity. In addition to the potential for escapes resulting from flooding, escape incidents may also occur due to inadequately constructed infrastructure, theft, and bird predation (pers. comm., Soledad Delgadillo, FAO, September 2023; pers. comm., Regal Springs representatives, September 2023). However, it is worth recalling that approximately 60% of tilapia production units across almost all Mexican states, remains mostly unregistered, and 50% of the surveyed active producers did not possess a pre-approved EIA by SEMARNAT (Ortega-Mejia et al., 2023; Martinez-Cordero 2021; ATT Innova, 2015).

Notably, Vazquez-Vera and Chavez-Carreno (2022) suggest that inland tilapia farms are particularly vulnerable to flooding, especially considering the projected increase in such events due to climate change. For instance, southern states like Veracruz and Tabasco, which have abundant water resources and flat terrains suitable for pond aquaculture, face a relatively high risk of flooding (Martinez-Cordero, 2021). It is important to consider the extensive distribution of farms across the country, as depicted in Figure 13, when analyzing the historical flooding events illustrated in Figure 25. Given the widespread presence of tilapia aquaculture in Mexico, these maps have limited utility in assessing the flooding risk of tilapia farms. However, they do highlight the underlying risk, particularly considering that aquaculture operations are typically closely associated with a water supply and may be more vulnerable to flooding events.

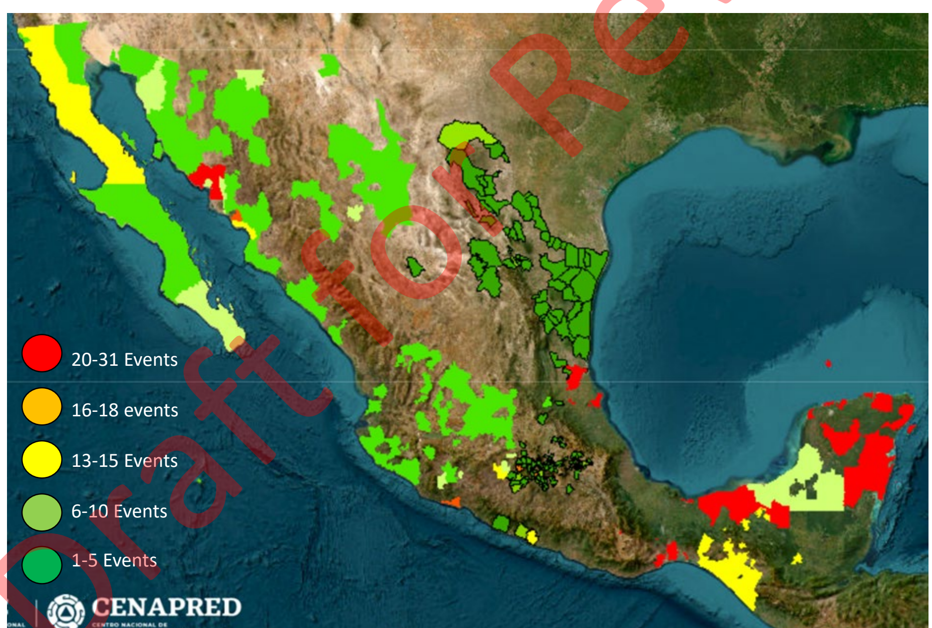

Figure 25. Number of flooding events in Mexico from 1960 to 2013 (CENAPRED[61], accessed July 2023; PRONACCH[62], accessed July 2023).

It is also important to consider that previous research conducted in wet tropical environments indicates that human-mediated translocation is the primary driver of dispersal, while flooding serves as a secondary mechanism that can transport tilapia from aquaculture ponds into natural water bodies and

[61] http://www.atlasnacionalderiesgos.gob.mx/archivo/visor-capas.html

[62] https://rmgir.proyectomesoamerica.org/server/rest/services/ANR/Fenomenos_Hidrometeorologicos/MapServer/48

across swampy drainage divides (Esselman et al., 2013). Water exchanges conducted by pond producers have been identified as a contributing factor to the heightened risk of escapes from these aquaculture production systems. As previously discussed in Criterion 2 – Effluents, tilapia pond production in Mexico can result in substantial water exchanges, with an estimated range from 5% to 20% (INAPESCA, 2018). While tilapia pond production often can be located near a water supply, a significant portion of aquaculture production in Mexico occurs in small ponds, and these systems are generally considered to have a lower risk of facilitating the spread of invasive tilapia species due to their isolation from natural water bodies.

Tilapia net pen aquaculture is commonly practiced in large water bodies, and recorded instances of escapes have been associated with interactions with native crocodiles, equipment malfunctions, and water elevation events in the reservoirs (Schmitter-Soto & Caro, 1997; Fitzsimmons, 2000b). Moreover, theft and sabotage targeting net pen producers have been identified as major factors to escape incidents (pers. comm., Soledad Delgadillo, FAO, September 2023; pers. comm., Regal Springs representatives, September 2023). Although these factors are beyond the control of farming measures or practices, they represent inherent risk factors that must be taken into account when evaluating open net pen production systems.

The existing mega farm has implemented an escape containment plan, which is monitored through ASC audits. Part of this plan involves using mesh sizes appropriate for the specific production stage and fish size. During the pre-growing stage, they employ double mesh consisting of net-widths of 0.25 and 0.50 inches (ASC, 2022). Additionally, they have established a comprehensive net inspection program to ensure that each net pen is thoroughly inspected before stocking and on a monthly basis. Inspection records are presented during ASC audits, and there have been no reports of torn nets during ASC diving revisions conducted since 2015 (ASC, 2022). Furthermore, when transferring organisms to breeding ponds, tightly sealed plastic bags are used to prevent any potential breakage. These bags are placed inside polystyrene boxes for added protection (Baide-Amaya, 2019). The internal transfer of organisms between cages is carried out using special buckets or containers designed to prevent harm to the fish and minimize the risk of escapes during the transfer from one phase to another. When net pens are relocated within the reservoirs or following adverse weather conditions that could compromise the structural integrity of the net pens, divers conduct inspections to ensure that no damage or tears have occurred during these events (pers. comm., Regal Springs representatives, September 2023). To further enhance containment measures, all cages are equipped with an additional upper border extending 15 to 20 cm above the water surface to minimize the potential for organism leaks by jumping. Moreover, anti-bird netting is installed on all cages to prevent escapes or undesired extractions (by fish-eating birds) within the cultivation area (Baide-Amaya, 2019).

However, it should be noted that currently there are no mandatory reporting requirements for aquaculture producers to document escape events, either within the EIA process or in existing legislation. As a result, there is a lack of available data and estimates regarding the extent of escaped tilapia into natural habitats in Mexico.

In 2020, among the total tilapia production of 114,768 mt in Mexico, approximately 96,977 metric tons were ascribed to “aquaculture” activities. Within this “aquaculture” category, 56.6% of the production derived from controlled systems (i.e., what is assessed here as aquaculture), while 43.3% originated from culture-based fisheries where tilapia are raised from eggs in hatcheries and subsequently stocked into waterbodies such as lakes and reservoirs, or potentially when fish escape from tilapia farms into the same waterbodies (Urías-Sotomayor and Maeda-Martínez, 2023; CONAPESCA, 2020). As discussed below in Factor 6.2, the status of stocking programs in Mexico is unclear, but Martinez-Cordero et al. (2021) also estimated that, on average, over the period from 1990 to 2018, roughly 86% of the annual tilapia capture fisheries in Mexico (equating to an average of 74 thousand metric tons per year) can be attributed to culture-based fisheries, with only 14% stemming from wild tilapia (refer to Figure 26). Despite some variance between these estimates, it becomes apparent that a substantial proportion of tilapia caught in Mexico's reservoirs is sourced from culture-based fisheries.

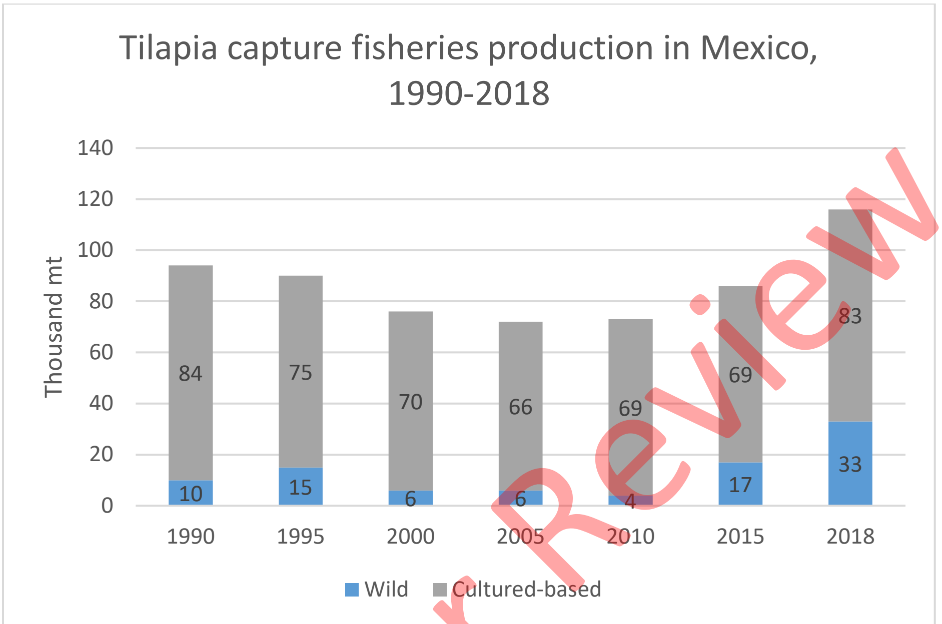

Figure 26. Tilapia production in Mexico from wild and cultured based fisheries from 1990 to 2018 (replicated from Martinez-Cordero et al., 2021).

The origin of culture-based tilapia, whether it stems from restocking initiatives (which likely constitutes the majority of tilapia populations in reservoirs) or escapes from aquaculture operations, remains uncertain. However, it is evident that tilapia populations in freshwater bodies face significant fishing mortalities. This is exemplified by the national tilapia production statistics in Figure 1, demonstrating substantial declines since 2018, with experts attributing overfishing as one of the contributing factors to this decline. Moreover, the limited understanding of waterbody carrying capacity exacerbates the issue of overfishing. This complexity is compounded by various technical factors, including tilapia hybridization hindering their reproductive success, bird predation, diseases resulting from parasites such as leeches and worms, and the introduction of fish predators like local mojarras, which may have initially brought in to control the population of introduced tilapia species (Martinez-Cordero et al., 2021). Furthermore, there are an estimated 300,000 tilapia fishers in Mexico, with the State of Chiapas alone authorizing 1,206 small vessels for inland tilapia fishing (as of 2023) (CONAPESCA[63], 2023; Cuarto Poder[64], 2020). This underscores a high likelihood of escaped tilapia from aquaculture operations being recaptured by local fishermen across Mexico. However, without a specific estimate of the percentage of

[63] https://datos.gob.mx/busca/dataset/permisos-y-concesiones-de-pesca-comercial-para-embarcaciones-mayores-y-menores
[64] https://www.cuartopoder.mx/chiapas/impulsaran-produccion-de-tilapia-en-chiapas/326350

escaped tilapia recaptured in Mexico, it is challenging to determine a precise recapture rate, hence no adjustment is allocated for net pens and pond producers.

Overall, there is a clear risk of escapes from tilapia farms in Mexico. Net pens are particularly vulnerable, but ponds are also likely to be at risk of flooding or other losses during production (e.g., if ponds are drained at harvest). Based on the implementation of an escape containment plan and a net inspection program (as documented in publicly-available ASC audit reports), the existing mega farm, as an open system producer, demonstrates to go beyond "best management" in the system design, construction, and maintenance; therefore, the Escape Risk score (Factor 6.1a) is 4 out of 10. For the rest of net pen systems, the Escape Risk score (Factor 6.1a) is 2 out of 10 and reflects the high risk of escapes due to the open nature of the production system but recognizes the Best Management Practices required through the EIA process. For ponds with moderate water exchanges (more than 10% per day) and a significant flood risk, the Escape Risk score (Factor 6.1a) is 4 out of 10.

Factor 6.2—Competitive and Genetic Interactions

Tilapia cichlid fishes of the genus *Oreochromis* are invasive across the world's tropical freshwaters (Garcida-Juarez, 2020). Tilapia can thrive in virtually any tropical freshwater and estuarine habitat, it easily changes its feeding behavior depending on which other fish species co-occur, and it spawns year-round (Xiong et al., 2022; Shipton et al., 2008; Njiru et al., 2004; Zengeya et al., 2012). All these factors contribute to the popularity of tilapia as a culture species, but also make it a potentially dangerous invasive species (Xiong et al., 2022; Zengeya et al., 2015). Nevertheless, tilapia is one of the most widely introduced species in the world (Xiong et al., 2022), and it follows that there is ample evidence regarding the invasive nature of tilapia and its impacts on native populations in ecosystems worldwide (e.g., Lowe et al., 2000; Starling et al., 2002; Canonico et al., 2005; Narváez et al., 2005; Oliveria 2005; Caraballo 2009). Esselman and Schmitter-Soto (2013), conducted a habitat suitability model for tilapia and found that approximately 7,510 kilometers of river habitat (24% of total river length) in Mexico's Yucatan Peninsula, Belize, and Northern Honduras were susceptible to colonization by tilapia. The study also indicated that pond aquaculture conducted in flood-prone areas was identified as the primary source of tilapia presence in the rivers of the study area, further confirming the risks of escapes through flooding discussed earlier (Esselman and Schmitter-Soto, 2013).

According to a study conducted in 2008 (Contreras-Balderas et al., 2008), a total of 113 exotic fish species had been reported in Mexico. Among these introductions, tilapia was introduced to Mexico during the 1960s and 1970s, and since then, it has become established in the wild across the country (Fitzsimmons 2000). As a planned governmental strategy, to enable integrated fisheries and energy generation, tilapia have been intentionally released into water reservoirs. This strategy has resulted in the widespread presence of tilapia throughout the country, as evidenced by over 389 human observations of tilapia reported through iNaturalist in Mexico (Figure 27).

Figure 27. Reported tilapia occurrences. The darker orange dots indicate more than one occurrence. (Global Biodiversity Information Facility[65], accessed July 2023).

Mexico is known to harbor at least 70 native fish species, many of which are local or regional endemics and occupy similar habitats as tilapia species (Miller et al., 2009; Froese & Pauly, 2019). One example is the Mayan cichlid in the Yucatan Peninsula, where it is evident that tilapia has extensively established populations in various freshwater aquatic systems (Gracida-Juarez, 2020). The Mayan cichlid exhibited inferior competitive abilities compared to Nile tilapia in experimental settings, with Nile tilapia displaying higher activity levels and aggressiveness (Gracida-Juarez, 2020). Martin et al. (2010) found that juvenile Nile tilapia outcompeted juvenile red-spotted sunfish by limiting access to shelter, leading to increased predation by largemouth bass (*Micropterus salmoides*). Moreover, in Mexico's central region, tilapia coexists with the Axolotle (*Ambystoma mexicanum*), an endangered species protected under NOM-059-ECOL-2010. Reports indicate that tilapia in these water bodies feed on Axolotle eggs and recruits and compete for resources with this endangered species (Aguilar-Moreno and Aguilar-Aguilar, 2019).

In the Infiernillo Reservoir, a previous study conducted by Jimenez-Badillo and Nepita (2000), revealed that the introduced tilapia species Oreochromis aureus has nearly completely displaced the native cichlid species (Ciclasoma istlanum) in the reservoir, primarily due to competition for food resources. The introduction of tilapia (cf. zillii) in Northwest Mexico in 1986 has been associated with significant ecological impacts. It has led to the displacement of the native species *Cyprinodon macularius*, a drastic decline in the population of another native species, *Fundulus lima*, and the displacement of four additional naturally occurring species in the region (*A. monticola, D. latifrons, G. maculatus, and E. picta*) (Ruiz-Campos et al., 2013). It is worth noting that introduced species account for approximately 50% of the total species composition in water basins in the Northwest region of Mexico, including the Colorado and Sonoyta water basins (Ruiz-Campos et al., 2013).

65 https://www.gbif.org/occurrence/map?country=MX&issue=CONTINENT_DERIVED_FROM_COORDINATES&taxon_key=4285694&occurrence_status=present

However, according to Gracida-Juarez's (2020) study, the presence of tilapia in the sampled lakes of the Yucatan Peninsula was limited, occurring in only three out of the six lakes and representing less than 3% of the total captured fish. The study did not find significant evidence suggesting that the presence of tilapia had a major influence on native fish biodiversity in those lakes. A significant factor that may restrict the impact of escaped tilapia on population growth and their expansion into water bodies is the widespread practice of masculinization in Mexican tilapia hatcheries (Pliankarom-Thanasupsin et al., 2021; Torres-Hernandez et al., 2010). This practice leads to tilapia populations predominantly composed of males, accounting for approximately 95% of the total stocking. Consequently, the likelihood of cultured tilapia significantly contributing to the establishment of feral populations is minimal. The National Commission for the Knowledge and Use of Biodiversity (CONABIO) classifies tilapia as an invasive species under category "E," which encompasses species unable to sustain a wild-reproductive population on their own (INAPESCA, 2018).

Currently, national reservoirs are not subject to systematic tilapia fingerling stocking programs (Urías-Sotomayor and Maeda-Martínez, 2023). However, it is noteworthy that CONAPESCA, through official decree, administers the Program for the Productive Improvement of Reservoirs. This program allocates financial resources to projects aimed at enhancing productivity within reservoirs, including restocking initiatives for tilapia in these aquatic environments (DOF[66], 2019). Since the start of this program in March 2019 until July 2020, a total of 14.7 million fry have been restocked in the States of Tabasco, Chiapas, Guerrero, Colima, and Sinaloa. This initiative seeks to revitalize tilapia populations and elevate fisheries productivity. Furthermore, there are reports indicating the coexistence of native and non-native cichlid species in both natural and artificial waterbodies (personal communication with Soledad Delgadillo, FAO, September 2023; Martinez-Cordero et al., 2021). Therefore, when considering that tilapia were introduced to Mexican water bodies for purposes other than aquaculture, plus the recent restocking efforts, it is challenging to determine the precise extent to which escaped tilapia contribute to previous and ongoing negative ecological impacts in the wild.

Overall, the non-native species of tilapia farmed in Mexico became ecologically established in the wild prior to the development of aquaculture due to active stocking by the government in the same water bodies where aquaculture is taking place (restocking efforts are as recent as 2020), which will result in 10 out of 10 based on the SFW aquaculture standard. However, they are also considered to have expanded their range in Mexico due to their subsequent introductions for aquaculture and somewhat inevitable escape, and continues to be a concern mainly for pond aquaculture conducted in flood-prone areas, which will result in score of 4 out of 10. Therefore, it remains unclear for pond producers if there is an ongoing potential for tilapia to be introduced to additional waterbodies in Mexico where they are not yet present. While there have been significant impacts reported caused by the introduction of non-native tilapia, through predation and competition, reports of coexistence with native species have also been highlighted. The potential for direct impacts to wild species or habitats following large escape events remains, but is considered to be low. Therefore, the score for Factor 6.2 is 10 out of 10 for all net pen producers, and 9 out of 10 for pond producers.

Conclusions and Final Score

Net pen aquaculture systems for tilapia carry a high risk of escape, but best practices for escape management, including the use of all male or sterile fish, are considered widespread. Similarly, ponds are also likely to be at risk of flooding or other fish losses during production (e.g., if ponds are drained at

[66] https://conapesca.gob.mx/wb/cona/acuerdo_rop_2019

harvest). While the existing mega farm's net pens still entail a high risk of escape, the producer has implemented an escape containment plan and a comprehensive net inspection program, which are monitored through ASC audits and reported publicly. While there are no data available on escapes events in Mexico or on post-escape recaptures; the potential impacts are reduced when the species has been historically introduced and continue to be actively stocked into the environment, especially for net pen producers which mainly operate in the same reservoirs that have been actively stocked up until recent years (2020). Tilapia were strategically introduced to Mexico by the government to enhance inland fisheries during the 1960s and 1970s, and since then, it appears several species became established in the wild across the country. Although this occurred before the large-scale development of the aquaculture industry took place, it is likely that aquaculture introductions (and subsequent escapes) increased the range of tilapia in Mexico. Hence, tilapia, including the dominant farmed Nile tilapia species, are considered fully established in Mexico for the purposes of this assessment, but partly due to aquaculture. The potential habitat effects and impacts on native biota resulting from aquaculture escapes are considered by SEMARNAT during the evaluation of project proposals and are integral to the EIA approval process. Nonetheless, it remains unclear if there is an ongoing potential for tilapia to be introduced to additional waterbodies in Mexico where they are not yet present. The final escape criterion score is based on the interaction of the risk of escape (Factor 6.1; scores of 4 of 10 for the existing mega farm and pond producers, and 2 out of 10 for the rest of net pen producers) and the risk of competitive and genetic interactions with wild species (Factor 6.2; score of 10 out of 10 for all net pen producers and 9 out of 10 for pond producers in Mexico). This results in a final score for Criterion 6—Escapes of 10 out of 10 for all net pen producers and 6 out of 10 for pond producers.

Criterion 7: Disease, pathogen and parasite interaction

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
- *Unit of sustainability:* 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

Mega farm

Risk-based assessment

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**4**
Critical	No	Yellow

Net pens and ponds

Risk-based assessment

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**2**
Critical	No	Red

Brief Summary

Despite being recognized for its inherent disease resistance, tilapia is susceptible to various infectious and noninfectious diseases, particularly as global and Mexican production intensifies. Major diseases affecting cultured tilapia in the Americas include gram-negative and gram-positive bacteria, fungi, parasites, and copepods. While there are several studies of the diseases affecting cultured tilapia in the country, information around how these diseases are impacting wild populations, is not readily available. Both net pens and pond farms are considered to be “open” to the environment, in terms of the potential for amplification of pathogens within them and the subsequent release of those pathogens into waters shared with wild fish. Although some biosecurity measures and best practices have been established (by the government’s National Service of Health, Safety, and Agri-Food Quality), their level of implementation among farms is uncertain. An exception here is the existing mega farm, for which the publicly available ASC audit reports document the implementation of the company’s biosecurity protocols. While some of literature suggests that disease prevalence and mortality positively correlate with the intensity of production, this cannot be confirmed, as diseases and parasites have been detected throughout the country regardless of the production level associated with each region. There is a demonstrable risk that pathogens will be amplified on farms and wild fish in the vicinity of farms will be exposed to them, but the potential impacts to wild fish populations remain uncertain. The limited amount of data, particularly on the potential impacts to wild fish, means that the risk-based assessment has been used (the Data Criterion score for the disease section is <7.5 out of 10). The known pathogen and parasitic transfer risk to wild species, the openness of the production systems, the unknown level of implementation and enforcement of biosecurity regulations and management measures, plus the registered events with high disease-related mortality rates, result in a final score for Criterion 7—Disease for both net pens and ponds (excluding the existing mega farm) of 2 out of 10. The existing mega farm's final score for Criterion 7—Disease (net pens) is 4 out of 10, based on the company's documented implementation of biosecurity protocols, but also on the fact that their production system is still open to the introduction and discharge of pathogens and parasites.

Justification of Rating

As disease data quality and availability is moderate/low (i.e., Criterion 1 score of 5 or lower for the disease category), the Seafood Watch Risk-Based Assessment was utilized.

Although tilapia has been recognized as a species with inherent disease resistance, it is susceptible to various infectious and noninfectious diseases, particularly as production scales have intensified (Debnath et al., 2023; Ortega-Mejia et al., 2023; Velazquez, 2022; El-Sayed, 2019; Fitzsimmons, 2007; Boyd, 2004). The widespread expansion of tilapia aquaculture in numerous countries, along with its associated environmental impacts and concerns about the potential transmission of diseases to humans, has garnered significant attention towards tilapia diseases in recent years (El-Sayed, 2019). Major diseases of particular concern for cultured tilapia in the Americas include:

- <u>Gram negative bacteria:</u> *Aeromonas hydrophila, Edwarsiella tarda, Pseudomonas fluorescens Corynebacterium, Vibrio sp.* (pers. comm., Regal Springs representatives, September 2023; Velazquez, 2022; ATT Innova, 2015; Soto-Rodriguez, 2013; Conroy, 2008).
- <u>Gram positive bacteria:</u> *Streptococcus sp., Mycobacterium sp., Flexibacter, Cytophagna, Nocardia* (pers. comm., Regal Springs representatives, September 2023; Velazquez, 2022; ATT Innova, 2015; Soto-Rodriguez, 2013; Conroy, 2008).
- <u>Fungi:</u> *Saprolegnias and Branchiomyces* (Velazquez, 2022; ATT Innova, 2015; Lara-Flores et al., 2013).
- <u>Parasites:</u> *Ciliates, Ichthyophthirius multifiliis, Chilodonella species, and Trichodines* (i.e., *Trichodina, Trichodinella y Tripartiella*); *Flagellated, including Ichthyobodo necator, Amyloodinium ocellatum,* and *Piscinoodinium pillulare*; Monogenae including *Gyrodactylus sp., Cichlidogyrus sp., Neobenedenia melleni; Digenea*, including *Diplostomum compactum*; and *hirudinea* (Velazquez, 2022; ATT Innova, 2015; Conroy, 2008).
- Copepodes: *Caligus, Lernaea, and Argulus* (Velazquez, 2022; ATT Innova, 2015; Conroy, 2008).

With regard to the diseases affecting tilapia production in Mexico, the monitoring efforts conducted by SENASICA (National Service of Health, Safety, and Agri-Food Quality) focus solely on *Streptococcus iniae* and *S. agalactiae*, both causative of the disease streptococcosis. Between 2019 and 2021, *S. iniae* was found to be the predominant strain (Pers. comm. SENASICA, May 2022). Although SENASICA did not specify the exact year, it reported higher occurrences of *Streptococcus* species during the summer and fall seasons (3.66% and 4.08%, respectively) compared to the spring and winter seasons (1.63% and 0.89%, respectively). This temporal pattern aligns with the observations of increased mortality reported by producers in Malpaso, where 97.7% of producers noted higher mortality rates during the summer (Velazquez, 2022). Contrary to SENASICA's prevalence reports, streptococcosis in tilapia is primarily associated with *S. agalactiae*, as indicated by studies conducted by Li et al. (2013, 2014) and Zamri-Saad et al. (2010), as well as other findings from Peru and Mexico (Ortega et al., 2016; Sheehan, 2009). However, a significant number of reports regarding *S. iniae* infections also involve tilapia, as documented by Hossain et al., (2014), Sheehan (2009), Shoemaker et al., (2000), Weinstein et al. (1997), and Zhou et al. (2011).

Streptococcosis has significant economic implications, particularly from fish losses further along the grow-out process. This disease can lead to mortality rates exceeding 50% during acute infections, typically occurring within a 3-to-7-day period or result in low, but consistent, daily mortalities during chronic infections (Yanong & Francis-Floyd, 2002; Zamri-Saad et al., 2010). Ortega et al. (2018) also noted a similar situation in two examined tilapia farms in Mexico, where affected individuals weighing between 150 and 250 g experienced high mortality rates and displayed signs of progressing towards chronic infection. It is noteworthy that the assessed farms were located approximately 160 km apart, with one in the Mexican state of Queretaro and the other in San Luis Potosi.

In 2020, a total of 20 aquaculture production units (UPAs) were operational in Sonora, and the Aquaculture Health Committee of the State of Sonora (COSAES) conducted microbiological testing at two selected farm sites. The tests aimed to identify the presence of fecal coliforms (i.e., *E. coli*), *Salmonella*, and *Vibrio cholerae*, but no detections were reported. However, COSAES did report a single incident of "low" mortality in the state, which was attributed to stress related to management practices and the presence of *Streptococcus agalactiae*. Additionally, COSAES detected *Francisella noatunensis, Streptococcos iniae, and Streptococcus agalactiae* in two reservoirs during 2020. Although the report did not provide a breakdown by pathogen, a total of 57 PCR positive results were obtained from wild fish samples, and 108 PCR positive results were obtained from cultivated fish samples. Unfortunately, the report did not provide specific details regarding the monitoring methods, location, fish species, or types of production systems. Furthermore, while COSAES reported a prevalence over 30% for *Streptococcus sp*. for the state of Sonora during 2020 production cycle, but no contextual information (i.e., number of farms or infected fish) or any explanations were provided justifying the reported prevalence.

The Aquaculture Health Committee of the State of Nayarit, CESANAY, has made a few reports publicly available, but they also lack detailed information similar to the reports from COSEAS. One such report pertains to the tilapia production cycles from 2018 to 2019, where CESANAY documented the presence of the pathogens listed in Table 16. It is important to note that the total number of fry included in Table 16 represents those cultured in the production system when the pathogen was detected. However, these values are aggregated and, in some cases, counted twice for certain pathogens. In their 2019 aquaculture health report, CESANAY provides information on the prevalence of these same pathogens based on 101 diagnostic tests conducted. The report indicates that the prevalence of *Streptococcus species* was 18.75%, *Francisella noatunensis* was 6.25%, and *Aeromonas hydrophilia* was 33%. It is worth mentioning that CESANAY's website, accessed in May 2023, also lacked detailed information. However, it did highlight the detection of *Aeromonas hydrophilia* in three tilapia farms in Nayarit during 2015, with an estimated mortality rate of 5%.

Table 16. Pathogen detected in tilapia farms in Nayarit for production cycles 2018 and 2019. (CESANAY[67], 2020).

Number of UPAs	Reported Pathogen	Total Fry in UPAs
5	Aeromonas hydrophilia	2,230,000
6	Streptococcus agalactiae	1,633,700
4	Streptococcus iniae	166,500
2	Francisella noatunensis	6,200

[67] https://cesanay.org/cesanay/wp-content/uploads/2015/08/patogenos-peces.pdf

CESANAY provides data on the occurrence of "high level" detections of parasites and bacteria in cultured fish in Nayarit, relative to the total number of analyses conducted. Although the data lacks of context and does not allow for definitive conclusions, it does indicate the presence of parasites and bacteria in aquaculture farms in Nayarit over the nine-year period covered in Table 17.

Table 17. Detections of high levels of parasites and bacteria relative to the total analyses performed during 2011 to 2019 in fish farms located in the state of Nayarit (CENASAY[68], accessed in May, 2023).

	2011	2012	2013	2014	2015	2016	2017	2018	2019
Parasites	12/73	3/85	3/85	3/85	2/80	0/80	5/70	6/70	0/0
Bacteria	1/175	1/278	0/160	0/168	3/83	11/75	10/70	21/70	7/14
Positive PCR	0/0	0/0	0/0	0/10	5/10	0/40	7/30	4/30	13/56

While dated, Soto-Rodriguez (2009) highlights that the presence of bacteria in the water is the primary cause of mortality of farmed tilapia in reservoirs located in Sinaloa. The combination of physicochemical water parameters and 14 bacteria with pathogenic potential increases the risk of an epidemiological outbreak in tilapia production across three water reservoirs in Sinaloa, namely Adolfo Lopez Mateos, Sanaloa, and Dique IV (Soto-Rodriguez, 2009). Reports indicate that bacterial pathogens have been responsible for an average mortality rate of 50% (equivalent to an estimated 3 thousand mt) prior to harvest in these Sinaloa reservoirs. Among the bacterial pathogens, bacterial hemorrhagic septicemia caused by *Aeromonas hydrophila*, *Edwarsiella tarda*, *Pasteurella multocida*, *Pseudomonas fluorescens*, and *Vibrio sp*. has been particularly significant, resulting in mortalities ranging from 5% to 100%. Table 18 presents the prevalence levels of these pathogens during February 2009, along with other bacteria isolated from these reservoirs. Notably, most of the bacteria listed in Table 18 exhibit a prevalence greater than 5%, indicating the potential for an outbreak according to Soto-Rodriguez (2009).

Table 18. Prevalence of bacteria genus or species isolated during February 2009 in tilapia net pens located in three water reservoirs in Sinaloa, Mexico: Adolfo Lopez Mateos, Sanalona, and Dique IV (Reproduced from Soto-Rodriguez, 2009).

Bacteria	Prevalence (%)
Aeromonas hydrophila	29.8
Micrococcus spp.	21.1
Plesiomonas shigelloides	19.3
Pseudomonas sp.	15.8
Salmonella sp.	15.8
Pseudomonas aueruginosa/fluorescens	12.3
Enterobacter cloacae	8.8
Staphylococcus	7
Proteus vulgaris	5.3
Achromobacter	3.5
Flavobacterium	3.5
Hafnia alvei	3.5
Alcaligenes fecalis	1.8
Chromobacterium	1.8

[68] https://cesanay.org/cesanay/wp-content/uploads/2015/08/PCES-PRODUCCION-2011-2019.pdf

Soto-Rodriguez et al. (2013) conducted an additional study in which tilapia were challenged with 17 bacterial strains, primarily belonging to the *Aeromonas* genus. Among these strains, *Aeromonas ichthiosmia, Aeromonas popoffii, Aeromonas veronii,* and *Aeromonas dhakensis* exhibited characteristics indicative of potential virulence factors, with only the latter demonstrating toxicity that led to 100% mortality. The virulent factors exhibited by this strain, including gelatinase, DNAase, lipase, cytotoxicity, and hemolytic activity, are lethal to fish, leading to its classification as a fish pathogen for the first time during this study. Notably, the pathogenesis mechanism of *aeromonads* remains complex and unclear, as it is considered to be multifactorial (Soto-Rodriguez, 2013). However, the adaptability of *A. dhakensis* to mild and extreme environmental conditions poses a significant risk to cultured fish (Soto-Rodriguez et al., 2018).

Furthermore, *Pseudomonas mosselii* and *Pseudomonas anguilliseptica* were also identified as potential pathogens for tilapia. However, *P. mosselii* did not exhibit signs of septicemia in the isolated kidney, while *P. anguilliseptica* was only associated with the loss of scales when isolated from the brain (Soto-Rodriguez, 2013).

Ortega, C., et al. (2016) confirmed the presence of *francisellosis* in tilapia farms in Mexico through an outbreak that occurred during the second semester of 2012. The reported case history revealed that when a tilapia farm in central Mexico requested a disease diagnosis, the infection had already become chronic and had been affecting the farm for nearly 6 months. Consequently, at the time of analysis, mortality rates were not prominently evident. However, mortality reached a rate of 40% during the initial outbreak. It is worth noting that prior to the outbreak, a batch of tilapia originating from Central America was introduced to the affected Mexican farm, but the number of farms and locations where this fish group was introduced remain unknown.

Smaller net pen producers in the Malpaso reservoir have encountered significant mortality rates, for example, according to Velazquez (2022), a survey conducted on 40 fish farming units (UPAs) in Malpaso revealed that 62.5% of the producers reported issues related to fungi, while 37.5% primarily dealt with bacterial agents. However, due to the absence of technical programs in many farms within the reservoir, these producers do not have recorded water quality parameters, hindering the determination of the primary causes of mortality in this area (Velazquez, 2022; Todo Tilapia, 2021). Some of these producers lack best management practices, like having biologists or divers on staff responsible for maintaining the net pens and addressing ongoing mortalities (Todo Tilapia, 2021). This absence of standard practices poses challenges in identifying appropriate measures to mitigate mortalities since they have also been linked to various other factors (that is, many pathogens are opportunistic and occur as secondary infections during periods of low water quality or in the presence of other stressors). For instance, in November 2016, over 120 metric tons of tilapia perished due to a vertical displacement of surface water, resulting in low concentrations of dissolved oxygen at the depth where the floating cages were located (Velazquez, 2022; Todo Tilapia, 2021).

In May 2019, the National Health Service for Food Safety and Quality (SENASICA) officially declared Mexico as free of tilapia lake virus (TiLV) through a newsletter publication. However, it is crucial to provide context regarding this significant global health concern, which primarily affects tilapia fry. SENASICA reported the detection of TiLV to the World Organization for Animal Health (OIE) on August 25th, 2018, following an epidemiological event that commenced on June 4th, 2018. During this outbreak, mortality rates ranged from 20% to 80%, resulting in a total of 243,900 recorded tilapia deaths. Additionally, 3,677,418 tilapias were culled as part of the disease control measures (SENASICA, 2020). SENASICA worked closely with the OIE to implement appropriate measures and effectively manage this sanitary emergency. A total of 334 tests for TiLV were conducted across 24 out of the 32 states in Mexico. The presence of the virus was confirmed in only six states: Sinaloa, Jalisco, Michoacan, Veracruz, Tabasco, and Chiapas. Furthermore, Mexico imposed restrictions on the importation of live tilapia from countries where TiLV had been detected. The swift and proactive response by SENASICA in addressing this sanitary emergency highlights their preparedness and underscores the well-established biosecurity protocols in place to effectively manage disease outbreaks in the country.

During the final quarter of 2022, the existing mega farm in Malpaso and Peñitas reservoirs did not achieve the required survival rates of ≥ 65% as stipulated by the Aquaculture Stewardship Council (ASC) standard. The recorded survival rates during this period were 52.79% in Malpaso and 58.72% in Peñitas (ASC, 2022). Although the ASC reports did not provide average mortality figures, they did present mortality numbers in relation to the company's practice of consistently removing fish mortalities on a daily basis. In Malpaso, a single net pen recorded a total mortality of 4,901 fish in June 2021, and in the following year (June 2022), another single net pen recorded a total mortality of 25,559 fish. Similarly, in Peñitas, a mortality of 9,599 fish was recorded in December 2021 from a single net pen, and in September 2022, an additional net pen reported a mortality of 11,357 fish (ASC, 2022). The existing mega farm reported a mortality rate of up to 40%, attributing variations to the life stage of the fish and external factors such as elevated water temperatures. Furthermore, according to Fletcher (2022), it is suggested that the existing mega farm experienced a significant increase in mortality levels in 2022. This surge in mortality was attributed to water quality issues resulting from the impact of Hurricane Fiona, which occurred in September 2022 (Fletcher, 2022).

Parasites

The parasitic genera *Cichlidogyrus and Gyrodactylus* have been infecting tilapia worldwide and have changed host to the native species (i.e., other cichlids) (Garcia-Vasquez et al., 2021; Fajer-Avila, 2017; Jiménez-García et al., 2001). In Mexico, two types of monogeneans, namely *C. sclerosus* and *G. cichlidarum*, have been introduced in 1945 and have successfully established throughout the country (Garcia-Vasquez et al., 2021; Aguirre-Fey et al., 2015). Aguirre-Frey et al. (2015), detected three species of monogenean gill parasites, including *Cichlidogyrus sclerosus*, *Cichlidogyrus dossoui*, and *Scutogyrus sp*., after examining 568 farmed tilapia in Veracruz, Mexico between September 2006 and August 2007. Out of the total count of 32,883 parasites, *C. sclerosus* was the most prevalent with 96.97% of the total (also responsible for the highest abundance of infection), followed by *C. dossoui* (2.27%) and *Scutogyrus sp.* (0.76%). Another study showed that all tilapia samples collected in San Luis Potosi during February 2013, were moderately infested with external parasites in skin and gills belonging to the genera *Gyrodactylus, Dactylogyrus*, and the protozoan *Trichodina* (Ortega et al., 2018). Of note, gill parasite presence is recorded to be highest during winter, when temperature ranged from 20-25 °C (November to March) (Aguirre-Frey et al., 2015). Mortalities as high as 20% have been observed in net pen production systems in reservoirs in Sinaloa, which were associated with the presence of *Gyrodactylus and Streptococcus sp.* (Fajer-Avila, 2017). It is worth noting that these parasitic infestations can increase the susceptibility to bacterial infections (Ortega et al., 2018).

Garcia-Vasquez et al. (2021) conducted a study in Mexico, sampling a total of 40 tilapia farms in three regions: North-West (Jalisco, Sinaloa, and Sonora), Centre-South (Puebla, Oaxaca, Veracruz, Tabasco, and Chiapas), and East (Yucatán) (See Figure 28). Researchers collected approximately 25 healthy tilapia individuals from each farm. In the Central-South region, native fish species such as Poeciliidae, Goodeidae, and Profundulidae were randomly captured from nearby streams and rivers; including an unidentified cichlid, which were collected in Chiapas. The findings of this survey confirmed that three African *gyrodactylid* parasites, have now spread widely across fish farms throughout the country.

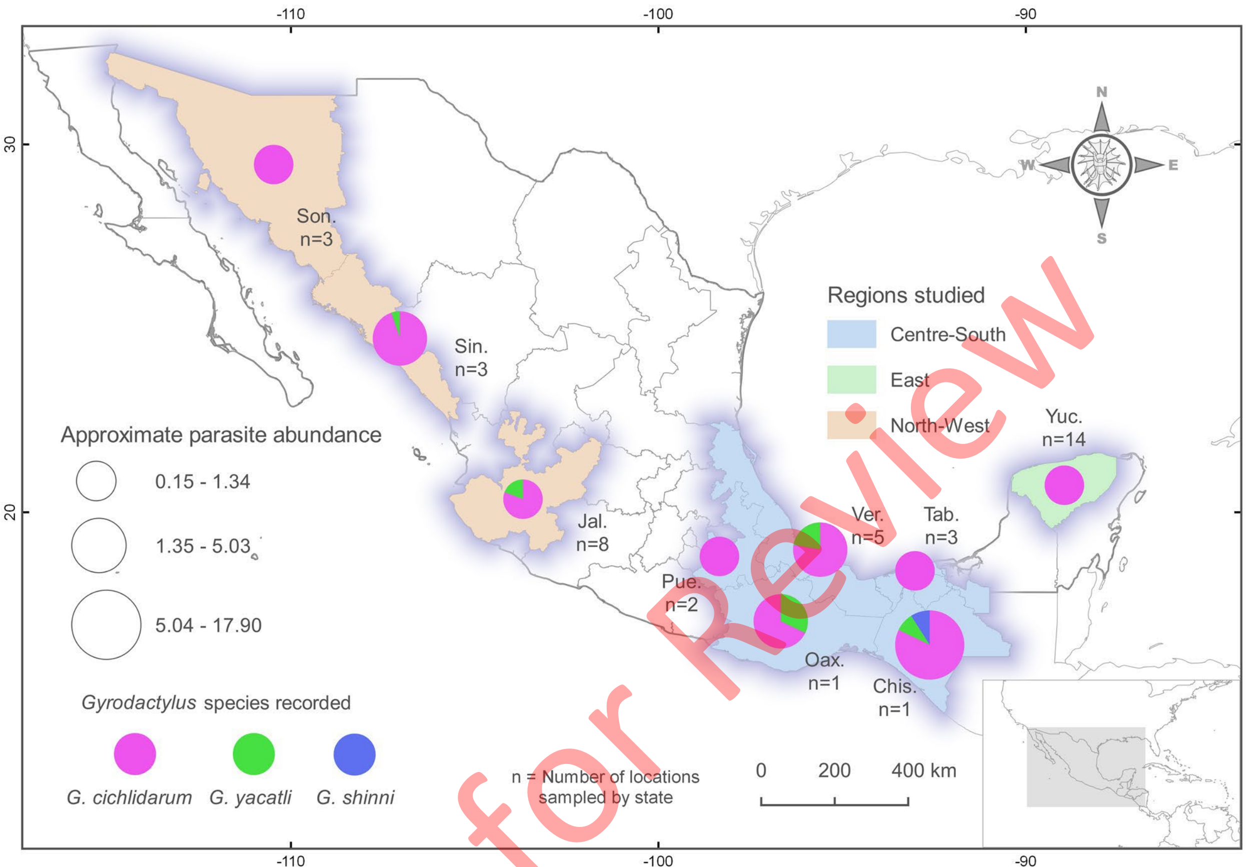

Figure 28. Map of Mexico, showing the distribution of *Gyrodactylus cichlidarum*, *G. yacatli* and *G. shinni* n. sp. and the localities of farms where tilapia and native fish were sampled. State names are as follows: Son: Sonora; Sin: Sinaloa; Jal: Jalisco; Pue: Puebla; Ver: Veracruz; Tab: Tabasco; Oax: Oaxaca; Chis: Chiapas; Yuc: Yucatán. (Taken from Garcia-Vasquez et al., 2021).

Regulation and Management

The Carta Nacional Acuicola (Version available: DOF, June 2012) provides recommendations on sanitary practices for various cultured fish species, but it does not specifically address tilapia. Instead, it refers readers to consult the Best Practice Tilapia Manual (BPTM) for relevant sanitary recommendations. Although the BPTM offers valuable sanitary guidelines (further discussed in the next section on Biosecurity), it is important to note that these recommendations are voluntary for producers and do not have legal standing, nor can they result in administrative sanctions.

While not specific to aquaculture or tilapia, the Federal Law of Animal Welfare[69] establishes the foundation for diagnosing, preventing, controlling, and eradicating diseases and pests that affect animal welfare. It also regulates best practices in primary production and processing facilities involved in the

[69] https://www.diputados.gob.mx/LeyesBiblio/pdf/LFSA.pdf

production of live organisms for human consumption. This law assigns jurisdictional responsibilities to the General Secretary, who oversees all aspects of animal health outlined in the law.

The General Law of Fisheries and Aquaculture[70] promotes and implements actions to align federal animal welfare and disease prevention measures with those established in other countries. It also defines the responsibilities of the National Health Service for Food Safety and Quality (SENASICA) regarding the application of sanitary measures mandated by this law. The Internal Ruling of the National Service of Welfare, Safety, and Quality of the Agri-food Sector[71] establishes the internal mechanisms for the functioning of SENASICA, outlining the responsibilities from the General Director to those of the regional technical units.

Moreover, Mexico has established state-level aquaculture health committees in collaboration with SENASICA to promote health practices among aquaculture farms within their states. These committees track disease outbreaks, implement prevention measures, carry out farm visits, and collect farm-level data throughout the grow-out season (pers. comm., Soledad Delgadillo, FAO, September 2023). They consist of representatives from academia, state government, and federal government, and they possess regulatory authority to ensure animal health and farm biosecurity.

Biosecurity

In addition to the aforementioned laws and regulations, the Best Practice Tilapia Manual (BPTM) serves as the primary sanitary guide for tilapia farmers, outlining measures to reduce the risk of disease outbreaks and maintain proper sanitary conditions on farms. The manual encompasses various biosecurity best practices, including equipment and personnel control, use of tested and quarantined fry sources, veterinary oversight, wildlife entry barriers, water quality monitoring and treatment, disease outbreak reporting, waste management, and record-keeping. In the case of equipment, the manual outlines specific protocols to ensure cleanliness and prevent cross-contamination. It recommends assigning dedicated cleaning utensils and supplies for each production area, which should not be used interchangeably between areas. Furthermore, personnel should be instructed not to wear any jewelry or makeup, and they are required to adhere to the company's established personal hygiene protocols. This includes refraining from working while suffering from a contagious disease and utilizing hygiene stations during operation processes. When monitoring for disease and water quality, producers are advised to establish strategic monitoring locations. These locations should encompass key areas such as water entry points, water distribution channels, hatchery tanks or incubators, grow-out tanks, and water discharge points. This allows for swift identification of contamination sources and facilitates timely corrective actions. The manual also provides guidelines for acceptable levels of heavy metals, pesticides, and other chemicals in the water used for fish cultivation. It offers recommendations on siting considerations, personnel training, and references to relevant regulations, such as NOM-001-SEMARNAT-1996, which outlines requirements for water waste discharge. Furthermore, the Health Committee in Chiapas has devised a comprehensive training program scheduled for implementation in 2023. This program is designed to encompass all the biosecurity measures and best practices protocols

[70] https://www.diputados.gob.mx/LeyesBiblio/pdf/LGPAS.pdf

[71] https://www.gob.mx/cms/uploads/attachment/file/145508/REGLAMENTO_INTERIOR_DEL_SENASICA_FORMATO_EDITORIAL.pdf

mentioned earlier, with the intent of disseminating this knowledge among regional producers. (pers. comm., Mauricio Orellana, Neoaqua, April 2023).

While SENASICA has developed these best practice manuals and efforts have been made at the state and federal levels to promote their implementation, the extent to which producers adhere to these guidelines remains uncertain. Anecdotal evidence suggests that best practices are not widely implemented, and the rapid expansion of the tilapia industry in Mexico, accompanied by the entry of inexperienced producers, has led to disease outbreaks within farm populations and, in some cases, the transmission of pathogens to wild species (Velazquez, 2022; Todo Acuicola, 2021; Soto-Rodriguez, 2009). For example, a survey conducted in Malpaso between 2020 and 2021 found that 57.5% of producers did not implement access restrictions between different inland production areas, 72.5% did not follow biosecurity protocols, including equipment disinfection, and 67.5% lacked pest or wild fauna control devices to prevent undesired organisms from coming into contact with feed or farm equipment (Velazquez, 2022). While it is evident that most producers surveyed in this study do not fully adhere to the recommended biosecurity guidelines, it is crucial to acknowledge the presence of producers who do. Notably, a medium-sized net pen producer has provided documentation detailing their established protocols, which appear to align with the guidelines outlined in the BPTM. These protocols, as communicated by the producer, are designed to ensure the sanitation of their facilities, offer appropriate training to their employees, and set operational standards aimed at preventing cross-contamination from both internal and external sources. Examples of such measures include restricted access to specific production areas, pest control procedures, and storage protocols (pers. comm., Mauricio Orellana, Neoaqua, April 2023).

Considerable advancements have been achieved on a global scale regarding the vaccination of tilapia against prevalent diseases in aquaculture, specifically Streptococcus infections (Vásquez-Machado et al., 2019; Carrera-Quintana et al., 2022; Camero-Escobar and Calderón-Calderón, 2018). Nevertheless, an industry expert in tilapia aquaculture highlights that despite evidence demonstrating reduced mortality rates with the use of Streptococcus vaccines, only a minority of tilapia producers in the country implement such measures (interviewed by Panorama Acuicola[72], accessed February 2023). This reluctance to adopt vaccines is primarily attributed to perceived high costs and a lack of awareness regarding the long-term economic benefits resulting from decreased mortality (interviewed by Panorama Acuicola, accessed February 2023). Odolinski (2020) acknowledges that vaccination typically necessitates specialized facilities, labor, and cumbersome and costly work. Notably, a smaller tilapia producer in the Malpaso reservoir does not utilize vaccines but reports disease issues exclusively during the hatchery stage, specifically related to fungi (pers. comm., Mauricio Orellana, Neoaqua, April 2023). Hence, in this report it is inferred that vaccination rates are likely to vary among different types of producers, with larger, technically advanced farms being more inclined to employ them compared to the numerous small pond farms. It is important to note that these small-scale farms, operating at lower intensities, may not face the same disease concerns as large intensive farms, thereby requiring less reliance on vaccination. Furthermore, it is common for small-scale inland farms to be situated in regions where wild fish populations are absent in the vicinity of these farms (pers. comm., Soledad Delgadillo, FAO, September 2023).

[72] https://panoramaacuicola.com/2019/05/18/entrevista-a-juan-loustanau-gerente-de-operaciones-de-acuicola-gemso/

Regarding the biosecurity protocols implemented by the existing mega farm, it is evident that they adhere to the required standards bounded through the ASC certification process. The producer's production sites have successfully implemented a fish health plan, which encompasses various measures. These measures are designed to fulfill three key objectives: 1) safeguarding the farm against the introduction of pathogens, 2) preventing the spread of pathogens within the farm and to surrounding water bodies, and 3) minimizing the risk of developing disease resistance through responsible use of therapeutants. To fulfill the second objective, the existing mega farm ensures that their health laboratory conducts regular and periodic sampling, especially during disease outbreaks, to monitor the health status of their fish population. Moreover, they inspect fish batches before transferring them to the next stage of production, maintain records of diagnoses and, when necessary, collaborate with external laboratories to validate and confirm these diagnoses.

While Fletcher (2022) suggests that the increased mortality observed by the existing mega farm during final quarter of 2022, was attributed to water quality issues caused by Hurricane Fiona, as previously discussed; ASC audit reports suggest that a contributing factor could have been the incorrect implementation of the vaccination protocol. The existing mega farm implements a vaccination program for the application of Aquavac Strep Sa (Inactivated vaccine against Streptococcus Agalactiae Biotype 1b), and Aquavac Strep SaSi (Inactivated vaccine against Streptococcus Agalactiae Biotype 1b and Streptoccus Iniae) (ASC, 2020). This non-conformity was addressed by the first quarter of 2023 by implementing the appropriate vaccination protocol.

While the existing mega farm may be one of the few tilapia producers in Mexico implementing a vaccination program, it is important to note that these vaccines only target bacterial pathogens for two strains of *Streptococcus sp*. As mentioned earlier, there are numerous bacterial pathogens affecting cultured tilapia in the country, and various parasites also impact the welfare of cultured fish and pose a risk to wild populations. Therefore, considering the occurrence of disease-related mortalities on the farms and the interconnectedness of the production system with the ecosystem, the existing mega farm's present a moderate risk that diseases at the farm level can impact wild populations.

<u>Impacts to wild species</u>

Although most of the diseases recorded for tilapia being produced in Mexico have the potential to spread to other organisms, and field observations suggest that intensified aquaculture activities in Mexico are being accompanied by the appearance of new diseases (Ortega et al., 2018); it remains unclear the degree to which these diseases can impact wild populations. The studies referenced above on this topic either did not fully study wild populations or provided only isolated observations on horizontal pathogenic transfers from tilapia to other species. The limitation of this information makes it challenging to determine the degree to which pathogens discharged from net pen or ponds farms in Mexico, could affect fish in the wild (i.e., outside of the farm environment, where the conditions such as unnatural stocking densities and reduced water quality are considered to increase the susceptibility of tilapia to pathogens).

Specific Feedback Request from Expert Review
Further information is requested with regard to documented transmission or impacts from cultured tilapia related diseases to wild species in Mexico. This is an important aspect in the scoring of this criterion.
Response:

Nonetheless, there are studies supporting the potential transmissibility of diseases affecting cultured tilapia to be transmitted to humans and to wild species. For instance, *A. dhakensis* is commonly found in warm regions and has been recovered from various sources, including wild European eel as well as river water, human feces, and fish specimens (Soto-Rodriguez, 2013). Moreover, clinical strains of *A. dhakensis* have been linked to a range of human diseases worldwide, such as diarrhea, bacteremia, and wound infections (Alcantara-Jauregui, 2022; Soto-Rodriguez, 2013). Additionally, several strains of *streptococcus sp.* possess the ability to cause infections in humans and other animals, and Mi*crobacterium* paraoxydans from fish, had been isolated in human specimens in the past, and was determined to be pathogenic to sole fish; hence the importance to prevent outbreaks for these diseases (Franken et al., 2002).

Vertical transmission of *francisellosis* has not been proven, but still offspring have been diagnosed with the infection, suggesting that it may have been transmitted through water recirculation and high biomass (Colquhoun and Duodu, 2011). *F. noatunensis subsp. orientalis*, or closely related bacteria, commonly isolated from tilapia, has been found to cause disease in various fish species, including the three-line grunt and different ornamental cichlids. Experimental infections through intraperitoneal injection of *F. noatunensis subsp. orientalis* have been established in red sea bream (*Pagrus major*) and zebrafish (*Danio rerio*). The pathogenicity of *F. noatunensis subsp. noatunensis*, isolated from Atlantic salmon and cod, towards other fish species has not been evaluated or adequately documented in existing literature. Although the number of non-cod species studied by Ottem et al. (2008) was limited, higher quantities of *F. noatunensis* were generally identified in wild cod compared to other non-cod species.

While Garcia-Vasquez et al. (2021) suggests that there is not enough evidence to consider which fish species served as a vector for African gyrodactylid parasites to establish across Mexico; there is proof of parasite spillover from "tilapia" to native cichlids, and that *G. cichlidarum* is capable of infecting non-related poeciliids. This study also confirmed that these parasites have also been observed infecting native cichlids. Specifically, *Gyrodactylus cichlidarum* is extensively distributed in Mexico and infects both farmed and wild "tilapia" across the country, as well as native poeciliid fishes. This survey marks the first documented cases of infection in three native cichlid species in Mexico: *P. nebuliferus* and *V. fenestrata* in Oaxaca, and an unidentified native cichlid collected in Chiapas. As a result, is safe to assume that *G. cichlidarum* exhibits a relatively low level of host specificity. While there are noticeable variations in its appearance among individuals from different hosts and geographical locations, there is limited molecular variation within this species. This ability potentially enhances its capacity to spread among farms and various river basins, suggesting that aquaculture operations may increase the likelihood of pathogen presence and/or parasite amplification in nearby environments (Garcia-Vasquez et al., 2017; Naylor et al. 2000, Johansen 2011, Camus, 1998).

Furthermore, monogeneans have been observed infecting native Mexican fish species other than cichlids. Specifically, *C. sclerosus* has been found to parasitize the endemic blackfin goodea (*Goodea atripinnis*), while *G. cichlidarum* has been detected in three native poeciliids: the shortfin molly (*Poecilia mexicana*), porthole livebearer (*Poeciliopsis gracilis*), and two spot livebearer (*Pseudoxiphophorus bimaculatus*) (Garcia-Vasquez et al., 2021 and 2017). Of note, the monogenean class has been the third most recorded class of parasites recorded in Mexico since 1936 (Garcia-Prieto et al., 2022).

Although the Mexican tilapia industry has various organizational mechanisms at the federal and state levels, such as SENASICA, State Aquaculture Health Committees, and academic institutions, tasked with monitoring and controlling diseases in production, it has faced significant disease issues in recent years. The industry has also been a potential vector for the introduction of pathogens from the farm environment to wild populations of cichlids and other poeciliid fishes. While no major impacts on wild populations have been documented, the presence of non-species-specific diseases, such as *streptococcus sp*., *F. noatunensis subsp. Orientalis*, and monogenean parasites, indicates the industry poses a risk of pathogen amplification, release into the surrounding environment, and potential impacts on wild populations.

Conclusion

Despite being recognized for its inherent disease resistance, tilapia is susceptible to various infectious and noninfectious diseases, particularly as global and Mexican production intensifies. Major diseases affecting cultured tilapia in the Americas include gram-negative and gram-positive bacteria, fungi, parasites, and copepods. While there are several studies of the diseases affecting cultured tilapia in the country, information around how these diseases are impacting wild populations, is not readily available. Both net pens and pond farms are considered to be "open" to the environment, in terms of the potential for amplification of pathogens within them and the subsequent release of those pathogens into waters shared with wild fish. Although some biosecurity measures and best practices have been established (by the government's National Service of Health, Safety, and Agri-Food Quality), their level of implementation among farms is uncertain. An exception here is the existing mega farm, for which the publicly available ASC audit reports document the implementation of the company's biosecurity protocols. While some of literature suggests that disease prevalence and mortality positively correlate with the intensity of production, this cannot be confirmed, as diseases and parasites have been detected throughout the country regardless of the production level associated with each region. There is a demonstrable risk that pathogens will be amplified on farms and wild fish in the vicinity of farms will be exposed to them, but the potential impacts to wild fish populations remain uncertain. The limited amount of data, particularly on the potential impacts to wild fish, means that the risk-based assessment has been used (the Data Criterion score for the disease section is <7.5 out of 10). The known pathogen and parasitic transfer risk to wild species, the openness of the production systems, the unknown level of implementation and enforcement of biosecurity regulations and management measures, plus the registered events with high disease-related mortality rates, result in a final score for Criterion 7—Disease for both net pens and ponds (excluding the existing mega farm) of 2 out of 10. The existing mega farm's final score for Criterion 7—Disease (net pens) is 4 out of 10, based on the company's documented implementation of biosecurity protocols, but also on the fact that their production system is still open to the introduction and discharge of pathogens and parasites.

Criterion 8X: Source of Stock – independence from wild fish stocks

Impact, unit of sustainability and principle

- *Impact:* The removal of fish from wild populations
- *Unit of Sustainability:* 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

Net pens (including all farm sizes) and ponds

C8X Source of Stock – Independence from wild fish stocks	**Value**	**Score**
Percent of production dependent on wild sources (%)	0.0	0
Use of ETP or SFW "Red" fishery sources	No	
Lowest score if multiple species farmed (0-10)		n/a
C8X Source of stock Final Score (0-10)		**0**
Critical?	No	Green

Justification of Rating and Final Score

Tilapia strains used in aquaculture have been domesticated for decades; for example, Watanabe et al. (2002) describe the process to develop red tilapia stocks in the 1980s, along with the domestication of Nile tilapia. After the first seeds of Tilapia were imported from Auburn University in Alabama in 1964, it probably didn't take long for producers to become fully dependent on public and local hatcheries for their seed supply. This reliance on hatcheries has persisted in the industry up to the present day (Martinez-Cordero et al., 2021; ATT Innova, 2015). Also, as a non-native species, if any "wild" tilapia from Mexico were used as broodstock, they would not be included in the scoring of this criterion (i.e., there would not be any sustainability concerns with their capture and use). Therefore, Mexico's tilapia culture is considered to be fully independent of wild fish stocks, and the score for the exceptional Criterion 8X is a deduction score of 0 out of –10.

Criterion 9X: Wildlife mortalities

Impact, unit of sustainability and principle

- *Impact:* Mortality of predators or other wildlife caused or contributed to by farming operations
- *Unit of sustainability:* Wildlife or predator populations
- *Principle:* Preventing population-level impacts to predators or other species of wildlife attracted to 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

C9X Wildlife Mortality parameters	Score	
	Mega farm	Net pen and ponds
Single species wildlife mortality score	-2	-6
System score if multiple species assessed together	n/a	n/a
C9X Wildlife Mortality Final Score	**-2**	**-6**
Critical?	No	No
	Green	Yellow

Brief Summary

Detailed information on wildlife interactions in Mexican tilapia farms remains scarce, and there is a lack of data regarding the mortality numbers or population impacts (or lack thereof) of any species resulting from these interactions. Nevertheless, the widespread distribution of tilapia farms across diverse ecosystems in the country suggests that some degree of interaction between tilapia farming and wildlife is inevitable. Notably, Chiapas, the primary region for tilapia production in Mexico, harbors at least eleven species of ecological concern. Although non-lethal exclusion strategies, such as human presence, bird scaring tactics, and the use of nets to prevent avian entry into net pens or ponds, are apparently employed by these farms, dated and anecdotal evidence suggests that bird shooting might have been practiced, despite being illegal. According to third-party audits conducted on the existing mega farm, no registered wildlife mortalities have been reported, and the company has implemented a wildlife interaction plan. Based on these factors, it can be inferred that wildlife mortalities on this specific farm are likely limited to exceptional cases, such as accidental incidents. Therefore, the final numerical score for the existing mega farm for Criterion 9X – Wildlife Mortalities is -2 out of -10. In the case of other net pen and pond producers, the available information is not specific enough to draw definitive conclusions. It was determined that regulation and management practices for non-harmful exclusion and control are in place, but the enforcement and mortality numbers are unknown. Therefore, the final numerical score for Criterion 9X – Wildlife Mortalities for the net pen and pond producers is -6 out of -10.

Justification of Rating

The cultivation of tilapia attracts a diverse array of predators, including reptiles, birds, and small mammals, as reported by El-Sayed (2006) and Lucas and Southgate (2012). Due to the lack of available data on wildlife mortalities resulting from this interaction in Mexico (e.g., the species affected, mortality numbers, and/or information on population impacts or lack thereof), the risk-based assessments is used.

Piscivorous birds pose a significant challenge to aquaculture producers operating in both freshwater and saline environments (Wajsbrot, 2023). Their impact on aquaculture encompasses direct losses through predation, as well as the creation of serious lesions that can serve as entry points for secondary infection by pathogens. Additionally, the presence of avian predators near feeding areas not only directly affects feed consumption but also disrupts the natural fish feeding process. Moreover, these birds can facilitate the rapid spread of infectious fish diseases from one facility to another (Wajsbrot, 2023). To address this issue, aquaculture farmers employ various bird-repelling strategies, such as non-lethal deterrents like flagging, ribbons, and audio devices (Wajsbrot, 2023; Olachea, 2011). Nevertheless, the most practical and effective approach involves the use of physical barriers, such as enclosing net pens or ponds with nets or meshes (see Figures 29 and 30). The presence of working staff or harassment patrols is also helpful in deterring birds (Wajsbrot, 2023; SEMARNAT, 2012), and non-lethal scaring tactics have been widely recognized as the primary management approach in Mexico (DeWalt et al., 2002). As an example, a medium-sized net pen producer operating within Malpaso reservoir in the State of Chiapas has furnished a copy of their fauna control plan. This plan meticulously enumerates the species of concern in the area and explicitly prohibits any lethal fauna control measures within their facility (pers. comm., Mauricio Orellana, Neoaqua, April 2023). However, there have been suggestions of potential shooting incidents, as highlighted by DeWalt et al. (2002), and this practice may even be relatively common (Seafood Watch, 2021).

Regarding the existing mega farm, the publicly available information in ASC audit reports shows that the company has implemented a comprehensive wildlife interaction plan, which outlines specific procedures in the event of accidental mortality or entanglement of wild fauna within the production site. The plan states that any deceased or trapped animals should be removed and documented in the designated format (Mortality of predators in cages). Furthermore, the audits conducted by the ASC confirm that the existing mega farm employs mesh barriers to prevent birds from entering the net pens (see Figure 29), thereby avoiding any lethal predator controls (although an inherent risk of entanglement remains). It is worth noting that in November 2019, a minor non-compliance issue arose when the existing mega farm was found to lack an available or updated list of the species involved in farm interactions or observed within the production area. Nevertheless, the company proactively addressed this matter in the following months, resulting in compliance being regained by March 2020.

Importantly, the reported data indicated the absence of endangered species in the vicinity of the farm. Instead, the species detected on the site were classified as "least concern" under the IUCN, specifically black-crowned night-heron (*Nycticorax nycticorax*), and the great egret (*Casmerodius albus*). Such observations are considered applicable for the rest of net pen producers operating in the same waterbodies as the existing mega farm, Malpaso and Peñitas reservoirs.

Figure 29: Example of net pens covered by bird netting in circular floating cage at San Julian Lake, Veracruz (top left), Square cages at Ixcatlán, Oaxaca (top right), Square cages in the Dam La Angostura, Chiapas (Bottom left), Regal Springs' circular cages, Chiapas (Bottom right). Image reproduced from Martinez-Cordero et al. (2021).

Figure 30: Example of circular tanks in land covered by bird netting in Guamuchil, Sinaloa (left image) and in unknown location in Mexico (Martinez-Cordero et al., 2021; Rubio73, 2017).

As previously discussed, the state of Chiapas, Mexico, is the primary producer of cultured tilapia in the country, contributing to 66% of the national output. Notably, this southern region also boasts

[73] https://www.debate.com.mx/guamuchil/Todo-un-reto-la-produccion-de-tilapia-en-estanques-20170911-0163.html

remarkable biodiversity, hosting approximately 67% of all species found within Mexico. Economic activities surrounding the reservoirs in Chiapas, including aquaculture, have been identified as significant factors causing perturbations to the presence of wildlife in this region (ATT Innova, 2015). Consequently, it is important to assess the interactions between aquaculture and wildlife in this ecologically significant area.

For instance, in the four reservoirs connected by the Grijalva river, there are at least eleven species with ecological concern detected: The four fish species under especial protection are the Lacandon sea catfish (*Potamarius nelson*), Pale catfish (*Rhamdia guatemalensis*), Isthmian priapella (*Priapella intermedia*), and Sieve Cichlids (*Chiapaheros grammodes*). Additionally, two fish species, the yellow swordtail (*Xiphophorus clemenciae*) and Tailbar cichlid (*Vieja hartwegi*), are classified as threatened (Romero-Beltran et al., 2020b). Furthermore, the NOM-059-SEMARNAT-2010 identifies the river otter (*Lontra longicaudis*) and the black iguana (*Ctenosaura similis*) as threatened species in the region. Moreover, several other species, including the white-tail deer (*Odocoileus virginianus*), grey squirrel (*Siurus aureogaster*), and various rabbit species (*Sylvilagus sp*), fall under Appendix I of the IUCN and are therefore of conservation concern (ATT Innova, 2015). Regarding avian species, Romero-Beltran et al. (2020b) report the presence of diverse bird species in the area, such as the Gray Eagle, Roadside Hawk, Black Eagle, Vultures, Sparrowhawks, Blue Teal, Laughing Gull, Kingfisher, Swallows, Thrushes, Great-tailed Grackles, Herons, White Pelicans, Brown Pelican, Toucans, Parrots, Parakeets, and Cormorants. Given the presence of species of concern, it is of utmost importance to take a precautionary approach when assessing the interactions between aquaculture activities and wildlife in Mexico.

<u>Regulation and management</u>

SEMARNAT mandates EIA applicants to conduct a thorough evaluation of the fauna present at the project site (SEMARNAT, 2002). This assessment includes identifying species of conservation concern protected under NOM-059-SEMARNAT-2010 or international agreements like CITES. Additionally, the EIA should consider all species that may be affected by the establishment or operation of the project, regardless of their conservation status, and provide detailed information about species taxonomy, distribution, abundance, and seasonality. Furthermore, the potential interactions between fauna and vegetation coverage should also be addressed, considering that changes in vegetation, as a result of the operation, can indirectly impact the site's wildlife. This assessment should identify sensitive areas, such as nesting, breeding, and refuge sites, that could be affected by alterations to the habitat, and consequently cause wildlife mortalities.

According to Mexican law, only non-lethal means of controlling predators are permitted in aquaculture, such as acoustic and visual deterrents (SEMARNAT, 2014). The General Law of Wildlife[74] (2021) strictly prohibits any acts of cruelty towards wildlife and requires prior approval from SEMARNAT for any lethal actions targeting species under special protection or ecological concern. SEMARNAT also has the authority to implement industry closures in cases of imminent risk or damage to wildlife or its habitat. Any entity undertaking control or eradication measures affecting wildlife without prior authorization from the Secretary may face infractions and administrative actions.

However, there is a lack of readily available information on the effectiveness of enforcement measures for these protections. The existence of numerous unregistered tilapia producers (over 60% of estimated total UPAs) operating throughout various regions of Mexico, from tropical to desertic and coastal areas,

[74] https://www.diputados.gob.mx/LeyesBiblio/pdf/146_200521.pdf

contributes to high uncertainty regarding the implementation of authorized versus unauthorized wildlife deterrents and the potential wildlife mortalities associated with the tilapia aquaculture industry (Martinez-cordero et al., 2021).

Conclusions and Final Scores

Detailed information on wildlife interactions in Mexican tilapia farms remains scarce, and there is a lack of data regarding the mortality numbers or population impacts (or lack thereof) of any species resulting from these interactions. Nevertheless, the widespread distribution of tilapia farms across diverse ecosystems in the country suggests that some degree of interaction between tilapia farming and wildlife is inevitable. Notably, Chiapas, the primary region for tilapia production in Mexico, harbors at least eleven species of ecological concern. Although non-lethal exclusion strategies, such as human presence, bird scaring tactics, and the use of nets to prevent avian entry into net pens or ponds, are apparently employed by these farms, dated and anecdotal evidence suggests that bird shooting might have been practiced, despite being illegal. According to third-party audits conducted on the existing mega farm, no registered wildlife mortalities have been reported, and the company has implemented a wildlife interaction plan. Based on these factors, it can be inferred that wildlife mortalities on this specific farm are likely limited to exceptional cases, such as accidental incidents. Therefore, the final numerical score for the existing mega farm for Criterion 9X – Wildlife Mortalities is -2 out of -10. In the case of other net pen and pond producers, the available information is not specific enough to draw definitive conclusions. It was determined that regulation and management practices for non-harmful exclusion and control are in place, but the enforcement and mortality numbers are unknown. Therefore, the final numerical score for Criterion 9X – Wildlife Mortalities for the net pen and pond producers is -6 out of -10.

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

- *Impact:* Movement of live animals resulting in introduction of unintended species
- *Unit of sustainability:* Wild native populations
- *Principle:* Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

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

Introduction of Secondary Species parameters	Score		
	Mega farm	Net pens	Ponds
F10Xa International or trans-waterbody live animal shipments (%)	9	2	2
F10Xb Biosecurity score of the source of animal movements (0–10)	6	6	6
F10Xb Biosecurity score of the farm destination of animal movements (0–10)	0	0	2
C10X Introduction of Secondary Species Final Score	–0.4	–3.2	–3.2
Critical?	No	No	No
	Green	**Green**	**Green**

Brief Summary

The spread of pathogens such as tilapia lake virus and helminths, and introductions of new species of aquatic plants are examples of unintentional introductions of non-native species during movements of live tilapia or other fish species into and within Mexico. Although tilapia fingerlings were previously known to be shipped into Mexico from hatcheries in the U.S., Panama, United Kingdom, Vietnam, and Cuba, the current scale of this practice is unclear. The development of hatcheries in the main tilapia-producing states of Mexico is likely to have reduced such international movements substantially. The importation of smaller numbers of selectively bred tilapia broodstock from breeding centers elsewhere likely continues, but is now accompanied by quarantine and inspection requirements at the port of entry. This assessment is therefore based on the movements of tilapia within Mexico. Although there are 29 hatcheries, the broad distribution of farms means that there are considered to be substantial transwaterbody movements of tilapia produced in net pens and ponds (estimated to be 70-80% of production and a score of 2 out of 10 for Factor 10Xa). In contrast, publicly available audit reports from the existing mega farm show that their hatcheries are all located in close proximity to the growout location (and therefore <10% of the existing mega farm's production is considered to be based on transwaterbody movements and a score of 9 out of 10 for Factor 10Xa). Although the sources of live animal movements have some potential for biosecurity (e.g., reduced or zero water exchange, along with quarantine and monitoring), the movements of tilapia into and within Mexico continue to present a risk of unintentionally introducing non-native species, and the score for Factor 10Xb is 6 out of 10. The final score for Criterion 10X—Escape of Unintentionally Introduced Species is a deduction of –0.4 out of –10 for the mega farm, and –3.2 out of –10 for the rest of net pen and pond producers in Mexico.

Justification of Ranking

This criterion provides a measure of the risk that non-native species, apart from the farmed species, might be unintentionally introduced into a distinct waterbody (i.e., one in which they are not native or present) during the transportation of live fish. For example, in Mexico, the trade of ornamental and exotic fish species has led to the introduction of several species of aquatic plants, such as Eichhornia crassipes, *Hydrilla verticillata, Hygrophila polysperma, and Salvinia molesta* (Mendoza-Alfaro et al., 2021). Such introductions can have negative environmental impacts. For instance, *Hydrilla verticillata* can produce a toxin that is deadly to birds, causing avian vacuolar myelinopathy. Additionally, the global spread of emerging viruses like tilapia lake virus (TiLV), with sudden appearances in new locations, is often associated with the movement of live animals (SENASICA, 2020). Mexico has encountered the introduction of a total of forty helminth species, coinciding with the introduction of various aquaculture-cultivated species such as tilapia. Among these helminths, Cichlidogyrus sclerosus has become the most common branchial parasite in several tilapia species and hybrids cultivated in Veracruz (Mendoza-Alfaro et al., 2021). These instances of species introductions raise concerns about their potential ecological impacts on the native biodiversity and aquaculture practices in the region.

Factor 10Xa—International or Trans-Waterbody Live Animal Shipments

Martinez-Cordero et al. (2021) suggests that a substantial number of tilapia subsistence farmers and small to medium tilapia producers in Mexico (an estimated 2,361 UPAs fall under these production categories) rely heavily on specialized hatcheries and nurseries. In the country, there are a total of 29 hatcheries, including nine government-run facilities, distributed across 25 states (Martinez-Cordero et al., 2021). These hatcheries have been strategically positioned throughout Mexico, with higher fingerling production capacity aligned with states exhibiting elevated production output. Notably, these states include Chiapas, Tabasco, Jalisco, Veracruz, Campeche, Sinaloa, Sonora, and Hidalgo, arranged according to their total fingerling capacity. Although the production capacity of these hatcheries is currently considered to be sufficient to meet domestic demand, the practice of importing seeds and broodstock for enhancing the genetic pool has happened occasionally and is likely to continue (Martinez-Cordero et al., 2021; INAPESCA, 2003). For example, from 1964 to 2011, tilapia fingerlings have been imported from several countries, including the U.S., Panama, United Kingdom, Vietnam, and Cuba. These imports arrived at several Mexican states, such as Oaxaca, Morelos, Tamaulipas, Veracruz, Mexico City, Colima, and Sinaloa (Martinez-Cordero et al., 2021).

Despite the presence of 29 hatcheries across the nation, the extensive distribution of over 2,000 tilapia farms means that trans-waterbody movements have become a common practice within the industry. For instance, in Veracruz, local tilapia hatcheries were available but unable to fully satisfy the demands of local tilapia farmers, leading them to purchase tilapia seeds from other states (Martinez-Cordero et al., 2021). Furthermore, producers in the Malpaso reservoir frequently utilize seed produced in the state of Tabasco (ATT Innova, 2015). These instances underscore the reliance of the industry to move tilapia across ecologically distinct waterbodies in Mexico. Moreover, the lack of a stable supply of good quality tilapia seed is considered one of the main constraints for commercial tilapia farmers in Mexico (Martinez-Cordero et al., 2021). This limited seed supply has likely pushed tilapia farmers to source fingerlings from other states where they are available; potentially increasing the movement and distance from where tilapia fingerlings get sourced.

While the mobilization of tilapia within the country is a widely adopted practice, it is important to acknowledge that government-run hatcheries supply fingerlings to tilapia farmers, but they are primarily focused on restocking waterbodies to sustain culture-based tilapia fisheries in Mexico. It must be noted that these movements also represent a risk of unintentionally introducing a secondary species equivalent to the movements of tilapia for aquaculture movements and subsequent stocking into net pens or ponds.

SENASICA, as the overseeing authority, holds the responsibility of regulating biosecurity measures concerning aquatic animal movements at both national and international (imports) levels. The approval of health and safety certificates by SENASICA is mandated for the movement of aquatic organisms within the country, for the importation of aquatic animals, and for the quarantine units utilized during import processes. These requisite certificates are established and governed by various regulations and norms. For example, the third Title - Chapter V of the Fisheries Law Ruling[75] outlines the protocol for introducing species that are not naturally present in bodies of water under federal jurisdiction. In such cases, the Secretariat, with due consideration of the opinion of INAPESCA and based on the outcomes of the preceding quarantine period, will make decisions on the suitability of the introduction, in adherence to the stipulations derived from the regulations of this Law. Additionally, the possession of an aquaculture health certificate granted by SENASICA remains an obligatory prerequisite for obtaining the permit to introduce living species into bodies of water under federal jurisdiction. Furthermore, Article 130 of this ruling explicitly specifies that SENASICA's health and safety certificate is required for the domestic mobilization of any living aquatic species. However, notably, SENASICA[76] exempts tilapia from requiring this certificate for national movements, possibly attributed to the extensive and well-established presence of tilapia within the territory.

According to the General Law of Sustainable Fisheries and Aquaculture, specifically Article 95, the importation of seed, eggs, fry, larvae, post-larvae, or broodstock from wild or cultured species necessitates a pre-approved health and safety certificate from SENASICA. Additionally, SENASICA is responsible for issuing a certificate for the quarantine units to be used during the importation process. Under the norm NOM-010-PESC-1993[77] (Appendix C), a comprehensive list of diseases that warrant notification to SENASICA in case of detection in the imported lot is provided. To initiate the importation process, the Fisheries Secretariat, through its General Directorate, should receive and approve an importation request containing detailed information about the organism, including its quantity, life stage, and relevant particulars of the supplier, entry point to the country, and intended destination of the organism.

Given the apparent established nature of hatchery production in the country, it is reasonable to assume that international imports of live tilapia are likely limited to small quantities of broodstock. However, it is evident that "trans-waterbody" movements of tilapia fingerlings from hatcheries or nurseries to net pens and pond farms remain prevalent in the industry. In the case of the existing mega farm, it is noteworthy that the producer operates its hatchery in Chiapas, where their growout facilities are also situated. Moreover, since Malpaso and Peñitas reservoirs are part of the same water network connected by the Grijalva river, their reliance on transwaterbody animal movements is deemed to be low (less than 10% reliance on animal movement). Thus, the existing mega farm's score for Factor 10Xa is 9 out of 10. Nevertheless, due to the lack of comprehensive data on sources and typical movement

[75] https://www.diputados.gob.mx/LeyesBiblio/regley/Reg_LPesca.pdf
[76] https://sistemasssl.senasica.gob.mx/SINACAMWeb/pages/consulta/requisitos/filtrosAcuicola.xhtml#no-back-button
[77] https://www.gob.mx/cms/uploads/attachment/file/311367/NOM_010_PESC.pdf

practices within the tilapia farming system in Mexico, and in light of the concerns raised regarding the movements of aquatic plants, pathogens, and parasites (Mendoza-Alfaro et al., 2021; SENASICA, 2020), a precautionary assumption is made here, suggesting that the reliance on animal movement for the rest of net pen and pond producers is moderate to high, estimated at approximately 70.0-79.9%. The score for Factor 10Xa for the remaining net pen and all pond producers is therefore 2 out of 10.

Factor 10Xb—Biosecurity of Source/Destination

It is important to consider that the sources of live tilapia movements, from international and national movements of genetically improved tilapia strains, are likely to originate from tank-based systems characterized by high biosecurity standards, adopting technologies such as incubators, filters, and pumps, all of which are a common practice in selective breeding centers to provide a more stable and secure seed supply (Martinez-Cordero et al., 2021). Furthermore, as required by SENASICA's application process, an investigation into the background of parasitosis and diseases detected in the area of origin of the importation, along with its genetic history, is required. Moreover, for imported fish designated for aquaculture production, a mandatory quarantine period of 30 days must be implemented, as stipulated by NOM-011-PESC-1993[78]. This norm also outlines the specific requirements for the quarantine infrastructure, with a primary emphasis on maintaining an isolated and controlled environment within the quarantine unit. Both NOM-010-PESC-1993 and NOM-011-PESC-1993 further emphasize the need for adherence to international regulations and norms, necessitating proper coordination during the importation and quarantine processes. Hence, the biosecurity score for the source (including the consideration of the health certification and quarantine requirements) is therefore 6 out of 10.

The destinations of live tilapia movements are net pen or pond farms. As previously mentioned (Criterion 7 – Disease), SENASICA's Best Practice Tilapia Manual (BPTM) primarily focuses on delineating measures to mitigate the risk of disease outbreaks and uphold appropriate sanitary conditions on tilapia farms. The adoption of these biosecurity measures could also serve as a preventive measure against the cross-contamination of tilapia farms with other species. For example, as advised by the BPTM, farmers should keep separate water entry and exit points to prevent cross contamination, coupled with control mechanisms to restrict the entry of undesired species (Garcia-Ortega and Calvario-Martinez, 2008). Furthermore, the BPTM recommends producers to exclusively utilize tilapia seeds and fingerlings that have a health and safety certification by SENASICA. This recommendation seems to be specifically relevant to imported organisms, as tilapia is excluded from the certification requirement by SENASICA for domestic movements (Garcia-Ortega and Calvario-Martinez, 2008). Additionally, the existing mega farm needs to comply with ASC's third party certification requirement to use transport containers that should have no escape path for fish (ASC, 2022).

Regardless of the recommendations included in the BPTM, net pen farms are considered to be "open" to the environment in terms of the potential release of any hitchhiker species unintentionally included in live tilapia movements. Ponds are considered to be a moderate risk system, with uncertainty regarding the robustness of biosecurity prevention measures. The biosecurity score for the destination of movements is therefore 0 out of 10 for net pens, and 2 out of 10 for ponds.

The final score for Factor 10Xb—Biosecurity of Source/Destination is based on the higher biosecurity score of either the source or the destination (in this case the source) and is 6 out of 10.

[78] https://www.dof.gob.mx/nota_detalle.php?codigo=4729290&fecha=16/08/1994#gsc.tab=0

Conclusions and Final Score

The spread of pathogens such as tilapia lake virus and helminths, and introductions of new species of aquatic plants are examples of unintentional introductions of non-native species during movements of live tilapia or other fish species into and within Mexico. Although tilapia fingerlings were previously known to be shipped into Mexico from hatcheries in the U.S., Panama, United Kingdom, Vietnam, and Cuba, the current scale of this practice is unclear. The development of hatcheries in the main tilapia-producing states of Mexico is likely to have reduced such international movements substantially. The importation of smaller numbers of selectively bred tilapia broodstock from breeding centers elsewhere likely continues, but is now accompanied by quarantine and inspection requirements at the port of entry. This assessment is therefore based on the movements of tilapia within Mexico. Although there are 29 hatcheries, the broad distribution of farms means that there are considered to be substantial transwaterbody movements of tilapia produced in net pens and ponds (estimated to be 70-80% of production and a score of 2 out of 10 for Factor 10Xa). In contrast, publicly available audit reports from the existing mega farm show that their hatcheries are all located in close proximity to the growout location (and therefore <10% of the existing mega farm's production is considered to be based on transwaterbody movements and a score of 9 out of 10 for Factor 10Xa). Although the sources of live animal movements have some potential for biosecurity (e.g., reduced or zero water exchange, along with quarantine and monitoring), the movements of tilapia into and within Mexico continue to present a risk of unintentionally introducing non-native species, and the score for Factor 10Xb is 6 out of 10. The final score for Criterion 10X—Escape of Unintentionally Introduced Species is a deduction of –0.4 out of –10 for the mega farm, and –3.2 out of –10 for the rest of net pen and pond producers in Mexico.

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Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Appendix 1—Data Points and all Scoring Calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data	**Data Quality**		
Data Category	**Mega farm**	**Net pens**	**Ponds**
Production	10.0	10.0	10.0
Management	10.0	5.0	5.0
Effluent	7.5	7.5	5.0
Habitat	7.5	7.5	7.5
Chemical Use	7.5	2.5	2.5
Feed	7.5	2.5	2.5
Escapes	7.5	5.0	5.0
Disease	5.0	5.0	5.0
Source of stock	10.0	10.0	10.0
Wildlife mortalities	10.0	2.5	2.5
Escape of secondary species	10.0	2.5	2.5
C1 Data Final Score (0-10)	**8.41**	**5.455**	**5.227**
	Green	Yellow	Yellow

Criterion 2: Effluent	**Data and Scores**		
Effluent Evidence-Based Assessment	**Mega farm**	**Net pens**	**Ponds**
C2 Effluent Final Score (0-10)	**4**	**4**	**6**
Critical?	NO	NO	NO

Criterion 2 - Effluent Risk-based assessment	**Data and Scores**		
2.1a Biological waste production	**Mega farm**	**Net pens**	**Ponds**
Protein content of feed (%)	30.000	30.000	30.000
eFCR	2.000	1.600	1.600
Fertilizer N input (kg N/ton fish)	46.000	46.000	46.000
Protein content of harvested fish (%)	14.000	14.000	14.000
N content factor (fixed)	0.160	0.160	0.160
N input per ton of fish produced (kg)	142.000	122.800	122.800
N output in each ton of fish harvested (kg)	22.400	22.400	22.400
Waste N produced per ton of fish (kg)	119.600	100.400	100.400

2.1b Production System discharge	Data and Scores		
	Mega farm	Net pens	Ponds
Basic production system score	0.510	0.510	0.510
Adjustment 1 (if applicable)	0.000	0.000	0.000
Adjustment 2 (if applicable)	0.000	0.000	0.000
Adjustment 3 (if applicable)	0.000	0.000	0.000
Boundary adjustment (if applicable)	0.000	0.000	0.000
Discharge (Factor 2.1b) score (0-1)	0.510	0.510	0.510
Waste discharged per ton of production (kg N ton-1)	60.996	51.204	51.204
Waste discharge score (0-10)	3.000	4.000	4.000

2.2 Management of farm-level and cumulative effluent impacts	Mega farm	Net pens	Ponds
2.2a Content of effluent management measure	2	2	2
2.2b Enforcement of effluent management measures	4	4	4
2.2 Effluent management effectiveness	3.200	3.200	3.200
C2 Effluent Final Score (0-10)	**n/a**	**n/a**	**4**
Critical?	No	No	No

Criterion 3: Habitat	Data and Scores		
F3.1. Habitat conversion and function	**Mega farm**	**Net pens**	**Ponds**
F3.1 Score (0-10)	9	9	4
F3.2 – Management of farm-level and cumulative habitat impacts			
3.2a Content of habitat management measure	3	3	3
3.2b Enforcement of habitat management measures	3	3	3
3.2 Habitat management effectiveness	3.600	3.600	3.600
C3 Habitat Final Score (0-10)	**7.200**	**7.200**	**3.867**
Critical?	No	No	No

Criterion 4: Chemical Use	Data and Scores		
Single species assessment	**Mega farm**	**Net pens**	**Ponds**
Chemical use initial score (0-10)	8.0	0.0	0.0
Trend adjustment	0.0	0.0	0.0
C4 Chemical Use Final Score (0-10)	**8.0**	**0.0**	**0.0**
Critical?	No	No	No

Criterion 5: Feed	Data and Scores		
5.1 Wild Fish Use			
5.1a Forage Fish Efficiency Ratio (FFER)	**Mega farm**	**Net pens**	**Ponds**
Fishmeal from whole fish, weighted inclusion level %	3.200	4.000	8.000
Fishmeal from byproducts, weighted inclusion %	0.800	0.000	0.000
Byproduct fishmeal inclusion (@ 5%)	0.040	0.000	0.000
Fishmeal yield value, weighted %	22.500	22.500	22.500
Fish oil from whole fish, weighted inclusion level %	2.000	2.000	2.700
Fish oil from byproducts, weighted inclusion %	0.000	0.000	0.000
Byproduct fish oil inclusion (@ 5%)	0.000	0.000	0.000
Fish oil yield value, weighted %	5.000	5.000	5.000
eFCR	2.000	1.600	1.600
FFER Fishmeal value	**0.288**	**0.284**	**0.569**
FFER Fish oil value	**0.800**	**0.640**	**0.864**
Critical (FFER >4)?	No	No	No

5.1b Sustainability of Source fisheries	Data and Scores		
	Mega farm	**Net pens**	**Ponds**
Source fishery sustainability score	6.440	3.126	3.143
Critical Source fisheries?	No	No	No
SFW "Red" Source fisheries?	No	No	No
FFER for red-rated fisheries	n/a	n/a	n/a
Critical (SFW Red and FFER >=1)?	No	No	No
Final Factor 5.1 Score	**6.900**	**4.770**	**3.720**

5.2 Net Protein Gain or Loss (%)	Data and Scores		
	Mega farm	**Net pens**	**Ponds**
Weighted total feed protein content	30.000	30.000	30.000
Protein INPUT kg/100kg harvest	60.000	48.000	48.000
Whole body harvested fish protein content	14.000	14.000	14.000
Net protein gain or loss	-76.667	-70.833	-70.833
Species-specific Factor 5.2 score	**2**	**2**	**2**
Critical (Score = 0)?	No	No	No
Critical (FFER>3 and 5.2 score <2)?	No	No	No

5.3 Feed Footprint	Data and Scores		
	Mega farm	Net pens	Ponds
GWP (kg CO2-eq kg-1 farmed seafood protein)	**14.582**	**14.369**	**14.159**
Contribution (%) from fishmeal from whole fish	3.004	3.302	6.725
Contribution (%) from fish oil from whole fish	1.934	1.390	1.910
Contribution (%) from fishmeal from byproducts	0.870	0.000	0.000
Contribution (%) from fish oil from byproducts	0.000	0.000	0.000
Contribution (%) from crop ingredients	94.158	95.280	91.336
Contribution (%) from land animal ingredients	0.000	0.000	0.000
Contribution (%) from other ingredients	0.034	0.028	0.028
Factor 5.3 score	**6**	**6**	**6**
C5 Final Feed Criterion Score	**5.5**	**4.4**	**3.9**
Critical?	**No**	**No**	**Yes**

Criterion 6: Escapes	Data and Scores		
	Mega farm	Net pens	Ponds
F6.1 System escape risk	4.000	2.000	4.000
Percent of escapees recaptured (%)	0.000	0.000	0.000
F6.1 Recapture adjustment	0.000	0.000	0.000
F6.1 Final escape risk score	4.000	2.000	4.000
F6.2 Invasiveness score	10.000	10.000	9.000
C6 Escape Final Score (0-10)	**10**	**10**	**6**
Critical?	No	No	No

Criterion 7: Disease	Data and Scores		
	Mega farm	Net pens	Ponds
Evidence-based or Risk-based assessment	Risk	Risk	Risk
Final C7 Disease Criterion score (0-10)	**4**	**2**	**2**
Critical?	No	No	No

Criterion 8X Source of Stock	Data and Scores		
	Mega farm	Net pens	Ponds
Percent of production dependent on wild sources (%)	0.0	0.0	0.0
Initial Source of Stock score (0-10)	0.0	0.0	0.0
Use of ETP or SFW "Red" fishery sources	No	No	No
Lowest score if multiple species farmed (0-10)	n/a	n/a	n/a
C8X Source of stock Final Score (0-10)	**0**	**0**	**0**
Critical?	No	No	No

Criterion 9X Wildlife Mortality parameters	Data and Scores		
	Mega farm	Net pens	Ponds
Single species wildlife mortality score	-2	-6	-6
System score if multiple species assessed together	n/a	n/a	n/a
C9X Wildlife Mortality Final Score	**-2**	**-6**	**-6**
Critical?	No	No	No

Criterion 10X: Introduction of Secondary Species	Data and Scores		
	Mega farm	Net pens	Ponds
Production reliant on transwaterbody movements (%)	9.9	79.9	79.9
Factor 10Xa score	9	2	2
Biosecurity of the source of movements (0-10)	6	6	6
Biosecurity of the farm destination of movements (0-10)	0	0	2
Species-specific score 10X score	-0.400	-3.200	-3.200
Multi-species assessment score if applicable	n/a	n/a	n/a
C10X Introduction of Secondary Species Final Score	**-0.400**	**-3.200**	**-3.200**
Critical?	n/a	n/a	n/a