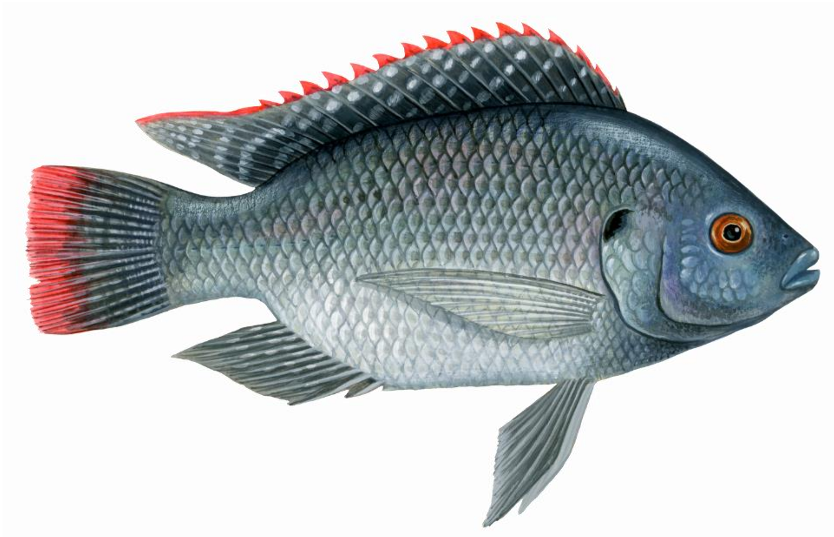
Environmental sustainability of tilapia farmed in ponds in Taiwan



Species: Tilapia (*Oreochromis* spp.)
Location: Taiwan (Province of China)
Method: Ponds
Type: Aquaculture
Author: Seafood Watch
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Assessed using [Seafood Watch Aquaculture Standard v4]

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Note: In line with international standards, including those set by the ISO and FAO, this report refers to "Taiwan (Province of China)" in the title; however, for simplicity, the term "Taiwan" will be used throughout the remainder of this document.

About Monterey Bay Aquarium Seafood Watch

The mission of the Monterey Bay Aquarium is to inspire conservation of the ocean and enable a future where the ocean flourishes and people thrive in a just and equitable world. To do this, the Aquarium is focused on creating extraordinary experiences that inspire awe and wonder, championing science-based solutions, and connecting people across the planet to protect and restore the ocean. We know that healthy ocean ecosystems are critical to enabling life on Earth to exist, and that our very survival depends on them. As such, our conservation objectives are to mobilize climate action, improve the sustainability of global fisheries and aquaculture, reduce sources of plastic pollution, and restore and protect ocean wildlife and ecosystems.

The aquarium is focused on improving the sustainability of fisheries and aquaculture given the role seafood plays in providing essential nutrition for 3 billion people globally, and in supporting hundreds of millions of livelihoods. Approximately 180 million metric tons of wild and farmed seafood is harvested each year (excluding seaweeds). Unfortunately, not all current harvest practices are sustainable and poorly managed fisheries and aquaculture pose the greatest immediate threat to the health of the ocean and the economic survival and food security of billions of people.

The Seafood Watch program was started 25 years ago as a small exhibit in the Monterey Bay Aquarium highlighting better fishing practices and grew into one of the leading sources of information on seafood sustainability, harnessing the power of consumer choice to mobilize change. The program's comprehensive open-source information and public outreach raises awareness about global sustainability issues, identifies areas for improvement, recognizes and rewards best practices and empowers individuals and businesses to make informed decisions when purchasing seafood.

We define sustainable seafood as seafood from sources, whether fished or farmed, that can maintain or increase production without jeopardizing the structure and function of affected ecosystems, minimize harmful environmental impacts, assure good and fair working conditions, and support livelihoods and economic benefits throughout the entire supply chain. As one aspect of this vision, Seafood Watch has developed trusted, rigorous standards for assessing the environmental impacts of fishing and aquaculture practices worldwide. Built on a solid foundation of science and collaboration, our standards reflect our guiding principles for defining environmental sustainability in seafood.

Seafood Watch Ratings

The Seafood Watch Standard for Aquaculture is used to produce assessments for farmed seafood resulting in a Seafood Watch rating of green, yellow, or red. Seafood Watch uses the assessment criteria to determine a final numerical score as well as numerical subscores and colors for each criterion. These scores are translated to a final Seafood Watch color rating according to the methodology described in the table below. The table also describes how Seafood Watch defines each of these categories. The narrative descriptions of each Seafood Watch rating, and the guiding principles listed below, compose the framework on which the criteria are based.

Green	Final score ≥ 6.665[1] and ≤ 10, and no red criteria, and no critical[2] scores.	Wild-caught and farm-raised seafood rated green are environmentally sustainable, well managed and caught or farmed in ways that cause little or no harm to habitats or other wildlife. These operations align with all of our guiding principles.
Yellow	Final score ≥ 3.335 and ≤ 6.664, and no more than one red criterion, and no critical scores.	Wild-caught and farm-raised seafood rated yellow cannot be considered fully environmentally sustainable at this time. They align with most of our guiding principles, but there is either one conservation concern needing substantial improvement, or there is significant uncertainty associated with the impacts of the fishery or aquaculture operations.
Red	Final score ≥ 0 and ≤ 3.334, or two or more red criteria, or one or more critical scores.	Wild-caught and farm-raised seafood rated red are caught or farmed in ways that have a high risk of causing significant harm to the environment. They do not align with our guiding principles and are considered environmentally unsustainable due to either a critical conservation concern, or multiple areas where improvement is needed.

[1] Each criterion is scored from 1 to 10 based on sub-factor scores. Criteria scoring ≤ 3.334 are considered red criteria.
[2] Very severe conservation concerns receive critical scores, which result in a red rating.

Guiding Principles

Seafood Watch® defines "sustainable seafood" as seafood from sources, whether fished or farmed, that can maintain or increase production without jeopardizing the structure and function of affected ecosystems.

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:

- **Criterion 1—Data: 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.

- **Criterion 2—Effluent: 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.

- **Criterion 3—Habitat: 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.

- **Criterion 4—Chemicals: 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.

- **Criterion 5—Feed: 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.

- **Criterion 6—Escapes: 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.

- **Criterion 7—Disease: Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites**
  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.

- **Criterion 8X—Source of Stock: 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.

- **Criterion 9X—Wildlife Mortalities: 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.

- **Criterion 10X—Introductions: 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.

Ratings scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

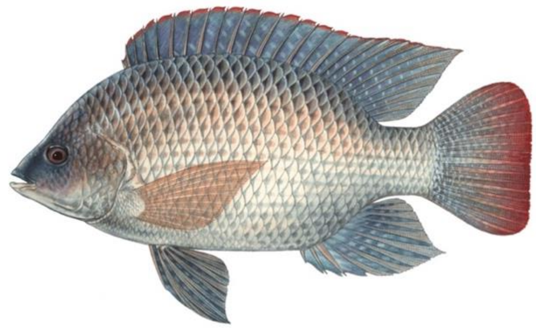
Final Score = sum of C1–C7, adjusted by C8X–C10X, divided by 7.

Green = Final score ≥ 6.665, and no red criteria, and no critical scores.

Yellow = Final score ≥ 3.335 and ≤ 6.664, and/or one red criterion, and no critical scores.

Red = Final score ≤ 3.334, or more than one red criterion, or one or more critical scores.

Final Ratings



Rating Details	**Species:** Tilapia (*Oreochromis* spp.) **Location:** Taiwan **Method:** Ponds **Volume:** 57,182 MT per year in 2023
Criterion 1—**Data**	6.6
Criterion 2—**Effluent**	8.0
Criterion 3—**Habitat**	6.3
Criterion 4—**Chemicals**	6.0
Criterion 5—**Feed**	5.5
Criterion 6—**Escapes**	5.0
Criterion 7—**Disease**	6.0
Criterion 8X—**Source of Stock**	0.0
Criterion 9X—**Wildlife Mortalities**	0.0
Criterion 10X—**Introductions**	0.0
Rating	**YELLOW** **6.2**

Executive Summary

In 2023, Taiwan produced 57,182 metric tons (MT) of farmed tilapia, representing one-third of its total finfish production and one-fifth of overall aquaculture output. In 2022, 33% of Taiwan's tilapia production was exported, and nearly three-quarters of this went to the United States, where tilapia is the fourth most popular seafood choice, behind shrimp, salmon, and canned tuna. The United States is presently the world's largest importer of farmed tilapia, and in 2022 it accounted for one-third of the total international trade in these species. Tilapia accounted for 46% of the total fisheries imports into the United States from Taiwan in 2022.

Although Taiwan has been the second-largest supplier of tilapia to the United States for many years (after China), in 2022 and 2023 the volume of imports from Colombia superseded those from Taiwan. Presently, Taiwan is the United States' third-largest provider of tilapia; in 2023, Taiwan supplied 8% of U.S. tilapia imports, while China and Colombia accounted for 67% and 11%, respectively.

The majority of aquaculture activity in Taiwan, including tilapia production, occurs on its western side, particularly along the southwestern coastal region. Tilapia production is especially predominant in Tainan county, although significant production also takes place in the regions of Chiayi and Yunlin. Smaller quantities are produced in the southern regions of Kaohsiung and Pingtung, and a small percentage is farmed in Taoyuan and Hsinchu in the north. Tilapia are primarily grown in intensive ponds in freshwater environments with the use of formulated feeds.

This Seafood Watch assessment involves a number of different criteria covering impacts associated with effluent, habitats, chemical use, feed production, escapes, disease, the source stock, wildlife and predator interactions, introduction of nonnative organisms (other than the farmed species), and general data availability. The following is a summary of the scoring determinations for each of these criteria, which are explored in more detail in the body of this report.

While there is a substantial body of peer-reviewed literature available concerning the global tilapia sector, robust data on many specific aspects of the Taiwanese tilapia sector are lacking. Although regulatory provisions are easily accessible online via the Taiwanese Ministry of Justice's (MOJ) Laws & Regulations Database and the FAO's FAOLEX Database, it is often challenging to decipher their practical implementation without additional input. To fill these various data gaps, outreach was made to a variety of relevant parties, including government departments, farmers, industry experts, and trade associations, with varying degrees of success.

Data quality and availability vary somewhat across the topics and criteria reviewed. Data concerning the general categories of Production and Management both received a moderate–high score of 7.5 out of 10, based on the breadth and relevance of academic literature and expert communications available. Confidence in the data's ability to robustly describe the ecological impact reviewed in each criterion was assessed as moderate for six of the nine criteria discussed, with scores of 5 out of 10 for Effluent, Habitat, Feed, Disease, and Wildlife Mortalities. Note that assessments for Effluent, Disease, and Wildlife Mortalities are predicated on risk-based methodologies, because of limited specific data. The data score for Chemical Use was also assessed as 5 out of 10. Although specific information on the quantity and types of chemicals used is lacking, there is reasonable confidence—based on expert input, regulatory context, and the low discharge nature of the production system—that the risk of environmental exposure is moderately low. This supports a moderate score despite the absence of direct usage data.

The Source of Stock category stands out with a high data quality score of 10 out of 10, supported by extensive historical and contemporary literature. Likewise, the exceptional criterion, Introduction of Secondary Species, also scored 10 out of 10. Escapes has a moderate–high score of 7.5 out of 10, relying on indirect evidence and expert communications in the absence of official reporting requirements. The variability in data quality across these categories reflects the challenges in obtaining comprehensive, sector-specific information, with the assessment of many criteria relying on a combination of academic literature, expert communications, and publicly available government resources.

Overall, while many aspects of the assessment benefit from publicly accessible resources and academic literature, numerous knowledge gaps remain in terms of species-specific or farm-level data. Key knowledge gaps include the practical enforcement of habitat and chemical use regulations at the farm level, typical compliance practices, and quantifiable data on chemical and drug usage. These gaps primarily reflect limited access to detailed, farm-level information from official sources. The final score for Criterion 1—Data Quality and Availability is 6.6 out of 10.

Because the effluent data quality and availability were not considered robust enough to fully understand the effluent impacts of tilapia production in Taiwan, a risk-based assessment approach was used. Based on this approach, and considering the typical feeds applied, it was estimated that the total input of nitrogen per MT of production equals 83.088 kg, which is reduced to 60.688 kg once the nitrogen in harvested tilapia is discounted. The amount of nitrogenous waste discharged from a typical production system was extrapolated from this estimate, while accounting for the particular water and pond management practices adhered to by farmers. Because of water scarcity issues, Taiwanese tilapia farmers mainly rely on the collection of rainwater to fill their ponds. This situation necessitates careful conservation of water resources, so farmers typically designate one or two of their ponds as reservoirs and recirculate water between these and their culture ponds via submerged pipes. Although water exchange rates in the culture pond are typically less than 1% per day, most water exchanges occur within the farm boundary, and discharges to the external environment occur infrequently. At harvest, farms will discharge water from ponds into reservoirs where water will be held and reused. Thus, it is estimated that, of the small amount of water released from farms, 9.71 kg N/MT is discharged from ponds (i.e., 16% of the total). Based on these findings, the score for Factor 2.1 is 9 out of 10.

The Fisheries Agency is responsible for overseeing and regulating aquaculture governance in Taiwan, while the Ministry of Environment (MOENV) is the central authority for environmental matters, including water resource and effluent management. A key piece of legislation is the Water Pollution Control Act (WPCA), which establishes the framework for monitoring and managing effluents from all sources, including aquaculture. The act mandates that enterprises above a certain size threshold must obtain discharge permits and monitor and report their effluents. While most tilapia farms in Taiwan, ranging in size from 1.5 to 6 hectares, fall below this threshold and are not subject to these specific requirements, they are still encompassed within the area-based, cumulative management framework established by the act. This framework ensures that effluent impacts, including those from smaller farms, are monitored and managed collectively to maintain compliance with water quality standards. This approach ensures that any breaches in water quality are detected through continuous government monitoring, thus effectively managing the collective impact of multiple industries, including aquaculture. As a result, Taiwan's effluent management system is considered comprehensive, reflecting a high level of regulatory coordination. The content of Taiwan's effluent management system for tilapia production receives a score of 5 out of 5 for Factor 2.2a. This score reflects the effective integration of water quality monitoring, the application of effluent limits aligned with the carrying capacity of receiving waters, and the cumulative approach that ensures that broader water quality standards are met despite the exemption of small farms from direct regulation.

Under the WPCA, authorities at all levels can inspect facilities based on pollution reports and the specific needs of different enterprises; if serious violations are found, results and sanctions are publicized. Although most tilapia farms are small and exempt from WPCA monitoring and reporting requirements, local authorities still monitor water quality and use total quantity control methods if standards are not met. Farmers can also access free water quality analysis at local government fish quarantine centers. MOENV reports that there has never been a case of total quantity control being implemented for fish farms, and communications with sector experts suggest that effluents from tilapia farms are not considered a cause for concern. The absence of reported incidents related to tilapia pond effluents lends credence to the efficacy of the enforcement of related management measures, even though tilapia farms are typically only monitored indirectly. This results in a moderate score of 3 out of 5 for Factor 2.2b. The final score for Factor 2.2 combines Factor 2.2a (5 out of 5) and Factor 2.2b (3 out of 5) to result in a final score of 6 out of 10. The scores for Factors 2.1 (9 out of 10) and 2.2 (6 out of 10) combine for a final score of 8 out of 10 for Criterion 2—Effluent.

Taiwanese tilapia farms are predominantly small-scale operations, which occupy approximately 3,233 hectares. Most aquaculture production, including tilapia farming, is concentrated in the southwest coastal region. Because a significant mountain range dominates Taiwan's interior, most of the flatlands (with the majority of the population) are concentrated west of this mountainous region. As a result, there is intense competition for land and water resources in the regions where tilapia farming occurs, and these lands have undergone significant anthropogenic alterations over several centuries. Tilapia farming zones are primarily located within what can be described as riparian lands, but expansion of the industry does not appear to be occurring currently.

Evidence indicates that the majority of modern tilapia farms were established on land that had already been modified for food production, including repurposed agricultural lands, former aquaculture ponds, and irrigation reservoirs. Many of the ponds currently used for tilapia farming were established during the sector's rapid expansion in the 1970s and 1980s, though some are likely to have existed for much longer.

Land subsidence is the most frequently cited environmental impact associated with aquaculture in Taiwan, which historically was exacerbated by groundwater extraction for fish farming and other industries. But regulatory interventions have significantly reduced the severity of subsidence by restricting groundwater use. Though subsidence remains a concern in some areas, key ecosystem services—including sediment retention, water regulation, and flood mitigation—are maintained at a moderate level. Based on the assessed moderate habitat value of the land and the evaluation of current ecosystem service functionality, the score for Factor 3.1—Habitat conversion and function is 7 out of 10.

The Fisheries Agency plays a central role in overseeing aquaculture governance, including planning, supervision, and the implementation of an area-based management approach. Farms operate in designated aquaculture zones, and a voluntary farm registration is in place, which is promoted and encouraged by an array of subsidies. Legal provisions—such as EIAs for larger developments, and requirements for farms to have permits certifying their water sources—ensure that new developments align with environmental standards. Any proposed expansion within aquaculture zones must also be reported to the authorities. Together, these regulatory measures have done much to facilitate effective industry oversight and a reduction in aquaculture-related habitat impacts (e.g., land subsidence). Based on these factors, and in accordance with the Standard, the overall management measures in place for aquaculture in Taiwan are considered robust, so the score for Factor 3.2a is 4 out of 5.

A key challenge for aquaculture regulators and policy makers in Taiwan is the sheer number of ponds and small farms involved in the sector. Although farm registration was initially introduced in 1978, it is unofficially estimated that around 15–20% of fish farms remain unregistered at the time of writing, because the government takes an uncoercive approach to the enforcement of farm registration. Despite this, the proportion of registered farms increases each year, and even if farms are not officially registered, every aquaculture pond is still assigned an individual pond number and is subject to aerial surveillance by the authorities.

Concerning farm-level enforcement activities and inspections, it is evident that scheduled and random inspections by local authorities occur from time to time, although only a small percentage of farms are inspected in any given year, indicating capacity constraints. These inspections involve checking equipment and general farm operations. Aquaculture associations collaborate with government authorities to oversee the sector, thus providing additional capacity to oversee thousands of small producers; however, as private entities, these associations lack the necessary authority to enforce regulations directly.

In summary, over time, Taiwan's regulatory framework for aquaculture has evolved into an area-based system that considers the cumulative impacts of fish farms. The trajectory of the enforcement of habitat protections in Taiwan is positive overall. But regulatory provisions are challenging to implement and enforce across a landscape of thousands of small pond farms. While high level enforcement organizations are identifiable and active, there is less certainty about the resources, capacity, and effectiveness of authorities at the local level, which are responsible for farm-level enforcement. According to the Seafood Watch Standard for Aquaculture, these attributes regarding the enforcement of habitat management measures are moderately effective, so the score for Factor 3.2b is 3 out of 5. Factors 3.1 and 3.2 combine to give a Criterion 3—Habitat final score of 6.3 out of 10.

According to historical academic literature, chemicals and antibiotics were typically not required in the production of tilapia because of the disease-resistant nature of these species. But as production intensified, so did the need for medicinal interventions, primarily from the emergence of new diseases, particularly bacterial diseases. While this has been the global trend in tilapia production, specific details concerning chemical use in Taiwan's tilapia sector are lacking, even though information about the regulatory environment is readily available online.

The regulatory framework seeks to control access to chemical therapeutants such as antimicrobials, but enforcement appears to face some challenges. For example, Taiwan's Veterinary Drugs Control Act oversees the quality and sale of veterinary drugs, whereas the Veterinarian Act seeks to ensure that veterinarians are directly involved in diagnosis, treatment, and documentation of controlled substance administration. Inspections by local government and Fisheries Agency inspectors further ensure adherence to regulations, with over 5% of aquaculture farms inspected annually. In addition, government-funded regional fish disease control stations offer free veterinary services to farmers, supported by a centralized database in which all cases and treatments are recorded. But farmers evidently can bypass this official system by purchasing veterinary drugs directly from pharmacies without a prescription, potentially resulting in undocumented and inappropriate drug usage.

Despite these regulations and controls, chemical usage within Taiwan's tilapia sector remains unclear. Although veterinary drug manufacturers and importers are required to submit data on drug types, quantities, and customer information to municipal authorities every 6 months, these records are not publicly accessible. At present, there are 11 antibiotics and 1 insecticide approved for use in tilapia production in Taiwan. According to experts, the use of chemical interventions on tilapia farms is infrequent, but when they are administered, the most commonly used drugs are amoxicillin, florfenicol, oxytetracycline, and oxolinic acid, all of which are commonly used globally in aquaculture. The World Health Organization (WHO) categorizes the first three of these are as being highly important antimicrobials (HIA), whereas oxolinic acid is categorized as a highest priority critically important antimicrobial (HPCIA).

Although no specific data were identified concerning the environmental fate of chemicals used on tilapia farms in Taiwan, the literature notes that the ecological impact of these four therapeutants potentially includes disrupting microbial communities, harming aquatic organisms, and inducing antimicrobial resistance. Trichlorfon, the approved insecticide for tilapia, which is commonly used in many countries for a range of pest control applications, has moderate toxicity to fish, birds, and aquatic arthropods, so caution is warranted in its application near water bodies, although its usage does not appear to be prevalent within the sector.

To ensure the safety of food products for consumers, the government implemented random drug residue testing on fish farms in 2006, to detect any chemical usage exceeding acceptable limits or the presence of illegal drugs. Farmers are reportedly near 100% compliant with the drug residue testing program, and the results of these inspections are published monthly on the Fishery Agency website; for example, of 804 farms inspected between March and August 2024, all were found to be compliant. Also, in its most recent Annual Report, the MOA reported compliance rates of 99.2% for premarket aquatic products and 99.9% for those tested in wholesale fish markets. Nonetheless, a small number of recent border rejections of Taiwanese tilapia imports into the United States due to drug residues highlights the potential gaps in this program.

In summary, there is limited information documenting chemical usage within the aquaculture sector; while usage of highly important and critically important antimicrobials is reportedly low, it presents potential concerns regarding antimicrobial governance and environmental risks. There appear to be gaps in enforcement effectiveness because farmers are able to obtain antimicrobials through pharmacies without prescriptions, and despite a food safety program aimed at detecting antimicrobial residues with reported high compliance rates, there have been recent border rejections in the United States. But an important element that must be considered is the low discharge rates of the pond systems. Taiwanese tilapia farms typically have quite low discharge rates (< 1% daily), as farmers prioritize water conservation. This farm practice significantly mitigates the potential environmental impact of any chemicals that are used during production.

Guidance for the assessment of this criterion in the Seafood Watch Standard for Aquaculture states that if chemical use (e.g., type or quantity) and/or impacts are unknown, then the production system-based assessment option should be used. Because the types of chemicals used are known, but the quantity and impacts are unknown, the production system drives the score. The production system has infrequent or limited discharge of water (e.g., < 1% per day), so the final score is 6 out of 10 for Criterion 4—Chemical Use.

Although detailed data on the specific composition of tilapia feeds used in Taiwan are sparse, the available information indicates that they contain low levels of fishmeal and fish oil and primarily consist of crop ingredients. Communications with experts in the Taiwanese tilapia sector inform that economic feed conversion ratios range between 1.6 and 2.0, so an average eFCR of 1.8 has been used in the various feed calculations. A substantial usage of by-products sourced from tuna fisheries for fishmeal results in a low Feed Fish Efficiency Ratio (FFER) of 0.26, indicating that 0.26 MT of wild fish are required to produce the fishmeal needed to grow 1 MT of tilapia. Marine-ingredient source fisheries are moderately sustainable, yielding a Factor 5.1—Wild fish use score of 7 out of 10. Data from Taiwanese feed companies show that the average weighted feed protein content for a typical on-growing diet is 28.85%. Given a whole tilapia protein content of 14% and an eFCR of 1.8, there is evidently a significant net loss of protein, which is calculated to be slightly over 73%, which results in a Factor 5.2—Net protein gain or loss score of 2 out of 10. The feed footprint, calculated as the embedded climate change impact (kg CO_2-eq) of the feed ingredients, is 20.51 kg CO_2-eq per kg of farmed tilapia protein, which results in a score of 5 out of 10 for Factor 5.3—Feed Footprint. Factors 5.1, 5.2, and 5.3 combine for a final score for Criterion 5—Feed of 5.45 out of 10.

Given the open nature of tilapia ponds in Taiwan and the potential for flooding to occur in culture areas, there is clearly a risk of tilapia escaping from farms. Though water exchange activities often present a significant escape pathway in other aquaculture settings, this is less of a concern in Taiwan, where farms discharge water infrequently as a result of water conservation practices. Escape risks are further mitigated by the implementation of best practices to minimize escapes, including the use of screens on inlet and outlet water pipes; also, government subsidies help to mitigate escape risk by encouraging measures on farms, such as increasing the height of embankments around ponds and making improvements to drainage systems. Although the Seafood Watch Standard for Aquaculture considers ponds with low daily water exchange rates (0–3%) and minimal flood risk to pose a low–moderate escape risk, the low-lying areas where tilapia are farmed in Taiwan remain vulnerable to periodic flooding, thereby increasing the likelihood of escapes. Accordingly, the escape risk (Factor 6.1) for tilapia farms in Taiwan is assessed as moderate, which warrants a score of 4 out of 10.

Regarding the potential competitive and genetic interactions (Factor 6.2) that may arise as a result of farmed tilapia escaping, these species are characterized by their robust physiological adaptability and prolific reproductive capacity; these traits have enabled tilapia to successfully acclimate to the many diverse environments into which they have been introduced worldwide. Although originally nonnative to Taiwan, resident tilapia populations have thrived here in natural environments since they were introduced in the 1940s. Advancements made in YY male tilapia technology mean that the tilapia stocked in Taiwanese ponds are now predominantly male, so any escapes that occur nowadays will mostly comprise male fish. As is the case in many other countries, tilapia have become an integral part of the local Taiwanese fish fauna found in brackish and freshwater environments.

Nevertheless, it is evident that the escape of cultured tilapia in Taiwan does present potential ecological risks, such as competition with wild species for habitat and food resources. In accordance with the Standard, and considering that tilapia have been fully ecologically established in Taiwan for many decades—due to introductions initially made for aquaculture and intentional release—Factor 6.2 is assessed as presenting a low–moderate risk of potential competitive and genetic interactions, which results in a score of 6 out of 10 for Factor 6.2. Overall, Factors 6.1 and 6.2 combine for a final score of 5 out of 10 for Criterion 6—Escapes.

In most global aquaculture settings, the impact of disease spillover from fish farms into the wider environment is poorly understood; this is also the case in Taiwan. Because of a lack of data available on this aspect of tilapia production in Taiwan, this criterion has been assessed using the Seafood Watch risk-based assessment, which combines an assay of the different types of diseases experienced on farms and their prevalence with a review of the measures that are in place to prevent and contain them.

Though tilapia are generally considered to be resilient species, production intensification in recent years has seen an increase in disease events across the global sector. Bacterial diseases have had a particularly significant impact on worldwide tilapia production, especially streptococcosis, which is estimated to be responsible for ≈90% of the mortalities experienced on Taiwanese tilapia farms. An emergent viral disease, tilapia lake virus disease (TiLVD), has also caused significant mortalities worldwide but has had minimal impact in Taiwan to date. This demonstrates the strength of the existing disease management system, including robust biosecurity measures, effective surveillance, and timely management of outbreaks, which help to mitigate the risk and impact of new diseases. Overall survival rates for tilapia in Taiwan, from stocking to harvest, are in the range of 65–95%.

A key factor in the assessment of this criterion is that Taiwanese tilapia farmers are keenly focused on conserving their water supplies, due to water shortages. The average daily water exchange rate is minimal (< 1%), and most water exchange occurs internally between ponds rather than leaving the farm. The main water source used by farmers is rainwater, which is collected and circulated between ponds, with one or two ponds often functioning as reservoirs. Water is only occasionally discharged into public drainage canals; for example, to prevent overfilling before a typhoon. This low-discharge farm practice significantly mitigates the risk of pathogen transfer from tilapia farms to the external environment.

To manage fish health issues, the government has established regional fish disease control stations in fish farming areas; these provide farmers with complimentary medical examination services, enabling them to promptly respond to any disease concerns as they arise. This is an important tool that helps to minimize the potential for disease outbreaks on farms, and a centralized database is used to track all cases. A supporting regulatory framework helps to prevent the occurrence and spread of infectious animal diseases and to ensure that fish diseases are appropriately diagnosed, treated, and documented by veterinarians. Regional aquaculture associations also play an important role in disease management.

According to the Seafood Watch Standard for Aquaculture, a score of 6 is justified in situations where fish health management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm level, and the production systems may discharge water once per production cycle. Therefore, a low–moderate score has been assessed for this criterion, resulting in a final score of 6 out of 10 for Criterion 7—Disease.

Tilapia species have been farmed since ancient times, and today they are one of the world's most abundantly cultured finfish. Their dominance in aquaculture has been made possible by their many favorable characteristics, allowing them to be easily domesticated and propagated in captivity. But before breakthroughs in monosex culture techniques, a significant constraint to the sector's development was tilapia's trait of early sexual maturation. This tended to result in uncontrolled spawning events in production ponds, which subsequently caused overcrowding, stunted growth, and suboptimal culture conditions. Since the mid 20th century, researchers in Taiwan have been at the forefront of R&D efforts to refine and improve tilapia propagation and culture techniques, including the development of broodstock programs. These endeavors have enabled the production of specific strains of tilapia in Taiwan that are well suited to local culture conditions. Because the tilapia sector in Taiwan has no reliance on wild tilapia stocks, the score for Criterion 8X—Source of Stock is 0 out of 10.

Tilapia farming in Taiwan primarily occurs on the western coastal plain, which is an important habitat for waterbirds. This is especially so because Taiwan is a stopover on the East Asian–Australasian Flyway, which spans the Arctic to New Zealand. Both migratory and local species of birds rely on Taiwan's wetlands, including artificial wetlands such as aquaculture ponds; hence, the main species of wildlife—and primary predators—encountered on tilapia farms are birds, particularly egrets. The level of predation is generally perceived as minimal by farmers, and only small-sized fish are targeted. Some farmers install bird netting during the fingerling stage to prevent fish loss, and typically remove it when fish reach a certain size, although many farmers do not feel the need for such measures. There are no specific requirements for the monitoring or reporting of wildlife interactions on tilapia farms. Thus, specific data on the frequency of these interactions and any related wildlife mortalities are lacking.

Wildlife protection regulations in Taiwan prohibit the hunting and killing of vulnerable species, and though permits can be granted for hunting general wildlife in specific circumstances, such activities are typically not permitted on pond farms. Penalties for illegally harming wildlife are strictly enforced, ensuring that both vulnerable and general wildlife species are safeguarded. Although Taiwan has many wetlands, including two of international importance, artificial wetlands have long been an integral part of the landscape and play a significant role in supporting high bird diversity and abundance. Despite the lack of data on mortalities, academic studies highlight the positive role of aquaculture ponds in providing habitat for birds and discuss how these habitats can be managed more proactively to benefit avian visitors; these literature sources particularly do not report any instances of bird harm occurring on fish farms. Considering these factors, the risk of wildlife mortalities on tilapia pond farms in Taiwan as a result of farming activities would appear to be quite low, so the final score for Criterion 9X—Wildlife Mortalities is 0 out of –10.

The Taiwanese tilapia sector does not require any international or trans-waterbody live animal shipments. Thus, no deduction is applicable, and the score for Criterion 10X—Introduction of Secondary Species is 0 out of –10.

The final score for tilapia (*Oreochromis* spp.) produced in ponds in Taiwan is 6.2 out of 10, which is in the yellow range. With no red or critical criteria, the final rating is yellow.

Introduction

Scope of the analysis and ensuing recommendation

Species:	*Oreochromis* spp. inclusive of hybrids
Geographic Coverage:	Taiwan
Production Method(s):	Ponds
Production Volume:	57,182 MT per year in 2023

Tilapia: A global species overview

Tilapia is the generic name applied to certain species of fish within the family Cichlidae, hence they are also commonly referred to as tilapiine cichlids (Kembou-Ringert et al. 2023) (GSID 2023a). The classification of tilapia has been the subject of ongoing taxonomical discussion since the genus *Tilapia* was first introduced in 1840 (Dunz & Schliewen 2013). Although tilapia species were previously grouped together in the genus *Tilapia*, this single classification was later split into three discrete genera: *Tilapia*, *Sarotherodon*, and *Oreochromis* (Bonham 2022). All three genera are substrate spawners that excavate a nest in which to spawn. *Tilapia* are also substrate brooders, whereas both *Sarotherodon* and *Oreochromis* are mouth brooders that immediately take fertilized eggs from the nest into their mouths for the duration of the incubation period through a few days post-hatch; *Sarotherodon* are maternal and paternal mouth brooders, whereas *Oreochromis* are maternal mouth brooders (Boyd 2004) (Popma & Masser 1999).

Tilapia typically inhabit freshwater environments, although some species exhibit varying degrees of salinity tolerance that allows them to colonize brackish-water habitats—some species can also breed in brackish water (GSID 2023b) (Senanan & Bart 2014) (Fitzsimmons et al. 2011) (El-Sayed et al. 2006). Tilapia feed on a low trophic level and are generally considered herbivorous, detrivorous, or planktivorous, although many species also display omnivorous feeding habits (Canonico et al. 2005). Though native to Africa and the southwestern Middle East—the latter was accessed through the Great Rift Valley (Chu et al. 2021)—resident populations of tilapia have become widely established in many tropical and subtropical regions around the world as a result of intentional and accidental release, which have significantly expanded their global range (Sood et al. 2019) (Senanan & Bart 2014) (Canonico et al. 2005) (Boyd 2004). Since the 1930s, tilapia have been introduced into nonnative areas for a variety of purposes, including aquatic weed and insect control, ornamentals for the aquarium trade, aquaculture, recreational angling, and a source of baitfish (Bonham 2022) (El-Sayed 2006) (Canonico et al. 2005).

Tilapia have a high physiological tolerance to a wide range of variable environmental parameters as well as a high reproductive capacity—both characteristics increase their invasive potential in nonnative environments (Bonham 2022) (Cassemiro et al. 2018) (El-Sayed 2006) (Boyd 2004) (SRAC 2005) (Pullin et al. 1997). The International Union for the Conservation of Nature's (IUCN) Global Invasive Species Database (GISD) lists six species of tilapia considered to be invasive alien species that threaten biodiversity (GISD 2023c). Conversely, numerous tilapia species are in decline within their native ranges: the IUCN Red List, which includes 96 species under the search term "tilapia," ranks nearly one-quarter of these species as "Critically Endangered," with a further ≈20% ranked in the categories of "Endangered," "Vulnerable," and "Near Threatened."[3]

Growth and development of the global tilapia aquaculture sector

[3] https://www.iucnredlist.org/search?query=tilapia&searchType=species

Literature suggests that tilapia culture may first have been practiced in Egypt some 4,000 years ago, making it one of the first varieties of fish to be domesticated (El-Sayed 2020). Tilapia's high reproductive capacity and tolerance to a wide range of environmental conditions make it an attractive species for aquaculture (Cassemiro et al. 2018), as evidenced by global production data recorded by the Food and Agriculture Organization of the United Nations (FAO). As shown in Figure 1, in 2023 nearly 6.8 million MT of farmed tilapia and other cichlids were produced globally, and over three-quarters (77%) composed Nile tilapia (*Oreochromis niloticus*). In 2023, grass carp was the world's most abundantly farmed finfish, making up 10% of total global production. Nile tilapia ranked second, accounting for 8%, just ahead of silver carp, which also contributed approximately 8% (FAO 2025). Though official FAO production data for 2024 are not yet published, global tilapia production is expected to have exceeded 7 million MT during 2024.[4]

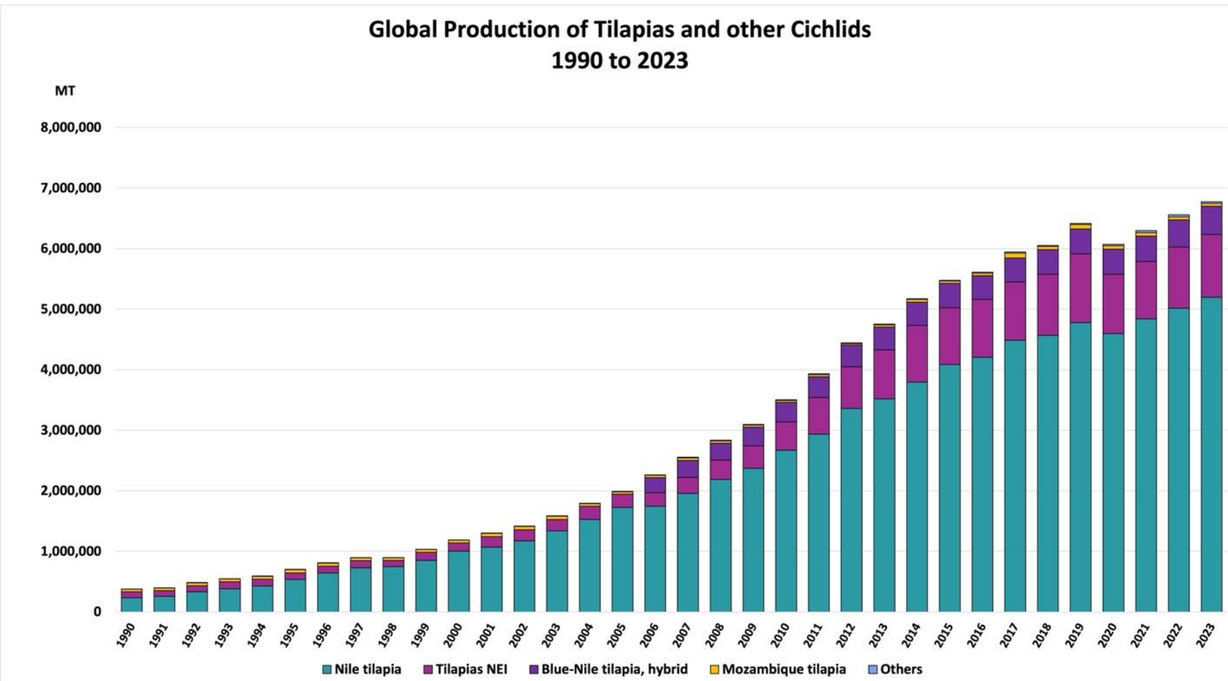
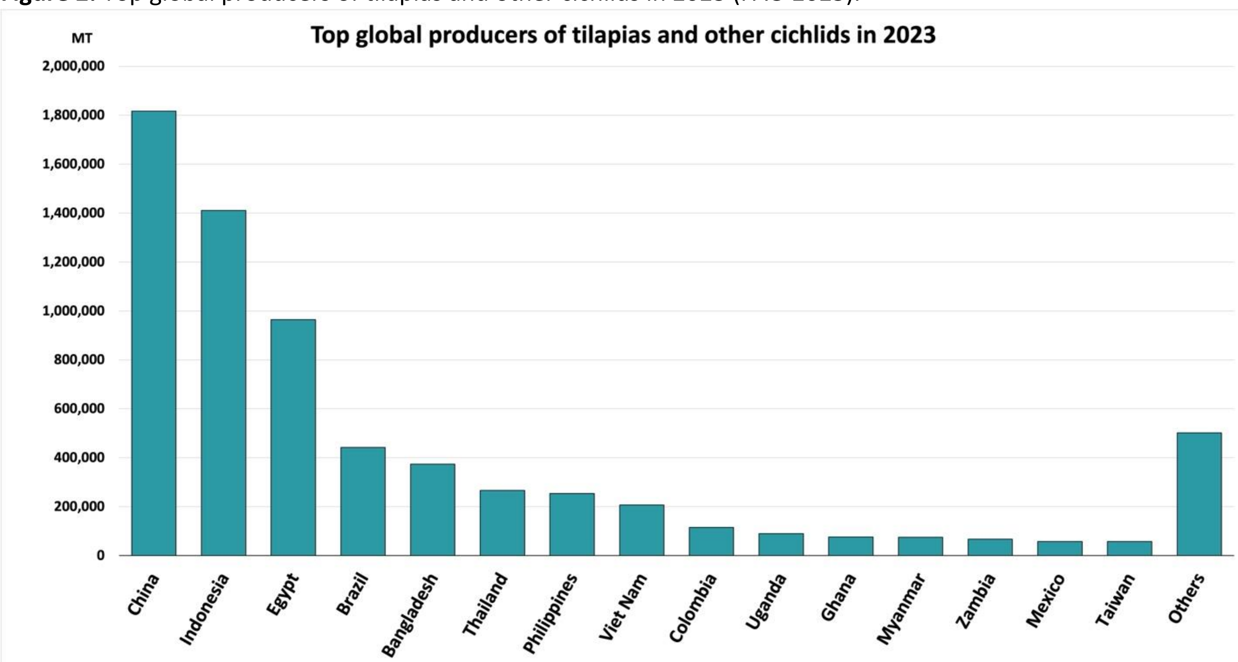


Figure 1: Global production of tilapias and other cichlids, 1990 to 2023 (FAO 2025).

[4] https://www.seafoodsource.com/news/supply-trade/global-tilapia-production-back-on-track-after-covid-related-pause-should-surpass-7-million-metric-tons-in-2025?utm_source=marketo&utm_medium=email&utm_campaign=newsletter&utm_content=newsletterReport%20on%20Indonesia%20shrimp%20industry%20adds%20to%20evidence%20claiming%20labor%20abuses%20in%20supply%20chain

The *Oreochromis* genus, to which Nile tilapia belongs, contains the species of tilapia that are most commonly found in aquaculture; this genus also includes Mozambique tilapia (*O. mossambicus*) and blue tilapia (*O. aureus*), which all readily hybridize in captivity (Bonham 2022). Because of the high degree of hybridization that occurs within the global tilapia sector, FAO data include a statistical unit, "Tilapias nei" (nei: not elsewhere included), which is used to capture these many variants[5]; this category, which is the second largest in Figure 1, comprises 15% of the global total. The balance of production shown in Figure 1 is blue Nile tilapia, a hybrid that accounted for 7% of global production in 2023; Mozambique tilapia, which constituted ≈1%; plus numerous "other" species, predominantly *Oreochromis* spp., which made up < 1% (FAO 2025).

Figure 2: Top global producers of tilapias and other cichlids in 2023 (FAO 2025).



Historical FAO production statistics indicate that Taiwan was the world's predominant producer of tilapia in 1950, the first year for which production data are available in FAO's aquaculture dataset. In 1950, seven countries (Taiwan, Egypt, China, Nigeria, Thailand, Indonesia, and Israel) reported cultured tilapia production to FAO that totaled 5,718 MT, of which 68% was produced by Taiwan (FAO 2025). Seven decades later, Taiwan is the world's 15th-largest producer of tilapia, accounting for 1% of total production, whereas the three largest global producers are China (27%), Indonesia (21%), and Egypt (14%) (Figure 2) (FAO 2025).

Global sector experts comment that tilapia is unique among the world's main aquaculture species as a result of the diverse array of settings and systems in which it is farmed. As a subsistence crop in some of the world's poorest regions, it plays an important role in supporting food security, whereas at the other end of the production spectrum, tilapia is farmed in high-tech systems and sold at a premium into high-end markets around the world (Fitzsimmons et al. 2011).

Development of Taiwan's tilapia aquaculture sector

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5 Considering global finfish production in 2023, "Tilapias nei" accounted for 1.62% of the total (FAO 2025).

The first recorded introduction of tilapia into Taiwan occurred in 1944, when a number of Mozambique tilapia were introduced from Indonesia by the Japanese; at that time, both Taiwan and Indonesia were under Japanese control (De Silva et al. 2004) (Chen 1954). But many literature sources reference 1946 as the year when tilapia were first introduced; on this occasion, two friends who had been prisoners of war together in Singapore returned to Taiwan, bringing 12 or 13 Mozambique tilapia (Kuo 1984) (Chuen & Huang 1981) (Chen 1954).[6] [7] [8] [9]

Over the next few decades, numerous other types of tilapia were introduced. As Taiwan's aquaculture technologies advanced, new tilapia hybrids were developed with the aim of optimizing certain characteristics, such as high fecundity, fast growth, cold resistance, and saltwater tolerance. Taiwan also produced the world's first red tilapia in the late 1960s by crossing a mutant reddish-orange female Mozambique tilapia with a standard male Nile tilapia. This red coloration typically commands a higher premium because red tilapia resemble the more highly valued marine red snapper. Other strains of red tilapia have subsequently been developed elsewhere (Lutz 2021) (SRAC 2005) (Modadugu & Acosta 2004) (Wohlfarth & Hulata 1981). To differentiate Taiwanese farmed tilapia in international markets, the name "Taiwan Tilapia" was officially adopted in 2002[10] (Chu et al. 2021) (Yu et al. 2015).

In 2023, tilapia was Taiwan's most abundantly farmed finfish, with 57,182 MT produced—accounting for one-third of the country's finfish production. Milkfish ranked second, at 27% of national finfish output. Considering all aquaculture production (including shellfish and crustaceans), tilapia represented 21% of the total (FAO 2025). The production volumes reported by Taiwan's tilapia sector over the last three decades are shown in Figure 3.Note that all of Taiwan's tilapia production is recorded in the category "Tilapias nei" in FAO statistics, because Taiwan does not officially disaggregate the production data provided to FAO (Xiaowei Zhou, FAO, February 2023 pers comm).

[6] https://ag.arizona.edu/azaqua/ista/China/TaiwanTilapiaSINORAMAMagazine.htm
[7] https://www.aquanet.com/taiwan-tilapia
[8] https://www.taipeitimes.com/News/feat/archives/2017/04/30/2003669672
[9] https://pansci.asia/archives/95701
[10] https://eng.coa.gov.tw/themedata.php?theme=engnews&id=3

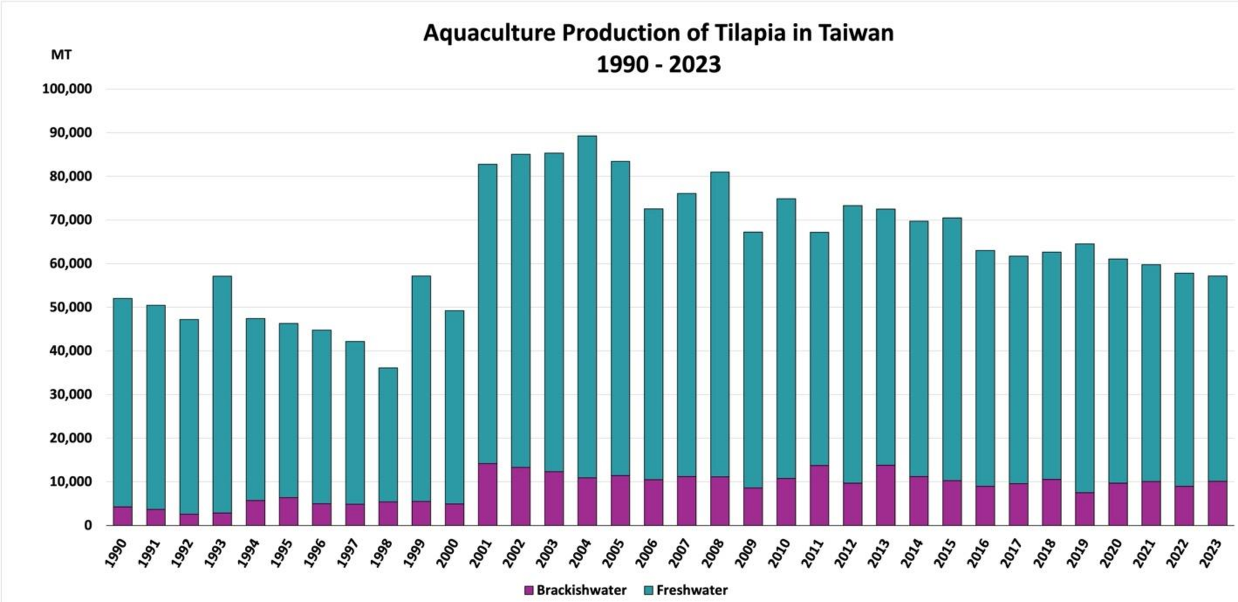


Figure 3: Aquaculture production of tilapia in Taiwan from 1990 to 2023 (FAO 2025). Note that all of Taiwan's farmed tilapia production is recorded by FAO in the category "Tilapias nei" (not elsewhere included).

A geographical overview of the Taiwanese tilapia sector

In East Asia, Taiwan is an island located at the junction of the East and South China Seas on the western edge of the Pacific Ocean. China lies to the northwest of Taiwan, Japan to the northeast, and the Philippines to the south (Figure 4).

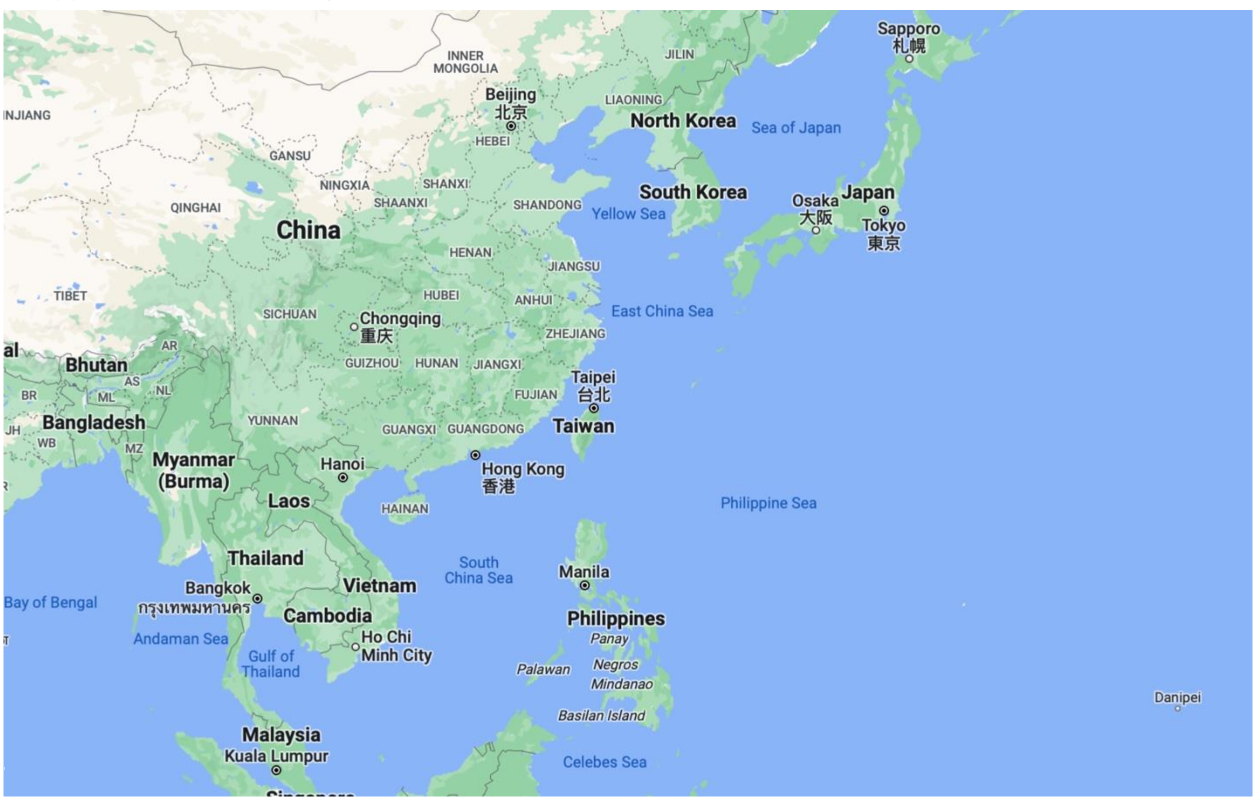
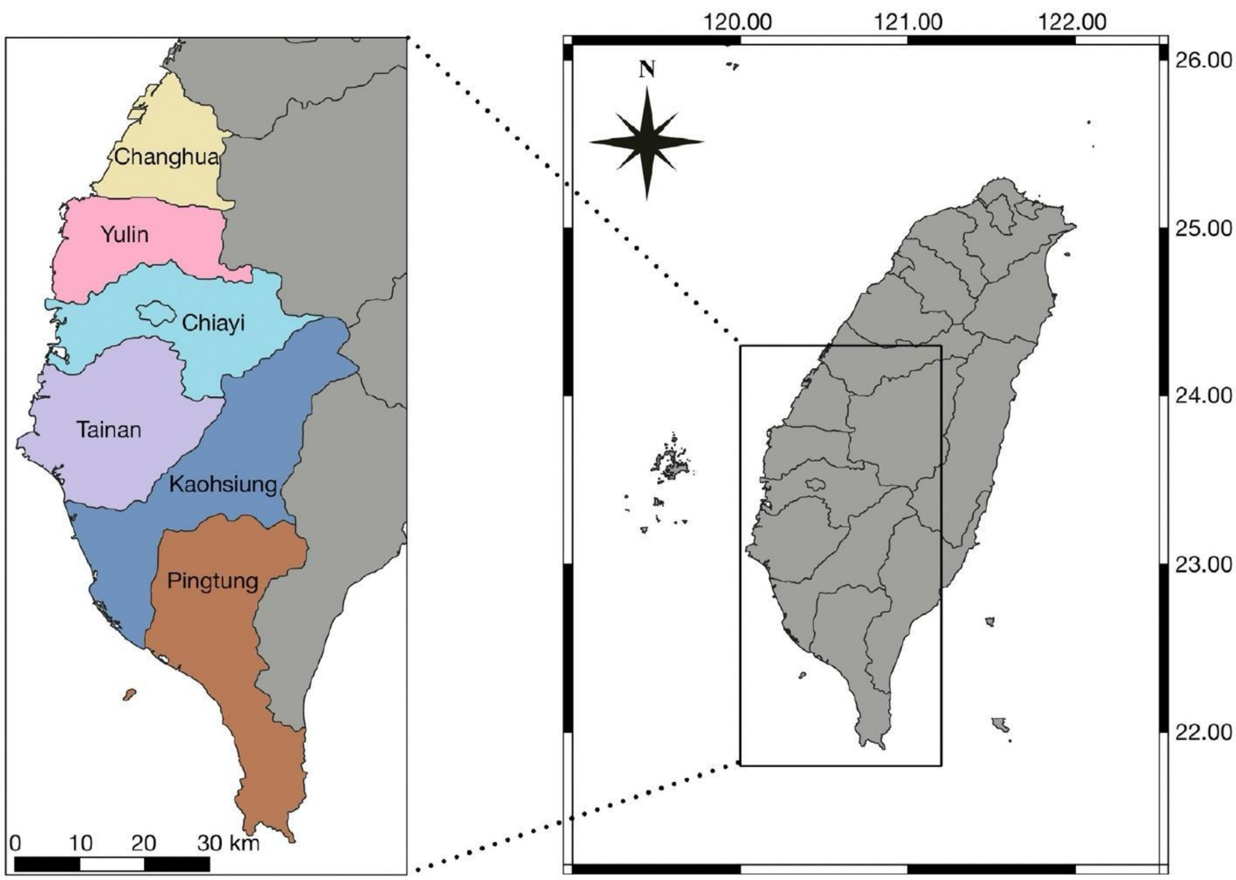


Figure 4: Geographical overview of Taiwan and surrounding countries (Google Maps 2023).

Two-thirds of Taiwan's landscape is mountainous, dominated by the Chung-yang Shan range, which trends north-northeast to south-southwest; this range has over 200 peaks higher than 3,000 m. To the west of the mountain range, rolling hills descend to alluvial plains and flatlands, where the majority of the population live and most farmland is located. Conversely, on the east, mountainous slopes descend sharply toward the coast, where there is little habitable land and the population is much sparser.[11] [12] Therefore, the majority of aquaculture activity takes place in the west: more specifically, along the southwestern coastal region (Chen et al. 2021). Taiwan has a subtropical climate, apart from the very south of the island, which is tropical. As a tropical fish, tilapia is sensitive to colder temperatures; thus, even though Taiwan's winters are typically short and mild, production of this species occurs in Taiwan's more southerly latitudes (Chu et al. 2021) (Huang et al. 2021).

Figure 5: Map of Taiwan with an inset showing the southwestern regions where the majority of Taiwanese



aquaculture production takes place. Reproduced from Chen et al. (2021), *Developing Payment for Ecosystem Service Schemes for Coastal Aquaculture in Southwestern Taiwan*. Reproduced with the permission of Professor Yao-Jen Hsiao, Institute of Applied Economics, National Taiwan Ocean University.

[11] https://www.britannica.com/place/Taiwan
[12] https://www.worldatlas.com/maps/taiwan

Taiwan's southwestern coast is characterized by various unique ecosystems, including estuary wetlands, muddy tidal flats, large-scale intertidal wetlands, lagoons, coastal sand dunes, and sandbars (Chen et al. 2021) (Lin 1996). Most of Taiwan's rivers flow westward toward the Taiwan Strait and the South China Sea, transporting large amounts of silt and mud to coastal estuaries; over time, these sediment depositions have developed into tidal lands that occupy the area between the high and low tide marks. Historical records indicate that these tidal lands have been gradually reclaimed in Taiwan since the 18th century and converted into fish ponds, salt fields, and farmland (Liu 2013).

Overview of the attributes of a typical tilapia farming system in Taiwan

Production regions
Most aquaculture production in Taiwan, including tilapia, is concentrated in the southwest coastal region. Within this area, the administrative region that produces the most tilapia is the southern county of Tainan, although significant production also takes place in Chiayi and Yunlin; these three regions account for approximately 40%, 30%, and 10% of total tilapia production, respectively. Smaller quantities are produced in the southern regions of Kaohsiung (≈5%) and Pingtung (≈2%). The locations of these five regions are highlighted in Figure 5. In addition, a small percentage (≈3%) is farmed in Taoyuan and Hsinchu in the north (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm) (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm), and the balance of production is contributed by small amounts farmed in other administrative regions.

Tilapia species
Tilapia production in Taiwan is predominantly focused on the culture of GIFT strain tilapia,[13] which contributes approximately 60% of the total, and hybrid tilapia (Nile tilapia♀ × blue tilapia ♂), which accounts for roughly 40%; there is also a small amount of hybrid red tilapia being cultivated (Taiwan Fisheries Research Institute November 2023 pers comm). Although Mozambique tilapia—the only tilapia species capable of tolerating high salinity—was historically the first tilapia species cultured in Taiwan, it is no longer widely farmed anywhere globally because of its unfavorable commercial traits (El-Sayed 2020). The minimal global production of this species among other major tilapia species is illustrated in Figure 1.

Pond size
Communications with local experts indicate that most tilapia farms in Taiwan are small-scale, typically ranging between 1.5 and 6 hectares, with most in the 1–3 ha range. But a small amount of fish are also produced in the north, where larger ponds (5–20 ha) are used (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Freshwater versus brackish-water production and the distance of ponds from the coast
Tilapia in Taiwan are primarily grown in freshwater, but also in brackish-water environments, as shown in Figure 3. Per FAO data, in 2023, 82% of tilapia were produced in freshwater versus 18% in brackish water (FAO 2025). While these FAO data do not specify the salinity of the brackish water used, communications with experts indicate that a pond farm in Taiwan is generally considered to be freshwater when the salinity is under 5 ppt, whereas brackish-water production is somewhat higher

[13] More information about GIFT (Genetically Improved Farmed Tilapia) can be found in Criterion 8X—Source of Stock.

(Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

In coastal aquaculture zones, the government has set up seawater supply systems to facilitate easy access to seawater for marine pond-based aquaculture operations, which cultivate species such as clams or marine finfish. Tilapia ponds are typically situated slightly inland from this marine zone, extending up to 10–15 km from the shoreline. Because of current regulations prohibiting well water usage, tilapia farmers primarily collect rainwater and circulate it between ponds. To mitigate water shortages, farmers will typically use one or two of their ponds as reservoirs; the rainy season and typhoons generally provide abundant rainwater, which replenishes these freshwater supplies. In addition, the government has constructed water supply channels in inland aquaculture areas and periodically notifies operators about designated times for drawing fresh water. These water channels are principally supplied by large public reservoirs, although the Water Conservancy Agency also manages numerous large water ponds (from 3 to 20 ha) that augment irrigation water supplies as needed (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Intensive versus semi-intensive production

Although official government statistics do not define the proportion of production that arises from intensive versus semi-intensive production systems, the Ministry of Agriculture's (MOA) website comments that most tilapia production is intensive.[14] Estimates from experts concur that intensive pond production systems account for ≈80–85% of the total, whereas the balance of production (≈15–20%) takes place in semi-intensive production systems (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm) (Taiwan Fisheries Research Institute October 2023 pers comm).

Seasonality: stocking through harvest

Because tilapia are tropical species, the breeding season for tilapia in Taiwan typically spans from March to November (Taiwan Fisheries Research Institute March 2023 pers comm). Culture conditions are generally not favorable in the lower winter temperatures, so most farmers leave their ponds empty or fallow during the colder months from December to March (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm). Literature concerning global tilapia farming notes that tilapia feeding significantly decreases below 20 °C, ceases entirely around 16 °C, and severe mortality occurs at 12 °C (El-Sayed 2020). Even so, a few farmers choose to continue on-growing tilapia during winter to take advantage of higher market prices. To mitigate the impact of cold weather, some farmers install a protective covering at the northern end of their ponds to block wind, a practice that can increase the temperature by an estimated 3–5 °C in winter (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Farming practices vary based on location, climate, and market demand. The majority of tilapia farmers adopt a continuous production approach to ensure steady harvests of market-sized fish, thus maintaining a consistent supply and economic stability. Because the primary fry production season occurs from March to June, most farmers align their stocking practices with this period. Farmers generally stock fish in spring and harvest them before the onset of winter; this typically involves harvesting fish from the pond in two to four stages throughout the season, per factory or market

[14] https://kmweb.moa.gov.tw/subject/subject.php?id=16572

demand, after which the pond is emptied and drained. On average, annual production per hectare is 50–70 MT (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Water exchange rates and pond management

Because of water shortages, Taiwan's tilapia farmers are keenly focused on conserving this precious resource, so they discharge water quite infrequently. Although experts comment that the average daily water exchange rate on tilapia farms is typically less than 1%, note that this is mainly to compensate for evaporative loss and that the exchange that occurs is most often between the farmers' own ponds, rather than a discharge that leaves the perimeter of the farm. As noted, farmers mainly collect rainwater that is then circulated and exchanged between their ponds as needed. Farmers typically use one or two ponds as reservoirs, and when it is time to harvest the pond, the pond water is collected into an adjacent pond; ponds are connected by underground pipes, which facilitate this movement of water. On occasion, farmers may need to release water from their ponds to prevent them overfilling, such as in advance of a typhoon when heavy rain is expected and their ponds and reservoir ponds are already at capacity. In such cases, this discharged water enters a designated public discharge canal, which eventually flows into the sea. But many farmers use the influx of rain as an opportunity to collect more freshwater (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Development Association March & October 2024 pers comm).

Once harvested, ponds are typically left empty for 2–3 months. Taiwan's regulations stipulate that the subsoil cannot be discarded or removed from the pond at will; therefore, as part of their pond management regime, farmers often use excavators to dig up the soil, which is left to dry and sterilize in the sun, sometimes with the addition of lime or zeolite powder to help promote and maintain the functionality of the subsoil. After this, the pond is refilled by pumping water back into it from an adjacent pond in preparation for restocking (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Summary of what composes an "average farm" in the ensuing report

While it is evident that tilapia are produced in both fresh and brackish water in Taiwan, with varying degrees of intensity (both semi-intensive and intensive), there are insufficient data available to decouple and differentiate these production methods and their potential environmental impacts. Thus, this assessment focuses on the characteristics of a typical farm, as indicated by the data available. Because the majority of Taiwanese tilapia farms are intensive systems (80–85%), with around 82% being freshwater-based, this assessment primarily focuses on evaluating tilapia raised in intensive freshwater ponds, with a low water exchange rate of around 1% per day. Though farms may need to discharge water from the farm occasionally, this happens infrequently: most of the time, farms are effectively zero-discharge. The average size of a tilapia farm in Taiwan is between 1.5 and 6 ha, with most in the 1–3 ha range (including grow-out ponds and one or two reservoir ponds); on an average farm, the annual production per hectare is ≈50–70/MT.

Industry statistics and the scale of the cultured tilapia sector in Taiwan

As shown in Figure 3, the annual production volume of Taiwanese tilapia in recent years is approximately 60,000 MT; the land area occupied to facilitate this production is approximately 3,000 ha. According to statistics from the Fisheries Bureau, in 2023 Taiwan's annual production of tilapia was 57,182 MT, produced on 3,233.73 ha of land. Note that the specific number of hectares in production may vary slightly from year to year due to variables such as water shortage, ponds being left fallow, or the construction of photovoltaic panel facilities over farms, in line with the government's alternative energy policy (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm). As noted, tilapia is Taiwan's most abundantly cultured finfish, accounting for one-third of its finfish production and one-fifth of its total aquaculture production (FAO 2025). To provide context among Taiwan's overall fisheries production, in 2018 the value of Taiwanese aquaculture was TWD37.5 billion (≈USD1.25 billion[15]), which equaled ≈40% of all its fisheries production in 2018 (Chen et al 2021).

Imports & Exports: Taiwan within the global tilapia marketplace

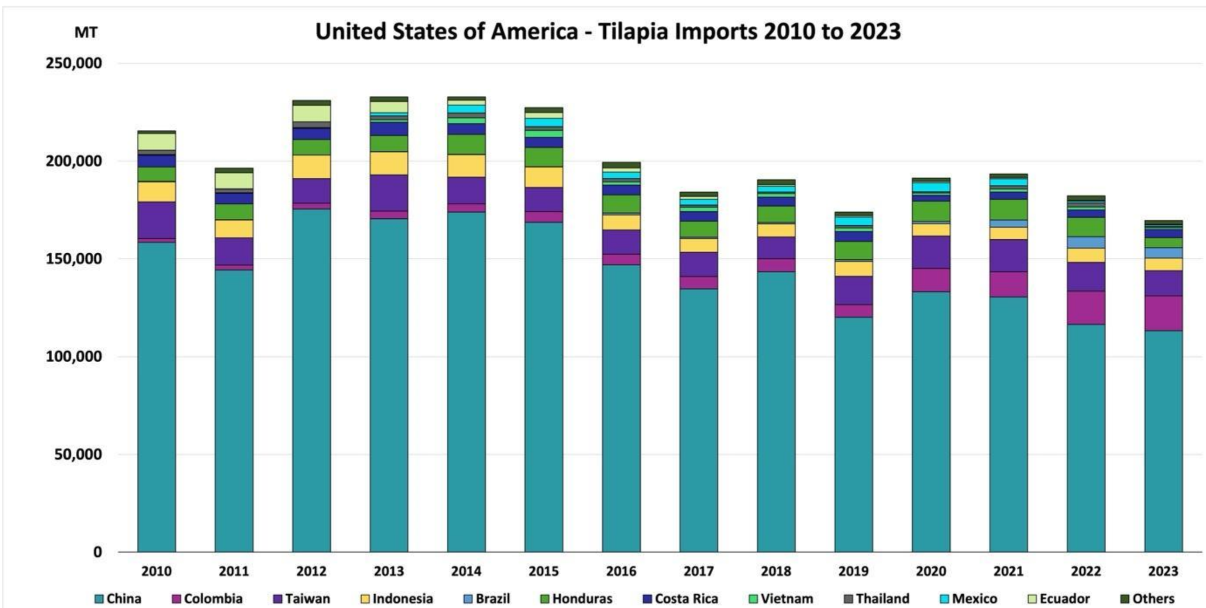


Figure 6: The main suppliers of U.S. tilapia imports from 2010 to 2023 and the overall volume imported each year (NOAA 2024).

As evident in Figure 1, the global tilapia sector has grown exponentially in the last three decades; however, only around 5% of this production makes its way into international markets. As a relatively low-cost, affordable fish, tilapia enjoys strong local markets in the countries where it is farmed, which are primarily in the Americas, Africa, and Asia (El-Sayed 2020). Presently, the largest market for tilapia exports is the United States, which received 33% of total global trade in this species in 2022 (FAO 2024). Globally, the largest tilapia supplier is China,[16] which produced more than 1.8 million MT in 2023 that comprised 74% Nile tilapia and 26% blue Nile tilapia, a hybrid (FAO 2025). The predominance of China as a supplier to the United States is evident in Figure 6, which provides an overview of U.S. tilapia imports from 2010 to 2023.

[15] https://www.exchange-rates.org/exchange-rate-history/usd-twd-2018
[16] https://leoseafood.com/tilapia-landing-page/

Considering the data presented in Figure 6, since 2010 China has on average supplied 72% of U.S. tilapia imports, whereas Taiwan has been the second main supplier, providing an average of 7%. This is followed by Honduras, Indonesia, and Colombia, each of which has on average supplied ≈4% over this period. But in 2022 and 2023, Colombia overtook Taiwan in U.S. tilapia imports, so Colombia is now the second-largest supplier and Taiwan is the third-largest (NOAA 2024). In 2023, Taiwan was the third-largest supplier of tilapia to the United States, accounting for 8% of imports, whereas the first- and second-largest suppliers were China and Colombia, which supplied 67% and 11%, respectively. Note that in 2020, tilapia ranked as the fourth most popular seafood choice in the U.S., behind shrimp, salmon, and canned tuna.[17]

The European Union has historically been a strong market for tilapia, but imports have declined in recent years, from a high of 65,423 MT in 2013 (El-Sayed 2020) to 35,797 MT in 2022 (FAO 2024). FAO global fish trade data indicate that, in 2022, the top three tilapia importing countries were the United States, Mexico, and Côte d'Ivoire, which accounted for 21%, 16%, and 9% of global tilapia imports, respectively (FAO 2024).

Exports of tilapia from Taiwan

FAO trade data indicate that, of the 31,900 MT of fisheries products[18] imported into the United States from Taiwan in 2022, 46% was tilapia.[19] Furthermore, of all the tilapia produced in Taiwan in 2022, 33% was exported, of which 72% was traded into the United States[20] (FAO 2025) (FAO 2024). In 2022, 89% of the tilapia imported into the United States from Taiwan was frozen whole fish, while 10% was frozen fillets; a negligible amount of fillets are also described in trade data as "tilapia fillets, fresh or chilled" (FAO 2024). Taiwan's primary export markets for tilapia from 2019 to 2022 are shown in Figure 7 and indicate a relatively consistent trend of volume by country through the period. Taiwan was the first country producer to sell tilapia internationally, in the mid-1980s. By the late 1990s, several other producers began to trade their products globally (Bonham 2022).

Common and market names for tilapia

In Taiwan, tilapia are commonly marketed as **台灣鯛** (Taiwan Tilapia)—a term that typically refers to domestically farmed hybrids of species such as *Oreochromis niloticus* and other *Oreochromis* spp. The English name "tilapia" is also widely used, particularly in export contexts. The traditional term **吳郭魚** (Wu-Kuo-yu; yu means "fish") is still recognized locally and is derived from the surnames of the two men who introduced tilapia into Taiwan in 1946; however, this name is more commonly associated with strains derived from *Oreochromis*

[17] https://www.seafoodsource.com/news/supply-trade/shrimp-scallops-among-americans-top-10-most-consumed-seafood-species-in-2020
[18] I.e., fish, crustaceans, and molluscs
[19] This is based on FAO's global fish trade dataset with "United States of America" selected as the reporting country. The data reported by Taiwan are slightly different: if "Taiwan Province of China" is selected as the reporting country, the share of the total attributable to tilapia is 46%.
[20] This is based on FAO's global fish trade dataset with "Taiwan Province of China" selected as the reporting country.

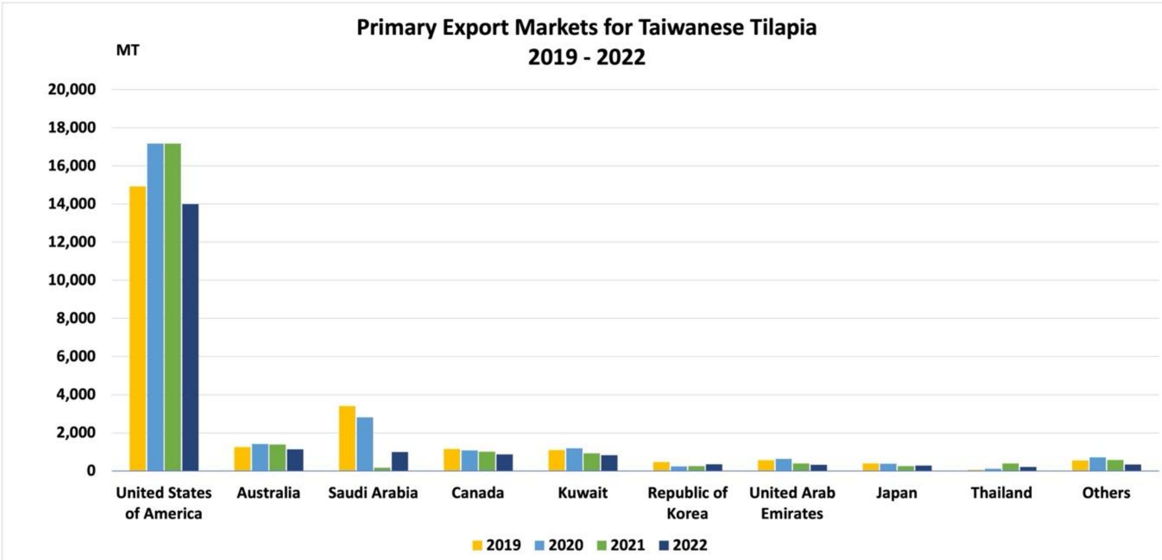


Figure 7: Primary export markets for Taiwanese tilapia,2019–22 (FAO 2024). Note: these data have been extracted from FAO's global fish trade dataset with "Taiwan Province of China" selected as the reporting country; for U.S. imports, if the search is performed with "United States of America" selected as the reporting country and "Taiwan Province of China" as the partner country, the reported volumes are slightly less.

mossambicus, rather than the full range of tilapia species and hybrids farmed today (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association May 2024 pers comm). In some cases, hybrid red tilapia are marketed as "Taiwan bream" to enhance consumer appeal (Xiaowei Zhou, FAO February 2023 pers comm). Taiwanese people also sometimes refer to tilapia as "South Pacific crucian carp" (TPM 2004).

Tilapia product forms

As the tilapia sector has grown, so have the number of tilapia product forms available. As noted, Taiwan was the first country to trade tilapia internationally, and at that time it was exported with minimal processing as a whole frozen fish. But the U.S. market expressed a preference for fillets rather than whole fish, and this demand was later met in the form of frozen fillets from Taiwan, Indonesia, and Jamaica, as well as fresh fillets exported from Jamaica, Costa Rica, and Colombia (Bonham 2022). Currently, Taiwanese tilapia exports are either frozen whole round fish or frozen fillets (Taiwan Fisheries Research Institute March 2023 pers comm). In addition to fresh and frozen fillets, numerous other product forms of tilapia are now available internationally, such as skin-on, skin-off, deep-skinned, individually quick frozen (IQF), smoked, and sashimi grade.[21] Other interesting tilapia by-products have entered the marketplace, such as tilapia leather, dressings for the treatment of burn wounds (Júnior et al. 2020), collagen products,[22] and decorative and functional items made from tilapia scales, including an innovative new alternative to wood and plastic (Fletcher 2022).

[21] https://leoseafood.com/tilapia-landing-page/
[22] https://agriculture.com.ph/2017/12/14/tilapia-taiwans-national-fish/

Criterion 1—Data Quality and Availability

Impact, unit of sustainability and principle

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

Data Category	Data Quality
Production	7.5
Management	7.5
Effluent	5.0
Habitat	5.0
Chemical use	5.0
Feed	5.0
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	5.0
Introduction of secondary species	10.0
Final Score (0–10)	**RATING 6.6**

Criterion 1 Summary

While there is a substantial body of peer-reviewed literature available concerning the global tilapia sector, robust data on many specific aspects of the Taiwanese tilapia sector are lacking. Although regulatory provisions are easily accessible online via the Taiwanese Ministry of Justice's (MOJ) Laws & Regulations Database and the FAO's FAOLEX Database, it is often challenging to decipher their practical implementation without additional input. In an attempt to fill these various data gaps, outreach was made to a variety of relevant parties, including government departments, farmers, industry experts, and trade associations, with varying degrees of success.

Data quality and availability vary somewhat across the topics and criteria reviewed. Data concerning the general categories of Production and Management both received a moderate–high score of 7.5 out of 10, based on the breadth and relevance of academic literature and expert communications available. Confidence in the data's ability to robustly describe the ecological impact reviewed in each criterion was assessed as moderate for six of the nine criteria discussed, with scores of 5 out of 10 for Effluent, Habitat, Feed, Disease, and Wildlife Mortalities. Note that assessments for Effluent, Disease, and Wildlife Mortalities are predicated on risk-based methodologies, because of limited specific data. The data score for Chemical Use was also assessed as 5 out of 10. Although specific information on the quantity and types of chemicals used is lacking, there is reasonable confidence—based on expert input, regulatory context, and the low discharge nature of the production system—that the risk of environmental exposure is moderately low. This supports a moderate score despite the absence of direct usage data.

The Source of Stock category stands out with a high data quality score of 10 out of 10, supported by extensive historical and contemporary literature. Likewise, the exceptional criterion, Introduction of Secondary Species, scored 10 out of 10. Escapes has a moderate–high score of 7.5 out of 10, relying on indirect evidence and expert communications in the absence of official reporting requirements. The variability in data quality across these categories reflects the challenges in obtaining comprehensive, sector-specific information, with the assessment of many criteria relying on a combination of academic literature, expert communications, and publicly available government resources.

Overall, while many aspects of the assessment benefit from publicly accessible resources and academic literature, numerous knowledge gaps remain in terms of species-specific or farm-level data. Key knowledge gaps include the practical enforcement of habitat and chemical use regulations at the farm level, typical compliance practices, and quantifiable data on chemical and drug usage. These gaps primarily reflect limited access to detailed, farm-level information from official sources. The final score for Criterion 1—Data Quality and Availability is 6.6 out of 10.

Justification of score

The following evaluates the quality and availability of data used to inform this assessment. Two general data categories are considered: Production and Management, whereas all other data categories pertain to the principal criteria considered in the main body of this report: Effluent, Habitat, Chemical Use, Feed, Escapes, Disease, Source of Stock, Wildlife Mortalities, and Introduction of Secondary Species.

Production

To support land use management, Taiwan's Ministry of Agriculture (MOA) offers a publicly accessible and comprehensive inventory survey map (MOA 2023) of agricultural and farmland resources. This map details the locations and areas of various agricultural activities, including fish farming, crop production, livestock, forestry, and leisure/recreational farms. Users can filter the map by these categories to view the specific areas where each type of land use is active, and it is also possible to zoom in on each cadastral address. Using this map, the total hectarage of the aquaculture sector can be determined, but it is not possible to disaggregate these data at the species level. Notably, communications with experts confirm that every aquaculture pond in Taiwan is assigned an individual pond number and is subject to aerial surveillance, even if the pond is not officially registered. Also, while there are specific areas designated for aquaculture, these designations are not prescriptive about the species that may be raised in each zone.

Regarding Taiwanese tilapia production volumes, the quantities referenced in this report are based on statistics extracted from the FishStatJ global aquaculture production database, which is maintained by the Food and Agriculture Organization of the United Nations (FAO). Of note, all of Taiwan's tilapia production is recorded in the category "Tilapias nei" (nei: not elsewhere included) in FAO statistics, a statistical unit that includes all possible species and hybrids of farmed tilapia, because Taiwan does not officially disaggregate the production data provided to FAO. But the Fisheries Research Institute, which is also under MOA, was able to clarify the strains of tilapia that are produced as well as the approximate split between these in terms of overall production.

In summary, the MOA's inventory survey map is a valuable tool for mapping aquaculture production areas in Taiwan, and FAO production statistics provide important insights into tilapia production volumes and trends. But without more granular data at the species level—both in terms of production regions and volumes—it is evident that there are some data gaps in the production information available. Nonetheless, given the strength of spatial data, the consistency of national production reporting, and the additional clarity obtained through expert communications with the Fisheries Research Institute, confidence in the production data is considered moderate–high. Thus, the data score for Production is 7.5 out of 10.

Management
The numerous laws that underpin the regulatory framework for the management of tilapia farms in Taiwan are generally easy to access online; two portals that were used extensively for this purpose were the Taiwanese Ministry of Justice's (MOJ) Laws & Regulations Database[23] and the FAO's FAOLEX Database.[24] But as is often the case with regulatory documentation, it is challenging to decipher their practical implementation without additional input.

Taiwan has a Freedom of Government Information Act in place and, in line with this act, government departments typically have an online mailbox to which questions can be submitted; while responses from these are generally prompt, it is difficult to gain a comprehensive understanding of the management structure in place for aquaculture through this medium, because a dialogue is not possible. The most relevant government entity concerned with aquaculture management in Taiwan is the Fisheries Agency, which is responsible for the administration and registration of land-based aquaculture. Although we had some direct communication with the agency during our research, we were unable to obtain detailed information about sector management in response to our data request. The agency referred us to the Taiwan Tilapia Alliance,[25] a producers' organization, for further information; however, this outreach did not result in additional data.

Therefore, most information regarding the management of tilapia farms in Taiwan was obtained through peer-reviewed publications, farmers, and in-country experts, including the Taiwan Fisheries Economic Development Association. Given the breadth and relevance of these alternative information sources, confidence in the data available to describe farm management is considered moderate–high, and the data score for Management is 7.5 out of 10.

Effluent
The literature notes that tilapia farming is generally regarded as having minimal environmental impacts, with fish primarily fed on vegetative materials. But no specific literature on tilapia farm effluents in Taiwan was identified. Thus, a risk-based methodology was implemented to estimate the amount of biological wastes generated and the quantity of these subsequently discharged. To arrive at these estimates, various data points were determined from a range of sources. The average protein content of aquafeeds was determined from data supplied by tilapia feed manufacturers in Taiwan. A typical economic feed conversion ratio (eFCR) was determined, based on conversations with local experts and farmers as well as from general academic literature on this topic. These values, combined with the protein content of harvested whole tilapia reported in academic literature, were used to estimate the total volume of nitrogen waste produced. In turn, these data were used to estimate the amount of waste discharged per metric ton (MT) of production, by taking the average water exchange rate values reported by sector experts and farmers into consideration.

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[23] https://law.moj.gov.tw/ENG/Law/LawSearchResult.aspx?ty=LAW&kw=aquaculture
[24] https://www.fao.org/faolex/country-profiles/general-profile/en/?iso3=TWN
[25] https://cales.arizona.edu/azaqua/ista/ista6/ista6web/presentation/p998.pdf

Concerning the management of farm-level and cumulative impacts related to tilapia farming, key data were obtained via communications with the Ministry of Environment (MOENV) as well as sector experts and farmers. While it is evident that a cumulative approach is implemented in water quality management in Taiwan, it is also evident that management measures are not specifically designed to be implemented at the farm level for the majority of tilapia farms, due to their small size, although over 5% of farms are inspected annually. Because it is not presently possible to robustly assess the near- and far-field nutrient impacts of effluent discharges from tilapia farms in Taiwan (due to limited farm-level data), some uncertainty remains about potential impacts. Therefore, the data available are considered to be moderate, which warrants a score of 5 out of 10 for Effluent.

Habitat

Considering habitat conversion and function, MOA's inventory survey map of agricultural and farmland resources is a key resource that helped to inform Factor 3.1. The functionality of this map allows for aquaculture production zones to be viewed at different geographic scales, providing a concise overview of the location and density of aquaculture in Taiwan, albeit not disaggregated at the species level. But it is clear from literature that tilapia are predominantly produced along the southwest coast of Taiwan, and the ecosystem characteristics of these regions are also described. A great deal of peer-reviewed literature discusses the geography of Taiwan, concurring that this coastal region is part of a highly populated, intensively managed landscape that has many competing demands for land and water resources. Both literature and communications with experts and farmers concur that the majority of present-day fish farms are located in areas that are now specifically designated for aquaculture, but that most of these farms were established in these areas many years ago. Also, according to historical data, the land footprint of tilapia ponds in Taiwan in the 1950s was somewhat less than it is at present, which appears to support the fact that most present-day farms were not built on virgin land but were constructed on land that had historically already been converted. Literature also notes that, historically, the overexploitation of groundwater and its related impact of land subsidence have been the most significant habitat impacts from pond aquaculture in Taiwan, although industry experts advise that most tilapia farmers no longer use groundwater to fill their ponds.

A considerable volume of literature describes the development of the regulatory framework for aquaculture in Taiwan with respect to farm siting and management (Factor 3.2). This is framed clearly in an historical context, with explanations why particular measures were implemented to tackle resource-use challenges and mitigate environmental impacts. In addition, the main environmental laws, regulations, rules, and policies pertaining to aquaculture are easily accessible in both the MOJ Laws & Regulations Database and the FAOLEX Database. It is also evident that the regulatory framework is actively evolving, and the current situation was elucidated through communications with industry experts. Notably, while local aquaculture associations are evidently important entities (albeit private) that are involved in collaborating with the government in aquaculture management, the Aquaculture Development Association did not respond to our request for information on the tilapia sector but referred us to the Taiwan Tilapia Alliance, which also declined to answer our questions. If information were forthcoming from these organizations, it would help strengthen our understanding of the role that they play and improve our knowledge of typical farm-level management practices.

The literature also discusses the enforcement of management measures and notably describes that, although Taiwan's governance structure is predominantly a top-down hierarchical system, participative management at the local level is also greatly encouraged. Again, input from the Aquaculture Development Association and the Taiwan Tilapia Alliance would help improve confidence in our understanding of this aspect of management and related enforcement measures. A number of online government databases were reviewed, which provide details of ongoing procedures such as environmental impact assessments (EIAs) and investigations into land use violations; however, these do not appear to include any references to matters related to tilapia farms.

In summary, while the location of farms and their habitat impacts are broadly known, as are the regulations and management framework for farm siting, knowledge gaps still exist about the enforcement of these regulations. Thus, the quality of information for this criterion is considered to be moderate—largely from the absence of input from key authorities, which limited our ability to confirm how habitat-related regulations are enforced in practice—and the score for Habitat is 5 out of 10.

Chemical Use

In general, the literature concerning the global tilapia sector concurs that cultivation of these species has historically not necessitated the use of harmful chemicals or antibiotics, but that as tilapia production has intensified in recent decades and new pathogens have emerged, the need for medicinal interventions has risen. But particularly for tilapia production in Taiwan, data regarding the quantity of chemicals and veterinary drugs used across the sector are unclear, and no publicly accessible data on this topic appear to be available. Efforts to obtain this information, including a request to the Fisheries Agency, did not yield specific details, so it is difficult to assess the actual practices and potential impacts of chemical and drug use by the sector. Note that the audit reports of several ASC-certified tilapia farms in Taiwan were reviewed; although these indicate that zero chemicals or antibiotics are used, the status of Taiwan's many other non-ASC-certified farms is essentially unknown.

Although specific chemical and drug usage data are elusive, the laws governing the management of such substances are readily available on the MOJ Laws & Regulations Database, as is a list of the drugs approved for use in tilapia production in Taiwan and their method of application. In turn, the World Health Organization's (WHO) respective categorization of these drugs is easy to access online. Communications with industry experts provided adequate information to determine those drugs that are most frequently used by farmers in the sector and also explained the important role of government-funded disease inspection stations.

Numerous academic publications note that, in the early 2000s, concerns over drug residues in Taiwanese cultured seafood came to the fore when several consignments—including tilapia—were detained and rejected by importing countries. Literature further clarifies the various measures that were subsequently put in place to rectify this situation, including the implementation of random drug residue testing on fish farms. This practice continues today, and data on compliance rates are published in the MOA's Annual Report. The Animal Drug Residue Standards, which farm operators must comply with, are available on the website of Taiwan's Food and Drug Administration (FDA). Though no evidence—or a lack thereof—of the subsequent environmental fate of chemicals used on Taiwanese tilapia farms was noted in the literature, one study was identified that sought to estimate the monthly average emission rates of oxytetracycline used by the wider aquaculture sector in Taiwan, and numerous other literature sources were located that describe and discuss the detection and impact of antibiotic residues in aquatic environments elsewhere.

In conclusion, though it appears that chemical usage on tilapia farms in Taiwan may potentially be low, this position cannot be robustly ascertained from the data, whether available or not. But personal communications provide confidence that discharges from farms to the external environment are minimal, and that on-farm water is commonly stored and reused through reservoir systems. Considering the data available—particularly the absence of robust chemical use data, but with moderate confidence in the relevance of discharge-related information—the data score for Chemical Use is 5 out of 10.

Feed

In a global context, it is often challenging to obtain specific aquaculture feed data because of its proprietary nature. This was also the case in our endeavor to obtain feed data for this assessment: even though numerous feed companies were contacted, only two responded to our feed data requests. Even so, these aggregated data are considered to reasonably represent the feeds used by the Taiwanese tilapia sector at large. Although this small sample size does not form a robust dataset, it is evident that the data provided are broadly comparable to those reported by tilapia feed suppliers elsewhere (e.g., in other Seafood Watch reports). The economic feed conversion ratio (eFCR) used in feed calculations was determined from communications with local experts and farmers as well as from academic literature on the global tilapia sector, and the value used in feed calculations is considered representative of typical production outcomes across the Taiwanese sector. The sustainability of the source of wild fish calculations were informed by FishSource scores as well as by relevant MarinTrust reports. The Feed Footprint was calculated using feed ingredient life cycle assessment (LCA) data extracted from the Global Feed Lifecycle Institute (GFLI) database, combined with the whole harvested farmed tilapia protein content reported in peer-reviewed literature. If feedback from more feed suppliers had been forthcoming, it would have allowed for greater diversity in the source data used in ensuing calculations, thereby increasing confidence in their accuracy. Thus, assessor confidence in the feed data available is considered moderate overall; this results in a data score for Feed of 5 out of 10.

Escapes
A range of peer-reviewed and grey literature is available that documents the introductions of tilapia into Taiwan, which began about 80 years ago in the 1940s; tilapia have subsequently become a naturalized species. Likewise, an array of academic literature documents the geological and climate characteristics of Taiwan, which influence the potential for escapes to occur. Typical pond management practices were described through communications with experts and farmers, including the implementation of escape prevention measures, which are also referenced in ASC audit reports pertaining to the sector. There are evidently no requirements for escapes to be reported to the authorities, so official escape statistics are unavailable; however, indirect evidence, such as newspaper reports after extreme weather events, provides insights into the continuing risk of such escape events occurring.

It is evident that resident populations of tilapia have become well established over the many decades since they were introduced into Taiwan, and they are now part of the local fish fauna. Literature notes that, globally, nonnative fish species have often been introduced into new habitats without any preliminary scientific evaluation of the existing aquatic ecosystems, as is the case in Taiwan. Consequently, determining the environmental impacts of introductions often relies on inference; in addition, it is challenging to separate such impacts from other concurrent anthropogenic influences. Although no data regarding the ecological impacts of escaped farmed tilapia in Taiwan were identified, communications with sector experts attest that tilapia is now regarded as a common fish species in Taiwan's natural environment and is generally not considered to present an environmental concern. There are no specific data on the volume of tilapia escapes; however, it is evident that, as a nonnative species, tilapia is not considered to present a genetic risk to local fish populations. Furthermore, in instances where farmed stocks are nonnative and they have become fully ecologically established in the production region as a result of aquaculture more than 10 years ago, the Seafood Watch Standard categorizes this as a low–moderate risk; as a data point, this historic introduction of tilapia is well documented in the literature available. Therefore, despite the lack of specific escape information, the data available to inform this criterion, in terms of escape risk and potential competitive or genetic impacts on wild fish populations, are considered to be moderate-high, which warrants a data score of 7.5 out of 10 for Escapes.

Disease
The literature notes that, globally, there has been limited research into the dynamics and impacts of disease transmission from aquaculture facilities into the surrounding ecosystem. Data on this topic were also found to be lacking in Taiwan, so a risk-based assessment methodology was employed. Conversely, there is a large body of global literature that discusses the diseases that affect tilapia culture worldwide, and some useful data specific to Taiwan were identified. Although communications with experts generally attest that the prevalence of disease in the Taiwanese tilapia sector is believed to be low, this could not be robustly confirmed because no official data on this were forthcoming, aside from data on the minimal impact of tilapia lake virus (TiLV), which is a notifiable disease. Likewise, from conversations with farmers and experts, it was ascertained that streptococcal infection is the disease of most concern to the tilapia sector in Taiwan, although no official data to confirm this were available. Concerning general farm practices and the implementation of control measures for disease and on-farm biosecurity, these were explained both through peer-reviewed literature and personal communications with experts. Regarding the regulatory framework that has been implemented to mitigate disease spread, details of the various statutes and responsible government departments and divisions are readily available online as are the relevant government acts, which are accessible via the MOJ Laws & Regulations Database and the FAOLEX Database. Overall, the data available are considered to be

moderate, in terms of assessor confidence in their ability to assess the impact of on-farm disease on wild species, which results in a data score for Disease of 5 out of 10.

Source of Stock
A large body of historic and contemporary literature documents the development of tilapia aquaculture, and it is evident that the sector has had no reliance on wild stocks for many decades. For example, peer-reviewed literature from the 1980s discusses technical advancement in hatchery technologies, including the production of new tilapia strains and hybrids developed to enhance specific traits such as high fecundity, rapid growth, cold resistance, and saltwater tolerance. It is also evident in the literature that, since the mid-20th century, researchers in Taiwan have been at the forefront of R&D efforts to refine and improve tilapia propagation and culture techniques, including the development of broodstock programs. Communications with Taiwan's Fisheries Research Institute also illustrated Taiwan's ongoing efforts into the refinement of tilapia breeding techniques and clarified the commercial strains of tilapia being farmed. The aforementioned data sources provide a high level of confidence in their ability to assess the source of farm stock used by the tilapia sector in Taiwan; hence, the data score for Source of Stock is 10 out of 10.

Wildlife Mortalities
Because there are no specific requirements for the monitoring or reporting of wildlife interactions on tilapia farms, official data on the frequency and impact of these are lacking. But communications with experts and farmers concur that birds are the type of wildlife that most frequently visits pond farms; these key informants also attest that predation is minimal and that farmers are not permitted to shoot at or set traps to capture these animals. It is also evident from these communications, as well as numerous peer-reviewed and grey sources of literature, that Taiwan is recognized internationally as an important habitat for birds and that both migratory and local species of birds rely on its wetlands, including artificial wetlands such as aquaculture ponds. Although there are apparently no data available to document wildlife interactions on farms, there are many academic papers that discuss the important role that ponds play in terms of providing habitat to birds, particularly overwintering birds. Even though a lack of data concerning wildlife mortalities on tilapia farms cannot be interpreted as evidence of no impact, it is noteworthy that, of the numerous academic papers identified that consider interactions between birds and aquaculture ponds in Taiwan (with a primary focus on how artificial ponds can best be managed to provide benefits to birds), none of these refers to any concerns regarding bird mortalities occurring on pond farms.

To ensure the protection of its diverse habitats and species, Taiwan has numerous regulations in place, which are readily available online on the MOJ Laws & Regulations and the FAOLEX Databases. It is evident that both vulnerable and general wildlife species are protected by law: the hunting and killing of vulnerable species is strictly prohibited, and though a permit to hunt general wildlife may be approved in certain circumstances, this is typically not an activity that would be permitted on a tilapia farm. Because farm-level data concerning wildlife interactions and mortalities are not collected, the data available do not provide a high level of confidence in their ability to assess the impact of on-farm wildlife interactions. But it must be considered that many literature sources are available that discuss the importance of aquaculture ponds to birds, without noting any concern for related mortalities. Thus, the data score for Wildlife Mortalities is considered to be moderate, which warrants a score of 5 out of 10.

Introduction of Secondary Species

This criterion draws on a combination of academic literature and expert communications. Robust academic sources provided insights into Taiwan's hydrological characteristics and the typical impacts of rapid water flow on ecological distinctiveness. Communications with experts, such as insights from Taiwan's Fisheries Research Institute and industry professionals, contributed practical knowledge about biosecurity measures in hatcheries and the minimal risk posed by the local fry production practices. Together, these sources provide a reliable foundation for evaluating this criterion; therefore, the data score for Introduction of Secondary Species is 10 out of 10.

Conclusions and Final Score

Data quality and availability vary somewhat across the topics and criteria reviewed. Data concerning the general categories of Production and Management both received a moderate–high score of 7.5 out of 10, reflecting the relevance and breadth of the academic literature and expert communications available, despite some gaps in granularity.

Confidence in the data's ability to robustly describe the ecological impact reviewed in each criterion was assessed as moderate for six of the nine criteria discussed, with scores of 5 out of 10 for Effluent, Habitat, Chemical Use, Feed, Disease, and Wildlife Mortalities. Of note, assessments for Effluent, Disease, and Wildlife Mortalities are predicated on risk-based methodologies due to limited specific data. In the case of Chemical Use, although direct information on the types and quantities of substances applied was limited, expert input, publicly available regulations, and the low-discharge nature of the production system provided sufficient context to support a moderate data score.

The Source of Stock category stands out with a high data quality score of 10 out of 10, supported by extensive historical and contemporary literature. Likewise, the exceptional criterion, Introduction of Secondary Species, scored 10 out of 10. Escapes has a moderate–high score of 7.5 out of 10, relying on indirect evidence and expert communications in the absence of official reporting requirements.

The variability in data quality across these categories reflects the challenges in obtaining comprehensive, sector-specific information, with many assessments relying on a combination of academic literature, expert communications, and publicly available government resources. The final score for Criterion 1—Data Quality and Availability is 6.6 out of 10.

Criterion 2—Effluent

Impact, unit of sustainability and principle

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

Effluent Risk-Based Assessment		
Effluent parameters	**Value**	**Score**
F2.1a Waste (nitrogen) production per of fish (kg N ton^{-1})	60.688	
F2.1b Waste discharged from farm (%)	16.00	
F2 .1 Waste discharge score (0–10)		9
F2.2a Content of regulations (0–5)	5	
F2.2b Enforcement of regulations (0–5)	3	
F2.2 Regulatory or management effectiveness score (0–10)		6.00
C2 Effluent Final Score (0–10)		**8.00**
Critical?	NO	**GREEN**

Criterion 2 Summary

Because the effluent data quality and availability were not considered robust enough to fully understand the effluent impacts of tilapia production in Taiwan, a risk-based assessment approach was used. Based on this approach, and considering the typical feeds applied, it was estimated that the total input of nitrogen per MT of production equals 83.088 kg, which is reduced to 60.688 kg once the nitrogen in harvested tilapia is discounted. The amount of nitrogenous waste discharged from a typical production system was extrapolated from this estimate, while accounting for the particular water and pond management practices adhered to by farmers. Because of water scarcity issues, Taiwanese tilapia farmers mainly rely on the collection of rainwater to fill their ponds. This situation necessitates careful conservation of water resources, so farmers typically designate one or two of their ponds as reservoirs and recirculate water between these and their culture ponds via submerged pipes. Although water exchange rates in the culture pond are typically less than 1% per day, most water exchanges occur within the farm boundary, and discharges to the external environment occur quite infrequently. At harvest, farms will discharge water from ponds into reservoirs where water will be held and reused. Consequently, it is estimated that, of the small amount of water released from farms, 9.71 kg N/MT is discharged from ponds (i.e., 16% of the total). Based on these findings, the score for Factor 2.1 is 9 out of 10.

The Fisheries Agency is responsible for overseeing and regulating aquaculture governance in Taiwan, while the Ministry of Environment (MOENV) is the central authority for environmental matters, including water resource and effluent management. A key piece of legislation is the Water Pollution Control Act (WPCA), which establishes the framework for monitoring and managing effluents from all sources, including aquaculture. The act mandates that enterprises above a certain size threshold must obtain discharge permits and monitor and report their effluents. While most tilapia farms in Taiwan, ranging in size from 1.5 to 6 ha, fall below this threshold and are not subject to these specific requirements, they are still encompassed within the area-based, cumulative management framework established by the act. This framework ensures that effluent impacts, including those from smaller farms, are monitored and managed collectively to maintain compliance with water quality standards. This approach ensures that any breaches in water quality are detected through continuous government monitoring, thus effectively managing the collective impact of multiple industries, including aquaculture. As a result, Taiwan's management system is considered comprehensive, reflecting a high level of regulatory coordination. The content of Taiwan's effluent management system for tilapia production receives a score of 5 out of 5 for Factor 2.2a. This score reflects the effective integration of water quality monitoring, the application of effluent limits aligned with the carrying capacity of receiving waters, and the cumulative approach that ensures that broader water quality standards are met despite the exemption of small farms from direct regulation.

Under the WPCA, authorities at all levels can inspect facilities based on pollution reports and the specific needs of different enterprises; if serious violations are found, results and sanctions are publicized. Although most tilapia farms are small and exempt from WPCA monitoring and reporting requirements, local authorities still monitor water quality and use total quantity control methods if standards are not met. Farmers can also access free water quality analysis at local government fish quarantine centers. MOENV reports that there has never been a case of total quantity control being implemented for fish farms, and communications with sector experts suggest that effluents from tilapia farms are not considered a cause for concern. The absence of reported incidents related to tilapia pond effluents lends credence to the efficacy of the enforcement of related management measures, even though tilapia farms are typically only monitored indirectly. This results in a moderate score of 3 out of 5 for Factor 2.2b. Factor 2.2a (5 out of 5) and Factor 2.2b (3 out of 5) combine for a final score of Factor 2.2 of 6 out of 10. The scores for Factors 2.1 (9 out of 10) and 2.2 (6 out of 10) combine for a final score of 8 out of 10 for Criterion 2—Effluent.

Justification of score

In common with other types of aquaculture production, effluents from tilapia ponds have the potential to pollute the water bodies into which they are discharged; this potential arises particularly as a result of three factors: nutrient loading, the accumulation of suspended solids, and oxygen demand. The aquaculture-generated nutrients of most concern are nitrogen and phosphorus, as these have the potential to cause eutrophication; whereas suspended solids—derived from feces, uneaten feed, plankton, and mineral particles—combined with low oxygen levels can have a negative impact on benthic habitats and biodiversity. Unlike some other types of production systems, pond culture's water is typically retained in the culture area for a considerable time, so natural biological processes can assist in the assimilation of wastes that are generated during production (Boyd 2004). Various measures can be implemented to help mitigate nutrient release, such as optimizing feed composition, incorporating functional feed ingredients, and managing fish gut health. Furthermore, the employment of mechanical and biological filtration principles, such as using sedimentation and settling ponds, can help mitigate downstream pollution by reducing the quantity of nutrients and suspended solids discharged (Nathanailides et al. 2023). The literature notes that tilapia farming is widely regarded as having minimal environmental impacts in commercial settings, with fish primarily fed on vegetative materials. In addition, although effluent discharge from intensive production facilities can be a concern, many tilapia farms in global settings integrate irrigation systems, converting these wastes into valuable fertilizer (Bohnam 2022).

Risk-based assessment
Because the effluent data quality and availability is moderate (i.e., the score for the Effluent category in Criterion 1—Data is 5 out of 10), 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. This is followed by a review of the content and effectiveness of the regulatory system in managing wastes from multiple farms, which is used to assess the potential cumulative impacts from the industry as a whole.

Factor 2.1: Waste discharge per metric ton of fish
This factor calculates the amount of waste nitrogen produced by the farmed tilapia (Factor 2.1a), and then the percentage of that waste that is discharged from the farm site (Factor 2.1b). Nitrogen is used as a proxy indicator of waste because of the ease of calculation based on the greater availability of data for the nitrogen in the protein component of feed or as fertilizer.

Factor 2.1a: Biological waste production per metric ton of fish
As explored in Criterion 5—Feed, the average protein content of tilapia on-growing diets used in Taiwan is calculated to be 28.85%—taking into account the 2018 global eFCR estimate of 1.7 by Tacon et al. (2022), the findings by Mengistu et al. (2020) of FCRs ranging from 1.5 to 2.5 for pond-farmed tilapia, and expert communications from the Taiwanese tilapia sector indicating local eFCRs between 1.6 and 2.0 (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm), with some farmers reporting 1.67 (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). Given this insight, an average eFCR of 1.8 has been selected (the mean of the eFCR range of 1.6–2.0) for the following calculations. Because fertilizer is not used, the fertilizer nitrogen input per MT of fish produced is calculated to be zero. The literature notes that the protein content of harvested whole fish is 14% (Boyd et al. 2007), so this value has been used in the ensuing calculations. In addition, the nitrogen content of protein has been included at a fixed value of 16% for calculation purposes, per the guidance in the Seafood Watch Standard for Aquaculture. The following shows how these factors have been used to calculate the amount of waste nitrogen produced by farmed tilapia in Taiwan.

Taiwan tilapia produced in ponds: Average values
a) Protein content of feed = 28.85%
b) Economic Feed Conversion Ratio (eFCR) = 1.8
c) Fertilizer nitrogen input per MT fish produced = 0 kg N/MT
d) Protein content of harvested whole fish = 14% (Boyd et al. 2007)
e) Protein nitrogen content factor = 0.16 (this is a fixed value; protein is 16% nitrogen)

From these it can be calculated that:
Nitrogen input per MT of fish produced = $(a \times 0.16 \times b \times 10) + c$ = 83.09 kg N/MT
Harvested nitrogen per MT of fish produced = $(d \times 0.16 \times 10)$ = 22.4 kg N/MT
Waste nitrogen produced per MT of fish = N input – harvested N = 60.69 kg N/MT

Thus, the Factor 2.1a score, which is an estimate of the nitrogen waste produced per metric ton of farmed tilapia, is 60.69 kg N/MT.

Factor 2.1b: Production system discharge
The amount of nitrogenous waste that is discharged from a production system is influenced by various natural processes in the pond, by any water treatment measures, and particularly by the water exchange rate—a factor that is of particular relevance to the situation in Taiwan.

As explored in the Introduction, the water exchange rates used on tilapia farms in Taiwan are quite low and typically average less than 1% per day. Water conservation is a priority for tilapia farmers in Taiwan because there is a shortage of freshwater in the country (Cheng et al. 2022). While the government has established freshwater distribution systems in inland aquaculture areas, which farmers can access periodically, farmers primarily rely on rainwater, which is collected, stored, and recirculated between interconnected ponds through underground pipes. To conserve water, farmers typically use one or two adjacent ponds as reservoirs; this closed-loop system minimizes external water exchange, and water is rarely discharged. Even when ponds are drained at the end of the season, culture pond water is transferred into adjacent ponds rather than being released (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Water is discharged to the external environment only occasionally and in particular situations, such as to prevent overfilling of ponds ahead of typhoons. The heavy rain that accompanies typhoons provides farmers with an opportunity to replenish their water supplies, but if a farmer's ponds are already at capacity, it will be prudent to drop the level of the pond water in advance to prevent overspilling. When this happens, water will be discharged into public drainage channels (Figure 8). But most of the time, pond farms in Taiwan typically operate as near-zero-discharge systems, and the daily exchange rate is so low that it primarily makes up for evaporative loss and does not typically involve a commensurate daily discharge (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

After harvest, tilapia ponds in Taiwan are drained and left empty for 2–3 months to rejuvenate. Regulations prohibit the removal of subsoil, so farmers manage sludge by excavating and drying it in place. To maintain pond functionality, they may treat the exposed soil with lime or zeolite powder. Once the process is complete, the ponds are refilled using water from adjacent ponds in preparation for the next production cycle (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & October 2024 pers comm).

Overall, the tilapia industry in Taiwan is considered to be a zero-exchange pond system over multiple cycles, resulting in a production system discharge adjustment of 0.24. It is acknowledged that on occasion (i.e., high rainfall events), farms may discharge water into

Figure 8: A typical Taiwanese aquaculture pond with a discharge channel on the left. (Image courtesy of Google Earth. Google, 2024, https://earth.google.com).

surrounding waterways in preparation for high rainfall events, but this appears to be only during exceptional circumstances. In addition, water that is discharged at harvest is circulated to retention ponds, and will be later reused, resulting in an additional reduction of –0.08. Despite being considered zero-exchange systems, it is acknowledged some water will be discharged, and it is estimated that 0.16, or 16% of nitrogen, is released when discharges periodically occur from Taiwanese ponds, so the score for Factor 2.1b is 0.16.

The combination of scores for Factor 2.1a (60.69 kg N/MT) and Factor 2.1b (0.16) means that an estimated 9.71 kg N per MT is discharged from ponds (i.e., 16% of the total), which results in a Factor 2.1 final score of 9 out of 10.

Factor 2.2: Management of farm-level and cumulative impacts

Factor 2.2a: Content of effluent management measures

Agencies
Although the Fisheries Agency plays a pivotal role in overseeing and regulating aquaculture governance by establishing and enforcing policies, the Ministry of Environment (MOENV) is Taiwan's central competent authority for matters related to the environment, including the management of water resources and effluents.

Legislation and regulations pertaining to aquaculture effluents
The Basic Environment Act, which is under the remit of MOENV, serves as the foundational law for environmental protection in Taiwan. Article 3 of this act emphasizes the equal consideration of environmental protection in economic, technological, and social developments, with priority for the long-term interests of the nation. To fulfill this mandate, the Environmental Impact Assessment (EIA) Act was established as a subsidiary legislation, incorporating the "polluter pays" principle and providing a systematic approach to prevent and mitigate adverse impacts of development activities, including those related to aquaculture.

While MOENV is responsible for the implementation of numerous regulations enacted to address the various types of environmental pollution that may occur in Taiwan, a key piece of legislation concerned with the management of water resources is the Water Pollution Control Act[26] (WPCA), which seeks to prevent and control water pollution, ensure the cleanliness of water resources in order to protect ecological systems, and improve the living environment and public health. The WPCA is supported and implemented by an array of standards, rules, and regulations. Because the WPCA is the key piece of legislation concerned with pollution control, more detail follows.

Water Pollution Control Act

The MOENV website notes that the main cause of water pollution in rivers, lakes, and other water bodies occurs when the discharge of effluents (industrial wastewater and sewage) exceeds the carrying capacity of the water body into which they are discharged. To address such issues and reduce water pollution, the Environmental Protection Administration (EPA)—the forerunner of MOENV—adopted a total quantity control method for sections of rivers that were more heavily polluted, whereby the amount of polluted water that can be released into the section each day is based on the carrying capacity of the specific water body.[27] Since 2002, MOENV/EPA has coordinated a national environmental water quality monitoring program to establish a long-term dataset of water quality variations, which includes the surveillance of river basins, reservoirs, and regional groundwater monitoring wells. The collection and analysis of these data help to improve water body management strategies and pollution control measures and assist with the adaptation and implementation of pollution prevention and control regulations.[28]

Definition of aquaculture enterprises that are governed by the WPCA

Article 2, VII of the WPCA defines the enterprises that fall within the remit of the WPCA as "companies, factories, mines and quarries, substitute wastewater treatment enterprises, livestock enterprises and other enterprises designated by the central competent authority," which includes fish farms (Ministry of Environment September 2023 pers comm). Communications with MOENV clarify that the control regulations of the WPCA are applied differently, depending on the scale of the enterprise and whether it is located in a tap water[29] control area or not. Note that an area defined as a "tap water quality and volume protection area" is designated as such by the Water Resources Agency[30] (WRA), which is an administrative agency under the Ministry of Economic Affairs (MOEA); this designation is done in accordance with the provisions of the Water Supply Act (WSA),[31] which seeks to ensure the provision of a sufficient and hygienic water supply (Huang, Shih-Pin, Water Resources Management Division, Water Resources Agency, MOEA December 2023 pers comm). Accordingly, aquaculture enterprises of various scales and characteristics are subject to the provisions of the WPCA as follows:

For fish farms located in a tap water quality and volume protection area, the WPCA applies to those in which:

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[26] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC040421
[27] https://www.moenv.gov.tw/en/F2DFFC5952173924
[28] https://www.moenv.gov.tw/en/6B6F32A5516C8FA7
[29] As defined in the Water Supply Act (WSA), the term "tap water" refers to sanitary public water that is supplied through pipes or other facilities.
[30] https://eng.wra.gov.tw/Default.aspx
[31] https://law.moea.gov.tw/EngLawContent.aspx?lan=E&id=10589&KW=tap+water

- The breeding area of combined fishing and stock farming business[32] reaches more than 0.25 hectares.
- The breeding area of freshwater fish ponds reaches more than 1.5 ha.
- The breeding area of saltwater fish ponds reaches more than 3 ha.

For farms that are not located in a tap water quality and volume protection area, the WPCA applies to those in which:

- The breeding area of combined fishing and stock farming business reaches more than 0.5 ha.
- The breeding area of freshwater fish ponds reaches more than 3 ha.
- The breeding area of saltwater fish ponds reaches more than 6 ha.

Because of a shortage of freshwater in Taiwan, the management of water resources is a priority for the government, which encourages the use of saltwater/brackish-water for aquaculture production. In Taiwan, most aquaculture takes place on land rather than in the sea, and therefore is referred to as inland aquaculture, of which there are two main types. The term “freshwater fishponds” (淡水魚塭) refers to ponds located in inland areas, which only have access to freshwater; whereas in areas immediately next to the coast, ponds are filled with either brackish-water or seawater, so these coastal ponds are called “saltwater fish ponds”
(鹹水魚) (Cheng 2017). Thus, it is evident that the WPCA applies to freshwater tilapia farms over 1.5 ha and brackish-water farms over 3 ha when these are located in a tap water control area; whereas in non-tap water control areas, the WPCA applies to freshwater farms over 3 ha and brackish-water farms over 6 ha. If the scale of a fish farm falls below these respective enterprise sizes, then it is not subject to the monitoring and reporting requirements of the WPCA (Ministry of Environment November 2023 pers comm). In this regard, it is relevant to note that most tilapia farms are small scale, averaging around 1.5 to 6 ha, with most in the 1–3 ha range (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Thus, it would appear that many farms fall below the size threshold defined by the WPCA; however, further insight concerning the percentage of tilapia farms that fall directly within the scope of this act was not readily available.

Area-based, cumulative management approach of the WPCA

Most tilapia farms may not individually be subject to the monitoring and reporting requirements of the WPCA, but because the majority of these farms are small and fall below the stipulated size threshold, an area-based, cumulative approach to water pollution management is implemented by this act. Thus, any breaches of effluent standards in tilapia farming areas will still be detected through ongoing government monitoring. Experts note that, although small farms are not legally required to adhere to these standards, the availability of government-established water quality guidelines enables farm operators to independently test their water quality to ensure that it meets acceptable levels (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm).

Communications with MOENV inform that the ministry conducts monthly water quality monitoring at 303 stations across 54 river basins throughout Taiwan. This monitoring program is designed to track changes in watershed water quality and to provide essential data for refining environmental and basin

[32] Note that this reference to “combined fishing and stock farming business” refers to enterprises that combine the simultaneous production of both livestock and fish (Ministry of Environment November 2023 pers comm).

management strategies. Monitoring stations are strategically located to represent diverse areas and capture mixed effluent from residential, industrial, and livestock sources. Although these stations do not exclusively focus on specific drainage canals and waterways related to aquaculture, their representative locations allow for significant changes in water quality to be captured in monthly reports, which can be addressed with appropriate follow-up actions, if needed. These water quality monitoring data, from both the ministry and local governments, are publicly accessible via the National Environmental Water Quality Monitoring Information Network[33] (Ministry of Environment, November 2024 pers comm).

Article 9 of the WPCA mandates that "total quantity control methods" for the discharge of wastewater or sewage must be implemented in the following situations:

- Those circumstances in which the use of effluent standards still fails to meet water quality standards for said water body due to the density of enterprises or sewage systems;
- Those circumstances in which the competent authority determines that special protection is required.

Using this approach, the identified impaired water bodies are made subject to greater scrutiny, monitoring, and remediation activities.

Article 10 of the WPCA goes on to state that competent authorities at all levels shall install water quality monitoring stations and issue regular, official announcements pertaining to these monitoring data, adopting appropriate response measures as needed. The sampling frequency adhered to by monitoring stations shall be determined in accordance with the specific pollution characteristics identified, and shall be on a monthly or seasonal basis, with a provision to increase sampling frequency when necessary. The frequency and location of water sampling will consider the geographic characteristics of each , as well as the quality and current situation of the water bodies; sampling frequency shall also be revised regularly by competent authorities at all levels according to each year's water monitoring report and the assessed need for water pollution remediation.

Article 14 of the WPCA stipulates that enterprises regulated by the WPCA must obtain a discharge permit and that they shall obey the items registered on the document while discharging. Furthermore, aquaculture enterprises listed under the WPCA shall comply with the relevant laws and regulations, including testing and reporting requirements. As stipulated in Article 22 of the WPCA Act, "Enterprises or sewage systems shall, in accordance with the format, content, frequency and method of competent authority regulations, report the operation of wastewater and sewage treatment facilities, analysis of effluent water quality and water volume, power consumption records, and other documents related to wastewater and sewage treatment to the special municipality, county or city competent authority. [The] Central competent authority should determine testing and reporting items for each industry type according to the characteristics of their wastewater; special municipalities, counties or cities competent authority may, based on discharge circumstances, increase testing and reporting items." Hence, MOENV advises that all aquaculture enterprises that fall within the remit of the WPCA are required to provide regular water quality reports to their respective local competent authority, in accordance with the format, content, frequency, and method specified by that authority (Ministry of Environment, September 2023 pers comm).

[33] https://wq.moenv.gov.tw/EWQP/zh/Default.aspx

In accordance with Article 84 and 86 of the Water Pollution Control Measures and Test Reporting Management Regulations[34] (including the attachment for Enterprise or Sewage System Test Report Items), aquaculture enterprises that are subject to the WPCA must include the following water quality parameters in their monitoring regimes: the hydrogen ion concentration index (pH), water temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS). The stipulated frequency of effluent water quality testing is once every 3 months or once every 6 months, depending upon the amount and nature of the wastewater generated by the enterprise. Currently, Taiwan's aquaculture effluent water regulations are BOD < 30 mg/L, COD < 100 mg/L, and SS < 30 mg/L[35] (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Discharged wastewater must meet the discharge water standards before being discharged (Ministry of Environment, September 2023 pers comm). Of note, if the aquaculture enterprise is located in a tap water quality and quantity protection zone, orthophosphate control limits for discharged water will also apply (Ministry of Environment, September 2023 pers comm). The Surface Water Body Classification and Water Quality Standards,[36] which are used to assist in the implementation of the WPCA, provide classifications of terrestrial and marine surface water bodies, to specify the scope of application and relevant environmental standards of water bodies on the basis of their characteristics.

Effluent standards for mixed industries
MOENV's Effluent Standards[37] consider the cumulative impact of different industries that operate in an area and outline how wastewater from multiple industries or mixed processes should be treated and monitored. Article 8 states: "In the event that enterprises, sewage systems, or building sewage treatment facilities belong to two or more industry types within the scope of the Standards or to a single industry type but have different processes, the combined treatment and discharge of wastewater shall conform to the effluent standards for each of the concerned industry types. If different control limits are available for the same control item, the stricter limit shall apply. In the event that the flow of wastewater from one of the industry types in the preceding paragraph is at least 75% of the total flow of wastewater, and that independent and exclusive cumulative water measuring facilities have been installed, an application may be submitted to the competent authority for the use of the effluent standards of concerned industry type as the basis of control for all common items".

Complementary enforcement mechanisms: certification schemes and monitoring support
Various complementary enforcement mechanisms, despite not being direct regulatory measures, support Taiwan's effluent management efforts. Certification schemes such as the Traceable Agricultural Product (TAP) System, based on the Taiwan Good Agricultural Practices (TGAP), which are aligned with the European Good Aquaculture Practices (GAP), require participants to monitor and maintain water quality data, thus indirectly aiding compliance. Though the government does not mandate regular water quality monitoring for all tilapia farms, those engaged in certification schemes independently conduct pond water quality monitoring two to three times a month. Currently, around 1,000 farmers are part of this program (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm), although the proportion of these that farm tilapia is unclear. In addition, 2,000 MT of Taiwanese tilapia is currently ASC certified (Hans Van Someren Greve, Aquaculture Stewardship Council January 2024 pers comm). More information on certification schemes is included in Appendix

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[34] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=O0040054
[35] https://faolex.fao.org/docs/pdf/tw164124.pdf
[36] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC164022/
[37] https://oaout.moenv.gov.tw/law/EngLawContent.aspx?lan=E&id=217

4—Certification and Assurance Schemes for Aquaculture. Also, farmers can access free water quality analysis services at government fish quarantine stations, further encouraging voluntary compliance. These initiatives, while not part of formal enforcement, enhance the overall efficacy of water quality management by fostering proactive monitoring among farmers.

Summary and assessment of the content of effluent management measures

The Seafood Watch Standard for Aquaculture considers the content of management measures to be comprehensive when an area-based, cumulative management system is in place for multiple industries including aquaculture, with effluent limits set for aquaculture in combination with other industries and when limits are based on the carrying capacity of the receiving waterbody. From the information available, it would appear that the management measures in place in Taiwan meet this definition. An area-based, cumulative management system for managing effluent discharge across industries, including aquaculture, is in place, with discharge limits aligned to the carrying capacity of receiving water bodies. This is evident from the implementation of the Water Pollution Control Act (WPCA), which adopts a total quantity control method for heavily polluted river sections, setting effluent limits based on the specific carrying capacity of those water bodies. This system ensures that water quality impacts from multiple industries, including aquaculture, are managed collectively rather than individually.

Although smaller tilapia farms are exempt from direct compliance requirements due to size thresholds, the cumulative management approach remains effective. It is supported by the Ministry of Environment's comprehensive water quality monitoring program, which tracks changes in watershed quality through 303 strategically placed monitoring stations. These stations capture aggregate impacts, ensuring that broader effluent standards are met and any significant water quality issues are identified and addressed. This system integrates data from various sources to inform environmental strategies, emphasizing the carrying capacity of water bodies as a central principle in effluent regulation. Thus, the content of Taiwan's effluent management system for tilapia production is considered to be comprehensive, and the final score for Factor 2.2a: Content of effluent management measures is 5 out of 5.

Factor 2.2b: Enforcement of effluent management measures

Regulatory oversight: inspections and enforcement

Effluent management for tilapia farms involves multiple agencies. While the Fisheries Agency specifically oversees the aquaculture sector, MOENV has overall responsibility for the control of environmental pollution and the enforcement of water quality management measures across all sectors. As discussed, the main regulation in this regard is the WPCA, according to which (Article 26) competent authorities at all levels may send personnel to inspect facilities. Communications with MOENV clarify that, in practice, the frequency with which respective competent authorities conduct inspections is dependent upon the content of pollution reports as well as the specific needs of individual enterprises (Ministry of Environment September 2023 per comm).

Enforcement results: water quality trends

As stipulated in the WPCA, and noted in Factor 2.2a, if the water quality in a receiving water body fails to meet specified standards, then total quantity control measures are implemented. Despite this provision, the Ministry of Environment (MOENV) has confirmed that no such measures have been applied to fish farms to date (Ministry of Environment September 2023 pers comm); hence, water quality monitoring results indicate that all water bodies occupied by the sector are within the specific standards, as described in the WPCA. Although effluents from land-based fish farms have evidently not been identified as a significant source of pollution, data indicate that implementation of the WPCA has been effective. The MOENV website notes that, while improvements still need to be made, the water quality of Taiwan's 50 major rivers has improved gradually over time. Monitoring has shown that the amount of severely polluted river sections has dropped from 14.0% in 2002 to 3.7% in 2021, with the number of monitoring stations detecting severe pollution decreasing from 66 in 2002 to 9 in 2021.[38] Presently, 11 rivers are selectively targeted with accelerated pollution remediation measures. MOENV notes that the main pollution sources are industrial and domestic wastewater as well as effluents from animal farming,[39] particularly that of pigs and cattle.[40]

Transparency and reporting
MOENV provides publicly accessible water quality monitoring data through its Environmental Water Quality Information website.[41] This platform offers monthly data for rivers, reservoirs, and groundwater, with the ability to search results by specific water bodies and geographic regions. An Annual Report on National Environmental Water Quality is also published, summarizing monitoring outcomes and trends. This report includes compliance rates for key water quality indicators, such as heavy metals and nutrient levels, and offers an overview of the status of Taiwan's major water resources. Historical data and monitoring outcomes are systematically compiled and made available, thus facilitating assessments of water quality over time and supporting research and management objectives. During the course of MOENV's inspections, if any serious violations are identified, they will be publicly disclosed, along with any penalties issued (Ministry of Environment, September 2023 pers comm).

Pursuant to the Freedom of Government Information Act, the EPA, as MOENV was previously known, established the Pollutant Release and Transfer Register Online System. If the activities of any enterprise give rise to water or air pollution, such incidents must be reported, as must any usage of toxic substances or chemicals of concern. These reports are then made publicly available via the online portal, together with details of any punitive measures taken or fines levied as a result of noncompliance.[42] No reports pertaining to effluent pollution arising from tilapia farms were identified; furthermore, key informants noted that they were unaware of the occurrence of any such issues (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm) (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

<u>Summary and assessment of the enforcement of effluent management measures</u>
According to the Water Pollution Control Act (WPCA), authorities at all levels can inspect facilities, and these inspections are based on pollution reports and specific enterprise needs; if serious violations are found, results and sanctions will be publicized. MOENV reports that there has never been a case of total quantity control being implemented for fish farms. Although most tilapia farms fall below the defined size threshold of the WPCA and are therefore exempt from its monitoring and reporting requirements, they are still indirectly monitored through the act's area-based, cumulative approach, which tracks the collective impact of farm operations and other industries. Note also that no reports of effluent pollution from tilapia farms have been detected in Taiwan's Pollutant Release and Transfer Register Online System, and sector experts who have been consulted are unaware of any significant effluent pollution issues arising from tilapia farms. The absence of reported incidents related to tilapia pond effluents

[38] https://www.moenv.gov.tw/en/1551A904BB942675/b28203ed-c7ac-48eb-80ed-81143624315b
[39] https://www.moenv.gov.tw/en/DEA1917828AADEA0
[40] https://www.moenv.gov.tw/en/EA1F2DC01EED7FDD
[41] https://wq.moenv.gov.tw/EWQP/en/Default.aspx
[42] https://env.moenv.gov.tw/en/Issue/Index/5bf853ea-8342-4acc-b40f-b3a3a3a93cf2

lends credence to the efficacy of the enforcement of related management measures, even though tilapia farms are typically only monitored indirectly. The Seafood Watch Standard for Aquaculture considers the enforcement of effluent management measures to be moderate in situations where enforcement organizations are identifiable and active but have limitations in resources or activities that reduce effectiveness, and where there are some gaps in monitoring or compliance data; this description is a good fit for the situation in Taiwan. Therefore, the final score for Factor 2.2b: Enforcement of effluent management measures is 3 out of 5. Factor 2.2a (5 out of 5) and Factor 2.2b (3 out of 5) combine for a final score for Factor 2.2 of 6 out of 10.

Conclusions and Final Score

Because the effluent data quality and availability were not considered robust enough to fully understand the effluent impacts of tilapia production in Taiwan, a risk-based assessment approach was used. Based on this approach, and considering the typical feeds applied, it was estimated that the total input of nitrogen per MT of production equals 83.088 kg, which is reduced to 60.688 kg once the nitrogen in harvested tilapia is discounted. Drawing from this estimate, the amount of nitrogenous waste discharged from a typical production system was extrapolated, taking into account the particular water and pond management practices adhered to by farmers. Because of water scarcity issues, Taiwanese tilapia farmers mainly rely on the collection of rainwater to fill their ponds. This situation necessitates careful conservation of water resources, so farmers typically designate one or two of their ponds as reservoirs and recirculate water between these and their culture ponds via submerged pipes. Though water exchange rates in the culture pond are typically less than 1% per day, most water exchanges occur within the farm boundary, and discharges to the external environment occur infrequently. At harvest, farms will discharge water from ponds into reservoirs where water will be held and reused. Thus, it is estimated that 9.71 kg N/MT are discharged from ponds (i.e., 16% of the total), which results in a final score for Factor 2.1 of 9 out of 10.

Taiwan's effluent management system, the cornerstone of which is the Water Pollution Control Act (WPCA), aligns with the Standard's definition of being comprehensive through its area-based, cumulative approach. This system collectively manages effluent impacts from multiple industries, including aquaculture, thus ensuring that discharge limits are based on the carrying capacity of water bodies. The WPCA supports this by setting limits for polluted river sections and monitoring water quality through 303 stations to capture cumulative effects. Although tilapia farms are typically exempt from direct compliance due to their small size, the broader system effectively manages water quality across all sectors, justifying a Factor 2.2a score of 5 out of 5.

Enforcement of effluent management measures for tilapia farms in Taiwan is carried out by multiple agencies, including the Fisheries Agency and the Ministry of Environment (MOENV). While small farms are exempt from direct regulation under the WPCA, they are still indirectly monitored through the act's area-based, cumulative approach, which tracks the collective impact of farm operations and other industries. The absence of reported incidents related to tilapia pond effluents lends credence to the efficacy of the enforcement of related management measures, even though tilapia farms are typically only monitored indirectly. As a result, the enforcement of effluent management measures is considered to be moderate. This results in a score of 3 out of 5 for Factor 2.2b. Factor 2.2a (5 out of 5) and Factor 2.2b (3 out of 5) combine for a final score of Factor 2.2 of 6 out of 10. The scores for Factor 2.1 (9 out of 10) and Factor 2.2 (6 out of 10) combine for a final score of 8 out of 10 for Criterion 2—Effluent.

Criterion 3—Habitat

Impact, unit of sustainability and principle

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

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		7
F3.2a Content of habitat regulations	4	
F3.2b Enforcement of habitat regulations	3	
F3.2 Regulatory or management effectiveness score		4.800
C3 Habitat Final Score (0–10)		**6.267**
Critical?	NO	**YELLOW**

Criterion 3 Summary

Taiwanese tilapia farms are predominantly small-scale operations, which occupy approximately 3,233 hectares. Most aquaculture production, including tilapia farming, is concentrated in the southwest coastal region. A significant mountain range dominates the interior, so most of the flatlands, with the majority of the population , are concentrated to the west of this mountainous region. Because of this geography, there is intense competition for land and water resources in the regions where tilapia farming occurs, so these lands have undergone significant anthropogenic alterations over several centuries. Tilapia farming zones are primarily located within what can be described as riparian lands, but expansion of the industry does not appear to be currently occurring.

Evidence indicates that the majority of modern tilapia farms were established on land that had already been modified for food production, including repurposed agricultural lands, former aquaculture ponds, and irrigation reservoirs. Many of the ponds currently used for tilapia farming were established during the sector's rapid expansion in the 1970s and 1980s, though some are likely to have existed for much longer.

Land subsidence is the most frequently cited environmental impact associated with aquaculture in Taiwan, which historically was exacerbated by groundwater extraction for fish farming and other industries; however, regulatory interventions have significantly reduced its severity by restricting groundwater use. Though subsidence remains a concern in some areas, key ecosystem services—including sediment retention, water regulation, and flood mitigation—are maintained at a moderate level. Based on the assessed moderate habitat value of the land and the evaluation of current ecosystem service functionality, the score for Factor 3.1—Habitat Conversion and Function is 7 out of 10.

The Fisheries Agency plays a central role in overseeing aquaculture governance, including planning, supervision, and the implementation of an area-based management approach. Farms operate in designated aquaculture zones, and a voluntary farm registration is in place, which is promoted and encouraged by an array of subsidies. Legal provisions—such as EIAs for larger developments and requirements for farms to have permits certifying their water sources—ensure that new developments align with environmental standards. Any proposed expansion within aquaculture zones must also be reported to the authorities. Together, these regulatory measures have done much to facilitate effective industry oversight and a reduction in aquaculture-related habitat impacts (e.g., land subsidence). Based on these factors, and in accordance with the Standard, the overall management measures in place for aquaculture in Taiwan are considered to be robust, so the score for Factor 3.2a is 4 out of 5.

A key challenge for aquaculture regulators and policy makers in Taiwan is the sheer number of ponds and small farms involved in the sector. Although farm registration was introduced in 1978, it is unofficially estimated that around 15–20% of fish farms remain unregistered at the time of writing, because the government takes an uncoercive approach to the enforcement of farm registration. Despite this, the proportion of registered farms increases each year, and even if farms are not officially registered, every aquaculture pond is assigned an individual pond number and is subject to aerial surveillance by the authorities.

Concerning farm-level enforcement activities and inspections, it is evident that scheduled and random inspections by local authorities occur from time to time, although only a small percentage of farms are inspected in any given year, indicating capacity constraints. These inspections involve checking equipment and general farm operations. Aquaculture associations collaborate with government authorities to oversee the sector, thus providing additional capacity to oversee thousands of small producers; however as private entities, these associations lack the necessary authority to enforce regulations directly.

In summary, over time, Taiwan's regulatory framework for aquaculture has evolved into an area-based system that considers the cumulative impacts of fish farms. The trajectory of the enforcement of habitat protections in Taiwan is positive overall. But regulatory provisions are challenging to implement and enforce across a landscape of thousands of small pond farms. Though high level enforcement organizations are identifiable and active, there is less certainty about the resources, capacity, and effectiveness of authorities at the local level, which are responsible for farm-level enforcement. According to the Seafood Watch Standard for Aquaculture, these attributes regarding the enforcement of habitat management measures are moderately effective, so the score for Factor 3.2b is 3 out of 5. Factors 3.1 and 3.2 combine to give a final score for Criterion 3—Habitat of 6.3 out of 10.

Justification of score

Factor 3.1—Habitat conversion and function

Where is the typical farm?
Tilapia farming in Taiwan is concentrated in the southwest coastal region, primarily within the municipalities and counties of Tainan,[43] Chiayi, and Yunlin, which account for approximately 80% of total production. Smaller volumes are also produced farther south in Kaohsiung and Pingtung, with limited production in Taoyuan and Hsinchu in the northwest. In these regions, tilapia pond farms are typically situated from just inland of the shoreline to 10–15 km inland (Shin-Chang Chen, Taiwan Fisheries

[43] https://www.aquanet.com/taiwan-tilapia

Economic Development Association October 2024 pers comm). As discussed in Criterion 2—Effluent, the primary water source for a typical tilapia farm in Taiwan is rainwater, which farmers collect and circulate between ponds using underground pipes. Farmers often use one or two ponds as reservoirs to store and manage water. Also, the government has constructed water supply channels in aquaculture zones, allowing farmers to draw freshwater from reservoirs during designated times.

The following Google Earth satellite images (Figures 9–11) provide a visual representation of typical tilapia farming locations in Tainan, Chiayi, and Yunlin, three of Taiwan's most important tilapia-producing regions. Aquaculture ponds can be identified in these images by their rectangular shape. They are generally dark green in color, though some may appear lighter depending on water conditions, algae growth, or sediment levels. In contrast, agricultural plots are also rectangular but tend to be lighter brown.

Figure 9: A representative tilapia farming region in Tainan, Taiwan (2024). Tainan accounts for approximately 40% of Taiwan's total tilapia production. This area includes multiple ASC-certified tilapia farms, illustrating the typical pond-based aquaculture landscape in the region. Google Earth Attribution: Satellite imagery from Google Earth, provided by Google, Airbus, and TerraMetrics (2024).

Figure 10: A representative tilapia farming region in Chiayi, Taiwan (2024). Chiayi contributes approximately 30% of Taiwan's total tilapia production. This specific area in Budai is a well-documented tilapia farming region (Liao & Chen 2008). Google Earth Attribution: Imagery © Google, Airbus, Maxar Technologies, Landsat/Copernicus (03/20/2024).

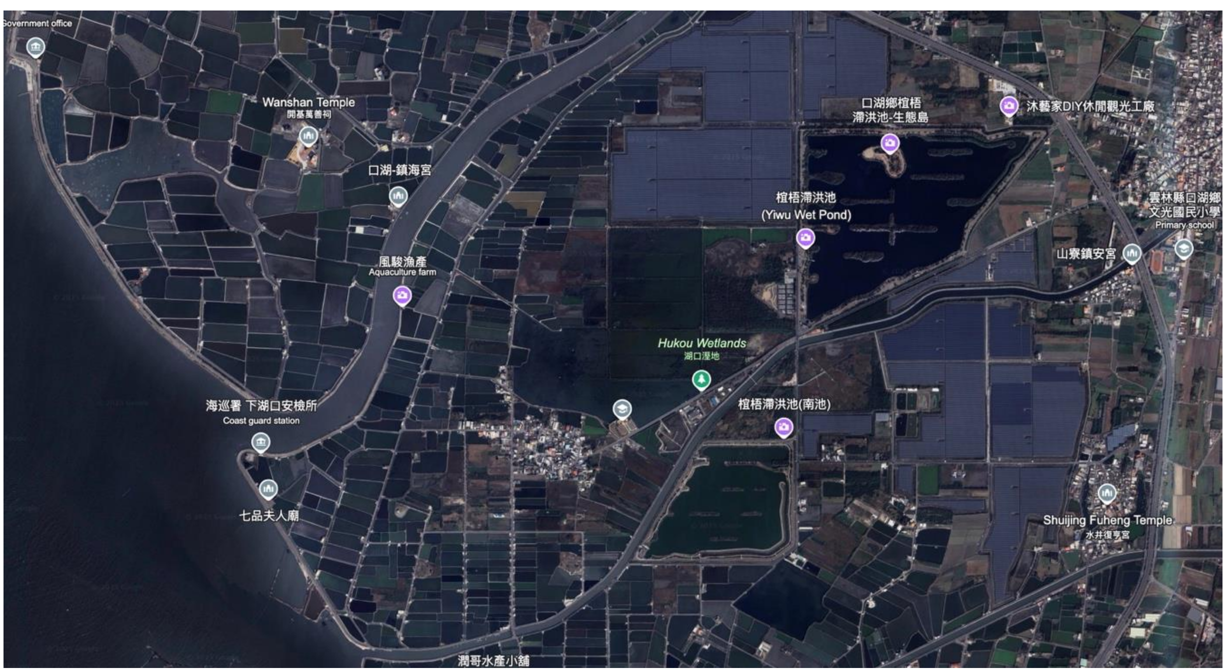

Figure 11: A representative tilapia farming region in Yunlin, Taiwan (2024). Yunlin contributes approximately 10% of Taiwan's total tilapia production. Google Earth Attribution: Imagery © Google, Airbus, Maxar Technologies (02/10/2024).

Tilapia farms are primarily located in flatland areas within these regions, as confirmed by the Ministry of Agriculture's (MOA) Farmland Resource Use Inventory Survey Map (MOA 2023). This interactive mapping tool provides spatial data on land use across Taiwan, including the hectares occupied by different agricultural and aquaculture activities. Although it does not allow filtering down to the species level, it confirms that the majority of aquaculture production, including tilapia farming, occurs in these lowland coastal areas. Further details on this resource can be found in Appendix 3—Ministry of Agriculture Farmland Resource Use Inventory Survey Map.

In total, Taiwan's tilapia sector utilizes ≈3,230 ha of land with more than 2,000 pond-based farms (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm), which support an annual production volume of approximately 60,000 MT that accounts for one-third of Taiwan's total cultured finfish production (FAO 2025). Given this scale of production and its concentration within these mapped regions, Tainan, Chiayi, and Yunlin serve as representative examples of where tilapia farming typically occurs in Taiwan.

What is the general ecosystem where farms are located?
Taiwan's southwestern coastal region, where the majority of farms are concentrated, is characterized by low-lying, flatland environments shaped by centuries of agricultural and aquacultural development. This region includes a mix of estuarine wetlands, intertidal mudflats, lagoons, coastal sand dunes, and artificially modified landscapes (Chen et al. 2021) (Lin 1996).

The Central Mountain Range dominates the island's interior, leaving little space for large-scale agriculture or aquaculture and forcing most farming activities onto the western coastal flatlands. Therefore, this intensely utilized region experiences strong competition for land and water resources (Chang et al. 2020). Rivers in this region flow westward, depositing silt and mud into estuaries. Over centuries, these sediment-rich tidal lands developed into expansive coastal lowlands, which have been progressively converted since the 18th century into farmland, fish ponds, and salt fields (Liu 2013).

To better understand the habitat mosaic in which tilapia farming occurs, the IUCN Global Ecosystem Typology (GET) classification tool (Keith et al. 2022) was applied in conjunction with Google Earth imagery and the MOA Farmland Resource Use Inventory Survey Map (MOA 2023).

First, the geographical zones where tilapia pond farms are concentrated—including Tainan, Chiayi, Yunlin, Kaohsiung, and Pingtung—were mapped. Although the MOA land-use data do not provide species-specific details on tilapia farming locations, typical tilapia farming regions were identified through a combination of literature sources, including ASC-certified tilapia farm records. This approach ensured that the mapped regions accurately reflect areas where tilapia farming is dominant. The exercise allowed a determination of the main biomes and ecosystem functional groups (EFGs) within the broader aquaculture landscape, which are summarized in Table 1.

Table 1: Primary biomes and ecosystem functional groups (EFGs) in the areas where tilapia are farmed in Taiwan, extracted from the IUCN Global Ecosystem Typology (GET) classification tool (Keith et al. 2022).

GET ID	Ecosystem Functional Group	Occurrence	Biome ID	Biome	Realm ID	Realm
F1.1	Permanent upland streams	minor and major	F1	Rivers and streams	F	Freshwater
F1.2	Permanent lowland rivers	major (partial) minor (partial)	F1	Rivers and streams	F	Freshwater

F1.4	Seasonal upland streams	major	F1	Rivers and streams	F	Freshwater
F3.1	Large reservoirs	major	F3	Artificial wetlands	F	Freshwater
F3.2	Constructed lacustrine wetlands	major	F3	Artificial wetlands	F	Freshwater
F3.3	Rice paddies	major	F3	Artificial wetlands	F	Freshwater
T1.1	Tropical/Subtropical lowland rainforests	minor	T1	Tropical-subtropical forests	T	Terrestrial
T2.4	Warm temperate laurophyll forests	major	T2	Temperate-boreal forests and woodlands	T	Terrestrial
T7.1	Annual croplands	major	T7	Intensive land-use	T	Terrestrial
T7.4	Urban and industrial ecosystems	major	T7	Intensive land-use	T	Terrestrial
MT1.1	Rocky shorelines	major (on coast)	MT1	Shorelines	MT	Marine-Terrestrial
MT1.3	Sandy shorelines	major (on coast)	MT1	Shorelines	MT	Marine-Terrestrial
MT2.1	Coastal shrublands and grasslands	major (on coast)	MT2	Supralittoral coastal	MT	Marine-Terrestrial
MT3.1	Artificial shorelines	major (on coast)	MT3	Anthropogenic shorelines	MT	Marine-Terrestrial
SF1.2	Groundwater ecosystems	major	SF1	Subterranean freshwaters	SF	Subterranean-Freshwater

The degree of anthropogenic influence on Taiwan’s southwestern coastal region is clearly reflected in the biome classifications in Table 1. The Intensive Land-Use Biome, the Anthropogenic Shorelines Biome, and the Artificial Wetlands Biome all feature prominently—highlighting the extensive modification of natural landscapes for aquaculture, agriculture, and urban development. Of particular relevance is the Artificial Wetlands Biome, which includes aquaculture ponds, large reservoirs, and rice paddies, which all are dominant features of Taiwan’s coastal landscape (see Figure 18, Criterion 9X). These modified environments have long-standing water management functions and support productive farming systems that have evolved over centuries.

In accordance with the Seafood Watch Standard for Aquaculture, and for the purposes of this assessment, the typical existing farm can be broadly described as being located in a riparian zone, which the Standard generally classifies as a habitat of moderate value.

Figure 12: A pond farm in Ligang Township, Pingtung County, Taiwan. Image by Taiwankengo, via Wikimedia Commons, licensed under CC BY-SA 4.0.

When did the typical farm begin?

The introduction of tilapia into Taiwan occurred in the 1940s when Mozambique tilapia (*Oreochromis mossambicus*) was brought from Indonesia by the Japanese. A 1954 report by the Chinese-American Joint Commission on Rural Reconstruction noted that, by 1953, approximately 6,000 ha of rice paddies and ponds were already stocked with tilapia (Chen 1954). By 1958, provincial governments began actively promoting aquaculture, leading to the development of new ponds in the southwestern coastal areas to support the sector's growth (Tang & Tang 2006). This suggests that tilapia farming was already well established in Taiwan by the mid-20th century.

The Kuo (1984) dataset shown in Figure 13 illustrates the continued expansion of Taiwan's aquaculture sector between the 1960s and 1980s. As production systems intensified during this timeframe, the production of tilapia began to sharply surpass that of traditional cultured species such as milkfish. Kuo (1984) notes that, by 1973, tilapia farming occupied 4,528 ha, which expanded to 10,256 ha by 1982, while production volume rose from 13,154 MT in 1973 to 51,504 MT in 1982. This rapid growth was largely attributed to selective breeding of productive strains and to advancements in culture technology and management (Kuo 1984).

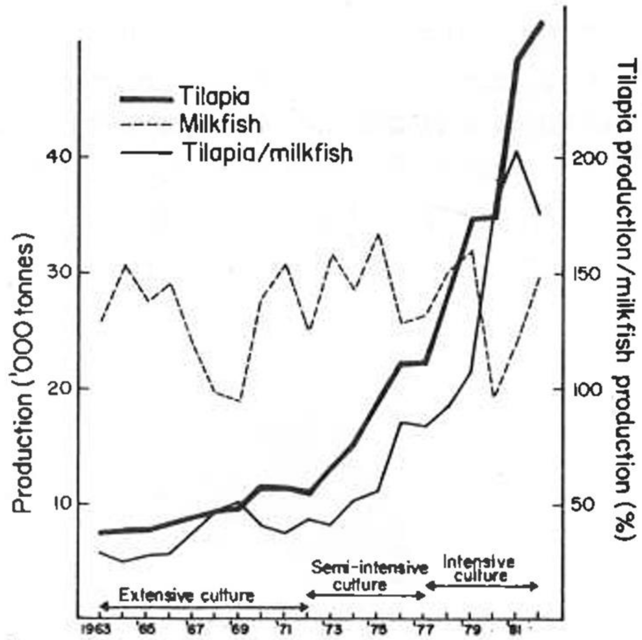

Figure 13: Chart showing the rapid increase in tilapia production in Taiwan from 1963 to 1982, surpassing other cultured commodities like milkfish, carp, and oysters (Kuo 1984).

Tang & Tang (2006) comment that the development of pond farms in the southwest region was particularly prolific during the 1970s and 1980s, when eel and prawn farming expanded significantly, becoming a major source of foreign exchange. During this time, government policies made aquaculture development a priority, leading to substantial increases in production from the 1960s through the 1990s (Chang et al. 2020). By the mid-1980s, Taiwan had become one of the first countries to export tilapia internationally (Bonham 2022), with production volume nearly doubling between the 1990s and 2004 (De Silva et al. 2004).

But eel and shrimp production peaked in the late 1980s and declined significantly thereafter (FAO 2025); hence, many ponds that were once dedicated to these species would have become available for alternative aquaculture production, such as tilapia. Although not well defined in the literature, this suggests that tilapia expansion in the 1990s was accommodated within preexisting aquaculture ponds rather than through new pond construction. Since 2004, tilapia production in Taiwan has also been in decline (FAO 2025).

By the end of the 1990s, the overall area dedicated to land-based aquaculture in Taiwan had declined significantly, largely because of government interventions to mitigate environmental impacts, particularly groundwater depletion and land subsidence. While existing ponds continued to be used, many were also “retired” because they were deemed to be inappropriately sited (Ting et al. 2015) (Liao & Chen 2008). The current tilapia farming area is now estimated to be ≈3,233 ha, down from 10,256 ha in 1982—nearly a 70% decrease in farmed area.

In light of this historical progression, the typical tilapia farm in Taiwan was established in the 1970s and 1980s, coinciding with the rapid expansion of aquaculture during this period. But given the long-standing presence of pond-based aquaculture in Taiwan, some of the ponds still in use today clearly predate this timeframe by a considerable margin.

What was the previous land use?
An analysis of historical and contemporary satellite imagery (Google Earth, 1985 vs. 2024), alongside the MOA Farmland Resource Use Inventory Survey Map, confirms that agriculture and aquaculture ponds have been a long-standing feature of Taiwan's landscape in tilapia farming regions (Figures 14–15).

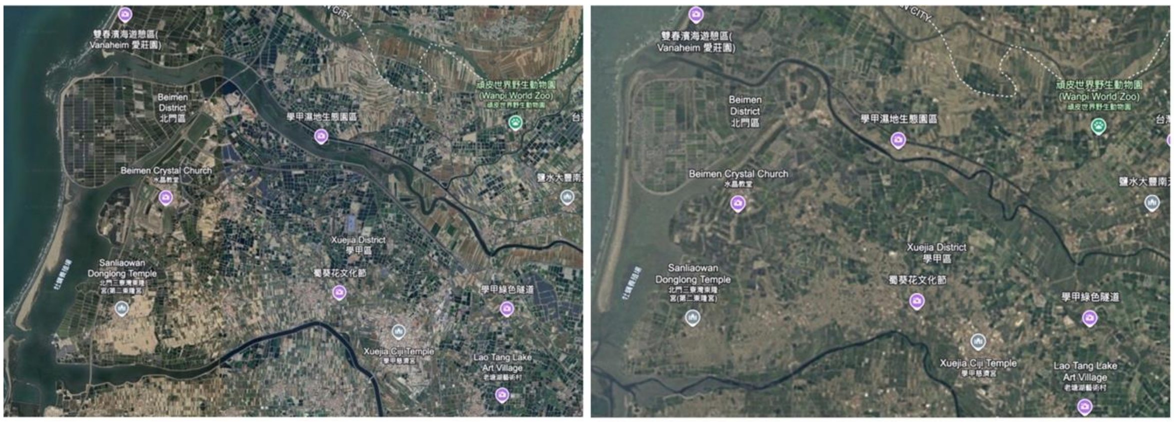

Figure 14: Satellite imagery of a tilapia farming region in Tainan, with the same region shown in 2024 (left) and 1985 (right), illustrating that extensive agricultural and aquacultural development was already well established by 1985 (Google Earth image attributions: Tainan, 2024—Satellite imagery provided by Google, Airbus, and TerraMetrics (2024); Tainan, 1985—Satellite imagery provided by Google and Landsat/Copernicus 1985).

Figure 15: Satellite imagery of a tilapia farming region in Chiayi, with the same region shown in 2024 (left) and 1985 (right), illustrating that extensive agricultural and aquacultural development was already well established by 1985 (Google Earth image attributions: Chiayi, 2024—Imagery © Google, Airbus, Maxar Technologies, Landsat/Copernicus. Imagery Date: older—03/20/2024; Chiayi, 1985—Imagery © Google, NASA, Landsat/Copernicus. Imagery Date: older—12/31/1985).

Although Google Earth imagery for these farming regions extends back only to 1985, it is evident from the literature that ponds have been a long-standing, integral component of Taiwan's agricultural landscape (Chen et al. 2019). Notably, rainwater collection in ponds has been a well-established agricultural practice in Taiwan, dating hundreds of years (Hsu et al. 2019). These water bodies, used primarily for irrigation and water management, have existed for centuries, with records indicating their presence as early as 1622 (Chou et al. 2013). Historical records also confirm that large-scale land conversion for agriculture has been ongoing for over 300 years (Yang et al. 2022). This suggests that some modern-day tilapia farms are likely located on sites that have been continuously used for food production for hundreds of years.

Following the introduction of tilapia to Taiwan in the mid-1940s, the literature notes that thousands of hectares of rice paddies were stocked with tilapia in the 1950s (Chen 1954), and that by the 1970s, more than 5,000 ha of paddy fields had already been converted into fishponds, reflecting a well-established integration of aquaculture into agricultural landscapes (Kuo 1984).

During the 1970s, polyculture and integrated farming systems became popular, particularly the co-cultivation of tilapia and carp alongside livestock operations such as hog and duck farming. These systems took advantage of animal waste as a nutrient source to support aquatic food webs (Kuo 1984). Some aquaculture expansion also occurred on reclaimed tidal land, utilizing previously modified coastal landscapes (Cheng 2017). As general aquaculture production expanded through the 1960s and 1980s, new pond construction was documented (Kuo 1984), although it remains unclear to what extent existing ponds were repurposed versus newly built. By the late 1980s and early 1990s, shrimp and eel production declined significantly (FAO 2025), making it likely that some ponds previously used for these species were transitioned to tilapia farming.

Based on the available evidence and historical records, most modern-day sites used for tilapia farming in Taiwan were not developed on pristine or unmodified landscapes but on land that had already been extensively used for food production, including other aquaculture species or agricultural crops such as rice.

Does the resulting ecosystem function remain?
Taiwan's southwestern coastal plain, where most tilapia farms are located, has undergone significant anthropogenic modification over time. Historically, this region has been shaped by intensive agriculture, urbanization, and aquaculture development (Lee et al. 2015). As a result, one of the most frequently cited environmental concerns associated with aquaculture in Taiwan is land subsidence exacerbated by the overextraction of groundwater (Chen et al. 2021) (Tang & Tang 2006), although various natural and human-driven factors have contributed to this issue over time.

Geodetic surveys indicate that subsidence and coastal erosion were already well documented in Taiwan as far back as 1904 (Lin 1996). But the rapid expansion of aquaculture in the 1980s significantly exacerbated the problem by the widespread drilling of wells to extract groundwater for fish farming. By 1995, nearly 89% of all groundwater wells in Taiwan—across all sectors, not only aquaculture—were unregistered or illegal (Tang & Tang 2006), making it difficult to track the full extent of groundwater depletion (Lai 2019) (Hung et al. 2018). The overextraction of water for aquaculture and other industries led to severe subsidence, increasing flood risk, coastal erosion, and the salinization of coastal soils and aquifers (Chen et al. 2021) (Hung et al. 2018) (Lin 1996). In addition to its role in groundwater depletion, the rapid expansion of aquaculture also contributed to other localized environmental pressures, including habitat degradation and intensifying conflicts over land and water use (Chen et al. 2021) (Tang & Tang 2006).

In response to these acute problems of land subsidence, various mitigating measures were implemented by the government, particularly efforts to reduce groundwater dependency. Subsidies to retire unworkable fish ponds were also introduced, with these sites subsequently repurposed for other uses (Liao & Chen 2008). In addition, groundwater control zones were established in coastal areas, and strict limitations were placed on water rights (Fisheries Agency December 2024). Over time, these interventions led to a marked reduction in the footprint of significant land subsidence. According to Taiwan's Water Resource Agency (WRA), the area affected by severe subsidence shrank from 1,529 km^2 in 2001 to 419 km^2 by 2019 (Lai 2019). Moreover, industry experts note that for the last roughly 7 years, it has no longer been permissible for fish farmers to dig new wells to access groundwater, and the old wells are mostly not used anymore (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Further details on historical regulatory measures taken to address land subsidence can be found in Appendix 2—Historical Context: Aquaculture Sector Development in Taiwan.

Despite historical challenges related to acute land subsidence, particularly during the peak of groundwater extraction in the 1980s and 1990s, the literature notes that aquaculture provides multiple ecosystem services in addition to food production. These include water regulation, water purification, climate regulation, carbon fixation, habitat provision, and biodiversity support (Chen et al. 2021). Under appropriate management, pond farming systems can help stabilize local hydrology by storing and filtering water, thereby helping to mitigate extreme weather events such as flooding (Chen et al. 2021). Furthermore, aquaculture ponds can help support bird biodiversity by providing critical feeding and breeding habitats for waterbirds, helping to retain habitat value in otherwise heavily modified landscapes (Tu et al. 2020).

Overall, though aquaculture has contributed to long-standing environmental challenges in Taiwan's southwestern coastal plain, regulatory interventions and improved management practices have contributed to the stabilization of key ecosystem services, particularly those related to hydrological regulation and habitat maintenance. Subsidence remains an issue but is significantly less severe than in past decades. Meanwhile, the ecosystem functions of tilapia farming habitats, particularly those related to food production, sediment retention, and water regulation, continue to be maintained at a moderate level.

<u>Concluding statement for Factor 3.1</u>

From the preceding discussion, it can be concluded that tilapia farming in Taiwan is primarily located in the southwestern coastal region, within low-lying riparian zones, a habitat type classified under the Seafood Watch Standard as having moderate habitat value. Most farms were established in the 1970s and 1980s, coinciding with the rapid expansion of aquaculture; however, evidence suggests that pond-based aquaculture has existed in Taiwan for much longer, and some ponds still in use may predate this period. The available data indicate that modern tilapia farms were typically established on land already modified for food production, including earthen ponds, irrigation canals, reservoirs, rice paddies, and former aquaculture sites.

Although historical pressures, including land subsidence, freshwater salinization, and biodiversity loss, have altered some of the ecosystem functions where tilapia is farmed, habitat functionality has largely been maintained with moderate impacts. Since the 1970s and 1980s, food production in these areas has remained viable, and stricter controls on groundwater extraction have helped reduce key environmental pressures, particularly land subsidence, which, while still present, is significantly less severe than in the past decades.

Ecosystem services such as sediment retention, water regulation, and flood mitigation continue to function at a moderate level, while food production remains effective. Although water resource management remains a challenge, progress has been made across the aquaculture sector to mitigate its environmental impact. Accordingly, the score for Factor 3.1—Habitat Conversion and Function is 7 out of 10.

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

In Taiwan, tilapia farmers fundamentally require two key permissions: the right to use the land and access to a water source (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). These permissions, though seemingly straightforward, are underpinned by a comprehensive regulatory framework implemented by various government agencies. Land use is governed by zoning classifications managed by the Ministry of Agriculture (MOA), while water rights are allocated and monitored by the Water Resource Agency (WRA). For larger-scale operations, additional regulatory requirements may apply, such as Environmental Impact Assessments (EIAs) and effluent monitoring. These measures collectively create a robust framework for managing Taiwan's land and water resources sustainably.

<u>Overview of governance framework and structure pertaining to the aquaculture sector</u>

Taiwan's central government comprises five major branches, or yuans: the Executive Yuan, which serves as the principal policy-making body; the Legislative Yuan, which enacts and reviews legislation; the Judicial Yuan, overseeing the court system; the Control Yuan, which audits government agencies; and the Examination Yuan, managing civil service affairs.[44] In 2005, the Freedom of Government Information Law[45] was enacted to promote public access to government information, protect the right to know, and encourage public participation in democracy. Under the Executive Yuan, the Ministry of Agriculture (MOA)—formerly the Council of Agriculture (COA)[46]—oversees agriculture, forestry, fisheries, and animal husbandry in Taiwan. The MOA's mission is to address environmental challenges and ensure the sustainable development of agriculture. Its organizational hierarchy is shown in Figure 16.

[44] https://www.taiwan.gov.tw/content_4.php

[45] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=I0020026

[46] https://eng.moa.gov.tw/ws.php?id=9501

Ministry of Agriculture

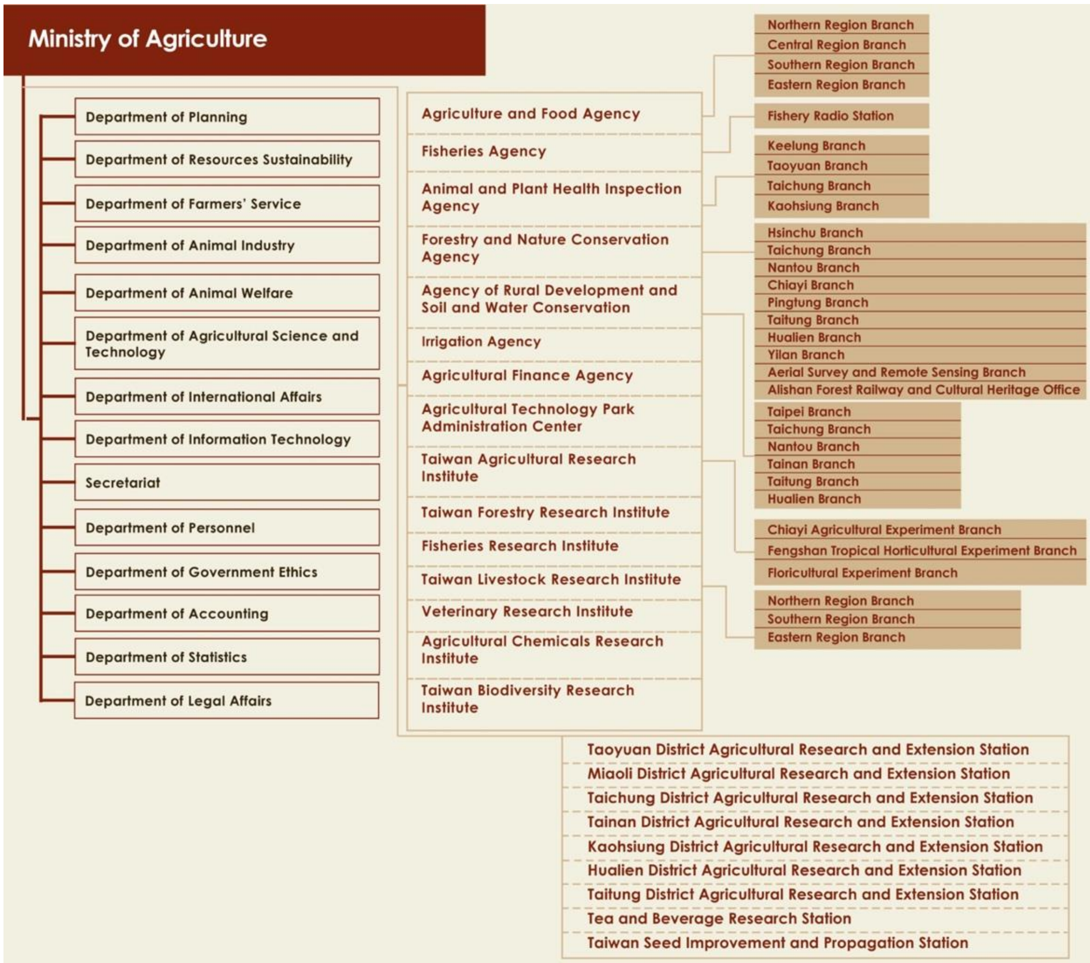

Figure 16: Organizational chart of the Ministry of Agriculture, which oversees the administration of agricultural, forestry, fisheries, and animal husbandry matters in Taiwan (Source: Taiwan Ministry of Agriculture website).

Fisheries Agency: Aquaculture Fisheries Division

Under the MOA is the Fisheries Agency, which incorporates the Aquaculture Fisheries Division, the Fisheries Regulations Division, and the Deep-sea Fisheries Division. Concerning the Aquaculture Fisheries Division, the stated mission of this organization includes:[47]

1. Planning and drafting of aquaculture development policies.
2. Planning and management of water and land resources for aquaculture.
3. Planning, drafting, and review of environmental improvement plans for aquaculture.
4. Planning, promotion, and supervision of the operation and management of aquaculture production zones.
5. Promotion and supervision of aquaculture technologies.
6. Drafting, promotion, and supervision of aquaculture production and marketing plans.
7. Planning, promotion, and supervision of registration and administration of land-based aquaculture.
8. Planning, promotion, and supervision of the management of sea areas demarcated for aquaculture fisheries.

[47] https://en.fa.gov.tw/view.php?theme=Mission&subtheme=&id=4

9. Providing advanced warning to the aquaculture sector of impending natural disasters and, in their aftermath, information gathering on damage caused and the recovery process.
10. Management and guidance of aquaculture product safety and sanitation.
11. Coordination in the work of animal quarantine and inspection for aquaculture products.
12. Planning, administration, and propagation management of field tests for GMO aquaculture animals and plants.
13. Other affairs relating to aquaculture management.

As noted under item seven, supervision of the registration and administration of land-based aquaculture falls within the remit of the Fisheries Agency. Likewise, item four outlines the agency's role in the supervision of aquaculture zones, which have been designated to facilitate an area-based management approach. In addition, items two and three highlight the agency's broader role in planning and supervising the industry within aquaculture production zones, encompassing the sustainable management and development of aquaculture activities. Collectively, these administrative duties are of primary importance for this factor.

Ministry of Environment

Also of particular relevance to the aquaculture sector is the Ministry of Environment (MOENV), formerly known as the Environmental Protection Administration (EPA), which operates directly under the Executive Yuan. MOENV is the central competent authority for matters pertaining to the environment at the national level, whereas regional governments function as competent authorities at the regional level—often further delegating such competence to specific regional departments as required (Lexology 2022). One of the principal stated objectives of MOENV is to "Strengthen environmental law enforcement with digital technology, use smart technology and the Internet to deal with general waste in multiple ways, improve environmental cleanliness and sanitation, sustainably manage soil and water resources by improving investigation and remediation technology to verify and increase soil and groundwater restoration and carbon sink capabilities; strengthen pollution source control, create a low-hazard living environment, and develop healthy and sustainable communities." Of note, in line with Taiwan's Freedom of Government Information Law,[48] MOE maintains an environmental open data platform[49] to facilitate transparency and provide public access to environmental data.

Aquaculture Development Association & regional associations

As noted, regional fish farmer development associations were introduced in the early 1990s, concurrent with the establishment of the Aquaculture Supervision Program and the development of aquaculture zones, which were implemented by the Fisheries Agency to restrict the operation of farms in areas with poor access to water sources. These associations became important institutions that helped the government to encourage improvements in farming practices across the aquaculture sector by, for example, engaging farmers in regular seminars and fish health clinics (Cheng 2017). Aquaculture associations continue to play an important role in the overall management and networking of the aquaculture sector in Taiwan and are united nationally under the Aquaculture Development Association (ADA), a nonprofit, peoples' organization, jointly established by farmers. The purpose of the ADA is to facilitate communications between farmers and the government, to assist in the collation of farming data, and at times to assist farmers in applications for government subsidies (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

[48] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=I0020026
[49] data.moenv.gov.tw

Article 2 of the association's Charter[50] states: "The Association is a non-profit social organization established in accordance with the law, with the purpose of cooperating with government policies and administration, coordinating and integrating the production, marketing and construction of aquaculture fisheries, improving the management level, and expanding aquaculture and related businesses."

The website of the ADA notes that the Taiwan Aquaculture and Fisheries Production Areas Development Association was established in 1996 and was officially renamed the Republic of China Aquaculture and Fisheries Development Association in 2004. In 1996, 42 aquaculture production zones had been established in Taiwan (Cheng 2017), whereas at present, there are 52 aquaculture production zones, 48 of which have a local aquaculture association based in the county or city of the production area.[51] Aquaculture production zones are designated for general aquaculture production and are not species specific. The term "aquaculture production zone" refers to the unified water inlet channels and drainage facilities provided by the government to help operators focus on production. It is relevant to note that the zones were introduced after these areas had already become well established as farming regions—not the other way around—and that the government latterly designated them as professional aquaculture production zones to implement effective management, particularly regarding the efficiency of water use, including supply and discharge. But fish ponds that are not in the aquaculture production zone can also legally engage in aquaculture (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Governance of aquaculture habitat management measures: an overview

The Basic Environment Act

The principal law underpinning environmental protection in Taiwan is the Basic Environment Act,[52] which came into force in 2002. Article 3 specifically states that economic, technological, and social developments must place equal emphasis on environmental protection based on the long-term interests of the nation. Furthermore, in the event that economic, technological, or social developments endanger the environment or have a seriously detrimental impact on the environment, the protection of the environment shall prevail. This act mandates the adoption of the polluter pays principle (PPP) into law and the establishment of an environmental impact assessment system to prevent and mitigate the adverse impacts of development activities, to attain the goal of environmental protection. This latter mandate is implemented by the Environmental Impact Assessment Act, along with several supporting regulations, rules, measures, and standards. The following explains the structure and execution of the Environmental Impact Assessment (EIA) process in more detail.

[50] https://www.fish1996.com.tw/charter.html
[51] https://www.fish1996.com.tw/founding.html
[52] https://faolex.fao.org/docs/pdf/tw164338.pdf

Water Act and the Water Supply Act
The Water Act[53] and the Water Supply Act[54] (WSA), both of which are under the remit of the Ministry of Economic Affairs (MOEA), are also of relevance to the aquaculture sector. The Water Act governs the administration and development of water works, including the control and utilization of surface or groundwaters for agricultural and aquacultural purposes, whereas the WSA safeguards public water sources. Under the WSA, certain zones are designated as protected areas with regard to water quality and quantity. Entities extracting surface water or groundwater within this designated protection area are required to pay catchment conservation and compensation fees. If the water is intended for agricultural purposes, the central authority and agricultural authority will jointly allocate subsidies to such users.

Environmental Impact Assessments
Article 5 of Taiwan's Environmental Impact Assessment Act[55] defines the types of development activities that are subject to an environmental impact assessment (EIA), including "The development or use of land for agriculture, forestry, fisheries or livestock." Further clarification regarding which types of aquaculture projects are subject to EIA is provided in Article 17 of "Standards for Determining Specific Items and Scope of Environmental Impact Assessments for Development Activities"[56] as follows:

> *Where one of the following circumstances applies with respect to construction or expansion related to fish farms or fish ponds, an environmental impact assessment shall be required if:*
>
> I. *The site is located in a wildlife refuge or a major wildlife habitat. However, this restriction shall not apply if the competent authorities in charge of the wildlife refuge and major wildlife habitat and the industry competent authority have granted their consent.*
> II. *The site is located in an important wetland.*
> III. *The site is located in a nature preserve approved and announced under the Taiwan Coastal Area Natural Environment Protection Plan.*
> IV. *The site is located in an underground water control area, and the application for development area is 5 hectares or more.*
> V. *The application for development area is 10 hectares or more.*

Furthermore, according to Article 12 of the "Environmental Impact Assessment Enforcement Rules,"[57] the municipality or county city governments are the competent departments for the environmental impact assessment of coastal aquaculture facilities and for the development of fish ponds (Ministry of Environment September 2023 pers comm). This document also provides a flowchart to clarify the different phases of the EIA process.

EIAs must be performed during the initial planning stage of a project and comprise two phases. Initially, the developer must prepare a phase one environmental impact study (EIS) and submit it to the competent authority. The authority then has 50 days (in special circumstances, this deadline can be

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[53] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0110001
[54] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0110055
[55] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC040372
[56] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=O0090012
[57] https://oaout.moenv.gov.tw/law/EngLawContent.aspx?lan=E&id=307&kwStr=Environmental%20Impact%20Assessment%20Enforcement%20Rules

extended a further 50 days) to complete a review of the EIS and notify the developer if a phase two assessment is required. This second phase is initiated if concerns have arisen regarding the potential for the proposed project or activity to result in a significant environment impact . In accordance with Article 18 of the EIA Act, the industry competent authority shall monitor and track activities during the development process and after completion, and the authorized institution shall monitor the execution of the EIA statement.

In many global settings, applications for fish farm expansions often trigger the requirement for an EIA; according to Taiwan's EIA Act, this is also the case in Taiwan when the proposed development area is ≥ 10 hectares, or it is ≥ 5 hectares and the proposed site is located in a groundwater control area. The EIA Act also discusses the rules pertaining to proposed developments in wildlife refuges or major wildlife habitats, nature preserves, and wetlands; though EIAs may be required in such instances, the EIA Act notes that this requirement will be contingent upon the decision of the respective competent authority.

Regulations to protect soil and groundwater

One of the principal legal instruments governing the protection of soil and groundwater pollution is the Soil and Groundwater Pollution Remediation Act[58] (SGPRA), which is implemented by the Soil and Groundwater Pollution Remediation Act Enforcement Rules.[59] The SGPRA, which lies within the remit of MOENV, is concerned with the prevention and remediation of soil and groundwater pollution; this act has been formulated to ensure the sustainable use of soil and groundwater, to enhance the living environment, and protect public health.[60] Implementation of the SGPRA is further supported by the Groundwater Pollution Control Standards[61] and the Groundwater Pollution Monitoring Standards,[62] which classify groundwater into two categories: Category 1 pertains to groundwater located in drinking water source protection areas, whereas Category 2 pertains to groundwater located outside of Category 1 areas.

The SGPRA mandates that competent authorities at all levels shall regularly monitor the quality of soil and groundwater and shall perform verification of sites suspected of having soil and groundwater pollution; also, they shall control pollution sources and investigate the state of environmental pollution. Article 17 defines actions that are prohibited within a soil and groundwater pollution control zone. The act also stipulates that, if an area of pollution is identified, then the site polluter shall submit a soil and groundwater pollution remediation plan pursuant to the investigation and assessment results. Furthermore, the central competent authority may, for the purpose of remediating soil and groundwater pollution, levy soil and groundwater pollution remediation fees; such fees are then utilized by the Soil and Groundwater Pollution Remediation Fund.[63]

Similarly, the Soil and Water Conservation ACT[64] (SWCA), which lies within the remit of the MOA, is concerned with the control and approval of measures affecting soil and water. It is enacted for the purposes of soil and water conservation treatment and maintenance (the application of engineering,

[58] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=O0110001
[59] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC164093
[60] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC164198
[61] https://faolex.fao.org/docs/pdf/tw164130.pdf
[62] https://faolex.fao.org/docs/pdf/tw164150.pdf
[63] https://oaout.moenv.gov.tw/law/EngLawContent.aspx?lan=E&id=304&KW=Soil+and+Groundwater+Pollution+Remediation+Act
[64] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=M0110001

agronomic, or vegetative measures to protect soil and water resources, maintain natural ecology and landscape, and prevent erosion, landslide, debris flow, and other disasters), conserving soil and water resources, reducing the possibility of disasters, the promotion of reasonable land use, and enhancing people's welfare. This act specifies that large projects shall be planned, designed, and supervised by soil and water engineers.[65] The SWCA is implemented by the Enforcement Rules of the Soil and Water Conservation Act.[66]

Also of relevance to the protection of soil and water is the Spatial Planning Act,[67] which specifically establishes guidelines concerning the measures to be taken to cope with climate change, assure land use safety, conserve the natural environment and cultural assets, promote the reasonable allocation of resources and industries, strengthen land consolidation and management mechanisms, and restore sensitive areas and damaged land in the pursuit of sustainable development.

Regulations regarding farm registration and subsidies

Farm registration, which was discussed briefly in Factor 3.1, was introduced as a control measure to help mitigate environmental impacts and to facilitate better oversight of the sector. As noted, though registration continues to be voluntary, the proportion of registered farms increases each year and is now approximately 80–85%. The administration of farm registration falls under the remit of the Fisheries Agency, a responsibility that was officially incorporated into the Fisheries Act in Chapter 8, Article 69, in May 2013.[68] This act specifies that the regulations for registration and management of inland aquaculture shall be prescribed by the municipal or county/city competent authority. Of note, registered farms are eligible for a wide range of subsidies from the government, including assistance to purchase energy-saving or green energy equipment such as solar panels and certified electric water wheels. Subsidies are also available to improve public infrastructure for registered farms, such as raising the height of embankments around ponds to enhance river basin management,[69] improving drainage systems,[70] and the installation of water-recirculating facilities[71]; local aquaculture associations are instrumental in the implementation of these subsidized projects. In addition, registered farms are eligible for financial relief in the event of fish losses incurred due to natural disasters, such as typhoons or cold weather[72]; if a farm were unregistered, it would not qualify for such subsidies or assistance (Chen & Qiu 2014). The Agriculture Development Act[73] is also instrumental in ensuring that agriculture/aquaculture activities are conducted legally and that farmlands are utilized in a reasonable manner; to this end, this act empowers competent authorities to take necessary measures to protect agricultural resources, and to formulate general plans for agricultural land utilization and exploitation. Certain subsidies for farmers are also referenced in this act.

Protection of wetlands

Since the Wetland Conservation Act[74] (WCA) was promulgated in 2013, any potential development related to tilapia farming or other activities must adhere to the Act's provisions, which are designed to

[65] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC210453
[66] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC210464
[67] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC167021
[68] https://faolex.fao.org/docs/pdf/tw40383E.pdf
[69] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181379
[70] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181706
[71] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181378
[72] https://www.ctwant.com/article/98073
[73] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=M0020001
[74] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC167279

prevent any net loss of wetlands. The WCA was established to protect the natural flood control functions of wetlands, maintain biodiversity, and promote the wise use and ecological conservation of these vital areas. Under Article 5, all government agencies and the general public are required to manage and use natural resources and the ecological functions of wetlands in a way that ensures there is no net loss of wetland area or function.

This mandate is also relevant for tilapia development projects, which must incorporate impact mitigation, offsite compensation, or ecological compensation if they affect wetlands. "No net loss," as defined by the WCA, means that any development or utilization of wetlands, such as the expansion of tilapia farms, must be counterbalanced by measures that fully compensate for any loss of wetland area or ecological functions. This includes adopting remedial measures to offset any adverse impacts caused by such developments.

Article 6 of the WCA further requires that government authorities, in collaboration with relevant agencies, routinely conduct comprehensive investigations into wetland ecology, pollution levels, and the socioeconomic conditions surrounding wetlands. This ongoing research and monitoring is crucial for ensuring that any tilapia development is informed by the most up-to-date information about the health and status of wetlands. The establishment of a centralized database and website[75] allows all relevant entities, including developers, to access the latest wetland status reports, thus ensuring transparency and adherence to the WCA's requirements.

The WCA also empowers the government to designate certain areas as "Wetlands of Importance," where stricter regulations apply. For tilapia development within these designated areas, developers are required to submit detailed usage plans for review. These plans must align with the WCA's "wise use" principle, ensuring that the wetland's ecological functions and biological service systems are not compromised. If tilapia farming is deemed necessary within a Wetland of Importance, the developer must implement compensatory mitigation measures, such as expanding the wetland area or creating additional habitats for species affected by the development. Moreover, Article 21 of the WCA specifies that lands within the borders of Wetlands of Importance may be used for agriculture, fisheries, and related industries under certain conditions. But tilapia development must comply with the WCA's stricter provisions to prevent any net loss of wetlands, and in cases where other laws impose stricter requirements, those must also be followed (Su 2014).

<u>Concluding statement: Factor 3.2a</u>
It is evident from the preceding overview that Taiwan's governance landscape has evolved considerably over the last three decades. During this time, significant progress has been made to strengthen and refine the content of habitat management measures pertaining to the aquaculture sector. This evolution in supervision of the sector has occurred against a backdrop of considerable historic environmental degradation, which became particularly evident toward the end of the 20th century, following a period of unprecedented and rapid sector expansion—at a time when there was little government oversight of such developments, aquaculture-related or otherwise.

Many of the legal instruments and management measures described were put in place specifically to help tackle the legacy of environmental decline that began to proliferate during the 1980s and early 1990s. For the aquaculture sector, such measures included the introduction of a voluntary registration system, the establishment of aquaculture zones, the provision of subsidies for the retirement of less

[75] https://wetland-tw.nps.gov.tw/en/index.php?

sustainable farms, and the prohibition of groundwater usage and sludge removal. Subsidies were also provided to encourage environmentally beneficial farm improvements, such as the installation of solar panels, water-recirculating systems, and improved drainage systems. By making these subsidies available to registered farms only, the government helped to drive greater compliance across the aquaculture sector, facilitating better industry oversight and the implementation of habitat impact mitigation measures. The governance framework also incorporates an area-based approach because farms now operate in designated aquaculture zones, which have access to approved water sources. As discussed in Criterion 2—Effluent, a cumulative approach is also adopted in the monitoring and management of water bodies into which effluents are discharged.

The Seafood Watch Standard for Aquaculture states that, to be considered robust, regulatory frameworks for aquaculture must be area-based and incorporate a management system that accounts for the cumulative impacts of fish farms, with regard to farm siting. The preceding review of Taiwan's habitat management measures demonstrates that both of these factors have been incorporated into the governance landscape for aquaculture and that management measures are based on maintaining ecosystem functionality. Any proposed expansion within aquaculture zones must also be reported to authorities, and EIAs are required for developments of 5 ha or more in a groundwater control area and for all developments of 10 ha or more; provisions for EIAs with regard to farms operating in wildlife refuges, major wildlife habitats, nature preserves, and wetlands are also made. But unsurprisingly, no EIAs for tilapia farms were detected in the government's online EIA document inquiry portal, which is indicative of both the small average size of pond farms and that they typically exist under grandfathered clauses due to the length of time they have existed. According to the Standard, the overall management measures in place for aquaculture in Taiwan are considered to be robust, so the score for Factor 3.2a is 4 out of 5.

Factor 3.2b: Enforcement of habitat management measures
While Factor 3.2a indicates that the content of habitat management measures for Taiwanese aquaculture is robust because they are area-based, account for cumulative impacts, and appropriately address proposed expansion, Factor 3.2b considers the degree to which these management measures are effectively enforced.

Enforcement of farm registration
Farm registration, as discussed, was introduced in 1978 as a voluntary control measure to encourage environmentally appropriate siting of farms in designated aquaculture zones. Registered farms also became eligible for a range of subsidies; thus, this strategy was also used to encourage the retirement of unworkable fish ponds (which had been established in earlier times in areas now considered inappropriate) because of the deleterious impact of groundwater extraction on surrounding habitats. But the literature notes that early implementation of farm registration proved to be somewhat problematic, as the result of the number of ponds that were already established in areas now deemed impermissible for aquaculture (Ting et al. 2015) (Chen & Qiu 2014).

Chen & Qiu (2014) reported that "black" farms (i.e., unregistered farms) had been a long-standing problem for the government and that nearly half of all inland farms were unregistered at the time of writing, and further noting that such farms are "regarded illegal." These authors commented that, in 2012, the requirement for registration was "stipulated by local governments"; however, it is evident that this "stipulation" did not equate to a strictly enforced mandate. Ting et al. (2015) similarly commented that numerous "illegal" ponds were still operational in Taiwan, of which the majority were established before the implementation of registration, which, as discussed, occurred in 1978. Therefore, it is evident that some ambiguity exists in the practical application of farm registration and the status that this bestows upon farm operators in the eyes of the law. The nuances of this situation are explained by Chen & Qiu: "To enhance management on culture activities, there is an approval and registration system for culture farms. For marine culture, the Fishery Act requires prior approval due to its occurrence in public water . . . For inland culture, prior approval is not explicitly required by law. However, there is a registration system for inland farms. Farms to be registered should conform to local regulations, which generally contain two main basic requirements. One is related to land usage, in which culture farms should be located in the areas where culture activities are legally allowed. The other is about water usage, in which fish farmers should have permits for using water issued by water resource authorities. Farms without registration, demarcated fishery rights or fishery access privileges are regarded illegal and treated like 'black' farms." Chen & Qiu further note, "There is an exception for the case in which inland farms are in line with regulations but do not apply for registration with local governments. It is also noted that the government does not take drastic measures to crack down on the illegal farms, instead taking a more practical and liberal approach to encourage them to become legal by providing subsides exclusively for legal farms. This approach has flexibility in maintain [sic] the status quo of culture activities and avoiding social conflicts between the government and fish farmers."

While the Taiwanese government continues to encourage fish farmers to become legally registered and promotes this through various subsidies, registration is still not a legal requirement. But all aquaculture ponds must have individual pond numbers and be under Fisheries Agency aerial photography surveillance. At present, it is unofficially estimated that around 15–20% of farms have not yet obtained a farm registration certificate, although this percentage continues to decline each year as more farms become registered. It is evident that the government's strategy to achieving 100% registration is a phased approach rather than one of coercion. Communications with experts suggest that older farmers are perhaps less likely to engage with the registration process; hence, as these farmers retire, the proportion of farms that are registered increases (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Investigation and enforcement of suspected land use violations

In its Annual Report for 2022, MOA notes that data collected in the farmland resource surveys are subsequently used by local governments to help them demark "agriculture development zones" and advance the realization of the Spatial Planning Act of 2016,[76] which seeks to proactively protect and maintain important environments used for agricultural production (MOA 2024). MOA's farmland use survey resource links to a page on the website of the Ministry of Economic Affairs (MOEA), which includes a chronological database of the investigation and enforcement of suspected land use violations, including any related enforcement activities[77]; this list, which is up to date, does not appear to include any fish farm related investigations.

Implementation of EIAs for fish farms

In Taiwan, tilapia pond farmers are generally not required to undergo Environmental Impact Assessments (EIAs), given the historical context of their operations. Most of these pond farms were established in the 1980s and 1990s, before the enactment of the EIA Act, and thus benefit from a "grandfather clause" that exempts them from this requirement. Though EIAs are mandated for new or expanded developments in other sectors, particularly for projects exceeding 10 ha or those in sensitive environmental areas, tilapia farms typically do not meet these criteria. Communications with experts also indicate that few EIAs have been conducted for aquaculture activities (Shin-Chang Chen, Secretary-

[76] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=D0070230

[77] https://www.cto.moea.gov.tw/FactoryMCLA/web/information/list.php?cid=1

General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Furthermore, although Taiwan has implemented a high degree of transparency in its EIA process, with project-specific information available to the public via the Environmental Impact Assessment Inquiry System[78] hosted by the Ministry of Environment (MOENV), no data concerning the aquaculture sector, including tilapia farming, are noted on this platform. This indicates the limited applicability of EIA requirements to tilapia farming under current regulations. But note that, in sectors where EIAs are required, any detected violations during an EIA inspection would result in fines, other penalties, and a deadline for corrective action.[79] Although the EIA process is typically not applicable to tilapia farms in Taiwan, many pond farms that were historically sited in inappropriate areas are no longer in operation as a result of the government's policy of encouraging their retirement through the provision of subsidies.

Other farm-level enforcement activities and inspections
Local government farm surveys are conducted every 4–5 years, during which economic data are collected and around half of all farms are visited (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). In addition, random farm inspections are conducted annually, when > 5% of farms are inspected in each farming region (Ministry of Agriculture January 2025 pers comm). The Fisheries Agency Annual Report for 2022[80] states that inspections involve checking equipment, general farm operations, and testing fish for drug residues. Also, drainage channels within aquaculture zones are subject to random inspections. Monthly inspection data is available on the Fisheries Agency website,[81] which includes details of the farms visited and the species that they produce.

In accordance with the Rules for Stocking Declaration and Review of Aquaculture Fisheries (RSDRAF) discussed in Factor 3.2a, farmers are required to declare their stocking quantities to the government by the end of May each year, as well as the amount harvested. These rules mandate that municipal or county/city governments should conduct random inspections of the reported cases submitted by the township (town, city, district) offices, and the random inspection ratio of each township (town, city, district) should exceed 5%.[82] Communications with farmers confirm that random inspections by the local government take place from time to time with regard to stocking declarations (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

Farmers also comment that, while some operators may keep logbooks to track data such as water quality monitoring, treatment of effluents, and use of chemicals and veterinary medicines, there is no requirement for these data to be reported directly to the authorities. But every county or city has an aquaculture association—which is a private organization, not governmental—and the government collaborates with them for the collection of any required data. Furthermore, any new information that the government wants to disseminate to farmers will be distributed via these associations, which may, for example, organize a seminar or workshop so farmers can be informed about new policies or other information relevant to aquaculture producers (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

A note on guidance vs. enforcement

[78] https://eiadoc.epa.gov.tw/EIAWEB/Default.aspx
[79] https://www.moenv.gov.tw/en/7167AD8232103DE
[80] https://www.fa.gov.tw/view.php?theme=Fisheries_Department_Annual_Report&subtheme=&id=25
[81] https://www.fa.gov.tw/list.php?theme=Unlisted_aquaculture_Report
[82] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181569

A number of literature references discuss that, although Taiwan's governance structure is predominantly a top-down hierarchical system, participative management at the local level is also greatly encouraged (Chen & Qiu 2014). In this regard, note particularly that, although Taiwan's constitution of 1947 intended to provide a foundation for democratic governance and rule of law, this only became possible after 1987, when martial law was lifted.[83] Thus, Taiwan is a relatively recently democratized country (Tang & Tang 2006), and today, democratic, bottom-up initiatives are considered a powerful tool to successfully bring about reform,[84] even though these measures are voluntary and not legally imposed.

This support of local-level governance is also evident in the important management role played by aquaculture associations in their local jurisdictions. Note that, under the authoritarian regime before 1987, there was a limited ability to form civil associations, so the lifting of martial law also paved the way for the development of aquaculture associations in 1992 (Cheng 2017). Concerning bottom-up aquaculture fisheries management, Chen & Qiu (2014) comment that: "'guidance' is better than 'immediate enforcement' for an old industry ready to be transformed. However, the disadvantage arises in that management measures might not be widely implemented due to their non-compulsory nature."

Concluding statement: Factor 3.2b

As noted, Taiwan's modern aquaculture sector began to develop in the early 1970s. At this time, the government's focus was on encouraging economic growth and industrial development, so there was little regulatory oversight in place to enable the identification and mitigation of emergent environmental issues, particularly when the sector's development began to accelerate rapidly. In the absence of an adequate environmental governance framework, habitat protection enforcement activities were largely lacking.

By the early 1990s, governance management measures were revised, and tools such as farm registration, the designation of aquaculture zones, and farm subsidies were used to encourage farms sited in inappropriate environments that lacked a suitable water supply to cease production. But a key challenge for regulators was the sheer number of ponds and small-holders involved in the aquaculture sector and the lack of capacity to implement enforcement activities.

Even though farm registration has been promoted by the government since 1978 and by a range of subsidies, it is unofficially estimated that around 15–20% of fish farms currently remain unregistered. The government have never taken a harsh approach to the enforcement of farm registration; however, the proportion of registered farms increases each year. Even if farms are not officially registered, every aquaculture pond is assigned an individual pond number and is subject to aerial surveillance by the authorities. Also, the government's publicly accessible database of land use violations and enforcement activities does not appear to include any investigations related to fish farms.

Regarding the implementation of EIAs for fish farms, while Taiwan has a robust EIA process in place, in practice this is not applicable to fish farms, which are typically only a few hectares in size. The majority of these farms have also been in operation for decades, predating the implementation of the EIA Act. Even so, if a new pond is used, this does need to be declared to the local authorities, so there is oversight in place for such expansion activities, whether or not they are of sufficient size to trigger the requirement of an EIA.

[83] https://www.taiwan.gov.tw/content4.php
[84] https://www.britannica.com/place/Taiwan/Government-and-society

Concerning other farm-level enforcement activities and inspections, it is evident that both scheduled and random inspections by local authorities take place from time to time, although only a small percentage of farms are inspected in any given year. To facilitate the collection of data from the large number of small-scale farms operating in the aquaculture sector, the government of Taiwan also works closely with aquaculture associations. Arguably, this bottom-up style of enforcement via associations lacks the equivalent authority of direct engagement with government officials, but it provides additional capacity to oversee thousands of small producers and facilitates the dissemination of new policies and other government information pertaining to the aquaculture sector.

In summary, the trajectory of the enforcement of habitat protections in Taiwan is overall positive. As noted in Factor 3.2a, Taiwan's regulatory framework for aquaculture has evolved to one that is area-based and accounts for the cumulative impacts of fish farms with regard to farm siting. But this framework is challenging to implement and enforce across a landscape of many thousands of small farms; though high-level enforcement organizations are identifiable and active, there is less certainty about the resources, capacity, and effectiveness of authorities at the local level, which are responsible for farm-level enforcement. According to the Seafood Watch Standard for Aquaculture, these attributes for enforcement of habitat management measures are moderately effective, so the score for Factor 3.2b is 3 out of 5.

Conclusions and Final Score

Tilapia farming in Taiwan occurs on riparian lands classified as having moderate habitat value under the Seafood Watch Standard. There appears to be minimal, if any, new pond development, and these areas have long been modified for food production, including repurposed agricultural lands, former aquaculture ponds, and irrigation reservoirs. Though many ponds currently used for tilapia farming were established during the sector's rapid expansion in the 1970s and 1980s, some predate this period. Land subsidence is the most frequently cited environmental impact associated with aquaculture in Taiwan, historically exacerbated by groundwater extraction for fish farming and other industries. But regulatory interventions have significantly reduced its severity by restricting groundwater use. Although subsidence remains a concern in some areas, key ecosystem services, including sediment retention, water regulation, and flood mitigation, continue to function at a moderate level. Based on these findings, Factor 3.1: Habitat conversion and function scores 7 out of 10, contributing to an overall Criterion 3—Habitat score of 6.3 out of 10.

In accordance with the Standard, Taiwan's regulatory framework is considered robust in that it is area-based and incorporates a management system that accounts for the cumulative impacts of fish farms, with regard to farm siting. The Ministry of Agriculture (MOA), through its Fisheries Agency, plays a central role in overseeing and administering aquaculture operations. The Fisheries Agency supervises aquaculture zones and farm registration, forming the foundation of the area-based management approach. These measures ensure that farms operate within designated aquaculture zones, and any proposed expansions must be reported to the relevant authorities. EIAs are required for developments of 5 ha or more in groundwater control areas and for all developments of 10 ha or more; provisions for EIAs for farms operating in wildlife refuges, major wildlife habitats, nature preserves, and wetlands are also made. Management measures are based on maintaining ecosystem functionality and minimizing habitat impacts, reflecting the agency's broader mandate to sustainably manage aquaculture production zones. Thus, the score for Factor 3.2a: Content of habitat management measures is 4 out of 5.

Regarding the application of management measures within this governance framework, there is less clarity about the efficacy of enforcement. Farms must comply with local regulations, which require possession of a permit certifying the legality and approval of their water source, as well as ownership of or permission to use the land, and location within designated aquaculture zones. Farm registration, though promoted and encouraged through subsidies, remains voluntary, and an estimated 15–20% of farms remain unregistered, falling outside of this formal registration framework. Despite this, all aquaculture ponds, registered or not, are assigned an individual pond number and are subject to aerial surveillance by authorities.

Though enforcement organizations are identifiable and active, they have limited resources and may lack the capacity to be assuredly and fully effective at the farm level, particularly with the sheer number of small farms in the aquaculture sector. Local government farm surveys are conducted every 4–5 years, during which around half of all farms are visited. In addition, random inspections covering more than 5% of farms annually ensure oversight of equipment and general farm operations. But this level of inspection leaves a significant proportion of farms unvisited in any given year, underscoring the challenges faced by enforcement authorities in comprehensively overseeing the sector. Although aquaculture associations play an important role in facilitating management of the sector in collaboration with government authorities, these associations are private entities, which lack the necessary authority to effectively deliver regulatory enforcement. Also, though robust EIA provisions are in place, specific information about the number of farms that are encompassed within this ruling is unclear, and it is evident that EIAs are typically not required for tilapia farms because of their small size. According to the Standard, these attributes indicate that the enforcement of aquaculture habitat management measures in Taiwan is moderately effective. Thus, the score for Factor 3.2b: Enforcement of habitat management measures is 3 out of 5. Together, the scores for Factors 3.1, 3.2a, and 3.2b give an overall score of 6.3 out of 10 for Criterion 3—Habitat.

Criterion 4—Chemical Use

Impact, unit of sustainability and principle

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

Chemical Use parameters	Score	
C4 Chemical Use Score (0–10)	**6**	
Critical?	NO	**YELLOW**

Criterion 4 Summary

According to historical academic literature, chemicals and antibiotics were typically not required in the production of tilapia because of the disease-resistant nature of these species. But as production intensified, so did the need for medicinal interventions, primarily from the emergence of new diseases, particularly bacterial diseases. This has been the global trend in tilapia production, but specific details concerning chemical use in Taiwan's tilapia sector are lacking, even though information about the regulatory environment is readily available online.

The regulatory framework seeks to control access to chemical therapeutants such as antimicrobials, but enforcement appears to face some challenges. For example, Taiwan's Veterinary Drugs Control Act oversees the quality and sale of veterinary drugs, whereas the Veterinarian Act seeks to ensure that veterinarians are directly involved in the diagnosis, treatment, and documentation of controlled substance administration. Inspections by local government and Fisheries Agency inspectors further ensure adherence to regulations, with over 5% of aquaculture farms inspected annually. In addition, government-funded regional fish disease control stations offer free veterinary services to farmers, supported by a centralized database in which all cases and treatments are recorded. But farmers evidently can bypass this official system by purchasing veterinary drugs directly from pharmacies without a prescription, potentially resulting in undocumented and inappropriate drug usage.

Despite these regulations and controls, chemical usage within Taiwan's tilapia sector remains unclear. Although veterinary drug manufacturers and importers are required to submit data on drug types, quantities, and customer information to municipal authorities every 6 months, these records are not publicly accessible. At present there are 11 antibiotics and 1 insecticide approved for use in tilapia production in Taiwan. According to experts, the use of chemical interventions on tilapia farms is infrequent, but when they are administered, the most commonly used drugs are amoxicillin, florfenicol, oxytetracycline, and oxolinic acid, all of which are commonly used globally in aquaculture. The World Health Organization (WHO) categorizes the first three as highly important antimicrobials (HIA), whereas oxolinic acid is categorized as a highest priority critically important antimicrobial (HPCIA).

Although no specific data were identified concerning the environmental fate of chemicals used on tilapia farms in Taiwan, the literature notes that the ecological impact of these four therapeutants potentially includes disrupting microbial communities, harming aquatic organisms, and inducing antimicrobial resistance. Trichlorfon, the approved insecticide for tilapia that is commonly used in many countries for a range of pest control applications, has moderate toxicity to fish, birds, and aquatic arthropods, so caution is warranted in its application near water bodies, although its usage does not appear to be prevalent within the sector.

To ensure the safety of food products for consumers, the government implemented random drug residue testing on fish farms in 2006 to detect any chemical usage exceeding acceptable limits or the presence of illegal drugs. Farmers are reportedly near 100% compliant with the drug residue testing program, and the results of these inspections are published monthly on the Fishery Agency website. For example, from a total of 804 farms inspected between March and August 2024, all were found to be compliant. Also, in its most recent Annual Report, the MOA reported compliance rates of 99.2% for premarket aquatic products and 99.9% for those tested in wholesale fish markets. Nonetheless, a small number of recent border rejections of Taiwanese tilapia imports into the United States because of drug residues highlights potential gaps in this program.

In summary, there is limited information documenting chemical usage within the aquaculture sector; although usage of highly important and critically important antimicrobials is reportedly low, it presents potential concerns regarding antimicrobial governance and environmental risks. There appear to be gaps in enforcement effectiveness because farmers are able to obtain antimicrobials through pharmacies without prescriptions, and despite a food safety program aimed at detecting antimicrobial residues with reported high compliance rates, there have been recent border rejections in the United States. But an important element that must be considered is the low discharge rates of the pond systems. Taiwanese tilapia farms typically have quite low discharge rates (< 1% daily) because farmers make water conservation a priority. This farm practice significantly mitigates the potential environmental impact of any chemicals that are used during production.

Guidance for the assessment of this criterion in the Seafood Watch Standard for Aquaculture states that if chemical use (e.g., type or quantity) and/or impacts are unknown, then the production system-based assessment option should be used. Because the type of chemicals used are known but the quantity and impacts are unknown, the production system is driving the score. The production system has quite infrequent or limited discharge of water (e.g., < 1% per day), so the score is 6 out of 10 for Criterion 4—Chemical Use.

Justification of score

Communications with experts indicate that tilapia farmers in Taiwan may use a variety of chemical substances, including pond preparation agents like lime or zeolite powder, disinfectants, piscicides, and probiotics. Experts also note that veterinary medicines, including antimicrobials and pesticides, are occasionally applied, though their usage is described as infrequent (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm). But detailed insights into the sector's chemical use remain limited, as academic literature on the topic is scarce and government data regarding the types, quantities, and frequency of chemical use in Taiwanese aquaculture appear to be unavailable.

Although a move toward greater transparency regarding chemical usage is evident in some aquaculture sectors, this lack of data availability is mirrored in many production settings, as noted by Rico et al. (2012) in their review of chemical use in Asian aquaculture. This study, which did not specifically include Taiwan within its scope, concluded that disinfectants, pesticides, and antibiotics are the most environmentally hazardous chemicals used in aquaculture. The authors determined that the high toxicity of these compounds to nontarget organisms, along with their potential for bioaccumulation across food chains, poses risks to biodiversity and the ecological functions of surrounding aquatic ecosystems. These authors also comment that government and public awareness around chemical use frequently focuses solely on economic and food safety risks, leaving potential ecosystem health risks inadequately addressed. Consequently, this criterion focuses particularly on the use of antimicrobials and pesticides, along with the related regulations and management mechanisms that govern their use.

Regulation and Management of Veterinary Medicines

Two key pieces of legislation that regulate the usage of veterinary medicines in Taiwan are the Veterinary Drugs Control Act and the Veterinarian Act.

Veterinary Drugs Control Act

In Taiwan, the Veterinary Drugs Control Act[85] and related Enforcement Rules of Veterinary Drugs Control Act[86] have been enacted to regulate the quality, prescription, and sale of veterinary drugs in Taiwan. Article 26.2 states that the competent authority may send personnel to animal farms (of livestock, poultry, and aquaculture) and feed factories to audit the use of veterinary drugs and may conduct biopsies on some animals. This act also stipulates in Article 32 that the usage of veterinary drugs (including target animal, purpose, route of drug delivery, dosage, withdrawal period, and precautions to take) must abide by usage guidelines prescribed by the central competent authority. Furthermore, the act states that animal and aquatic farmers and feed manufacturers must not use a raw veterinary drug or human drug to prevent diseases in animals or to regulate their physiological functions, and that competent authorities must monitor animal and aquatic farmers and feed manufacturers with respect to their veterinary drug usage. At the end of each January and July, veterinary drug manufacturers and importers are required to compile and submit data (including drug type, quantity produced or imported, quantity sold, and customer names) to the municipal competent authority for the record, and they must also retain these data for 3 years. This act also specifies a range of penalties that will be enforced if offenses occur; for example, any person found to be making or importing counterfeit/banned veterinary drugs will be subject to a prison term of 1 to 7 years, and a fine of up to TWD4.5 million (USD143,500 at the time of writing).

[85] https://www.ampeid.org/documents/taiwan-province-of-china/veterinary-drugs-control-act/

[86] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=M0130016

Veterinarian Act
The Veterinarian Act,[87] which regulates the veterinary profession in Taiwan, stipulates that a practicing veterinarian must not issue a diagnosis certificate or write a prescription without personally performing the diagnosis and/or treatment, nor should they issue an inspection certificate without personally conducting the inspection. Furthermore, if a controlled substance is administered, then the drug name, dosage, and application method must be documented. Also of relevance is the Examination and Review Criteria for Veterinary Drug Registration (2017), which was formulated in accordance with Article 12 of the Veterinary Act and provides guidance for the inspection and registration review of animal drugs.[88]

Animal and Plant Health Inspection Agency, Ministry of Agriculture
A key player in the oversight of veterinary medicines and their use is the Animal Health Inspection Division (AHID) of the Animal and Plant Health Inspection Agency (APHIA), which is a department of the Ministry of Agriculture (MOA). As described on the agency's website, the division oversees animal health inspection, disease prevention, veterinarian registration, and veterinary drug management. Another of its roles is to strengthen animal disease diagnostic capabilities and to develop animal disease control techniques. The division also conducts testing and registration of veterinary drugs and subsequently issues permits for these. In addition, the division is instrumental in managing sales of veterinary drugs and their application, and works to strengthen the veterinary drug residue monitoring program.[89]

<u>Inspections, Residue Testing, Documentation of Treatments, and Compliance Gaps</u>
The use of chemicals in aquaculture presents dual concerns: the potential risks to environmental health and the safety of food products for consumers. The following section explores Taiwan's approach to monitoring and managing chemical use in aquaculture through inspections and drug residue testing programs, traceability systems, and the documentation of treatments, highlighting measures designed to maintain compliance with veterinary drug standards and safeguard consumer confidence.

Inspections and drug residue testing on fish farms
In the early 2000s, concerns over drug residues in Taiwanese cultured seafood came to the fore when several consignments were detained and rejected by importing countries, including a 2003 shipment of tilapia into the European Union that was rejected for the detection of chloramphenicol, a chemical that is forbidden for use in food-producing animals in the EU[90] as well as numerous other countries including the United States and Canada (Chang 2017). This situation not only imperiled Taiwan's seafood export potential but also undermined confidence in cultured seafood within Taiwan, threatening domestic sales.

Because of these food safety concerns, the government introduced a program of random drug residue testing on fish farms in 2006, the aim of which was—and continues to be—to detect the presence of illegal drugs or drugs exceeding acceptable limits. The literature notes that this program was effective, with compliance rates reaching close to 100% in the following years (Chen & Qiu 2014). The MOA's most recent Annual Report notes that, in 2022, the MOA conducted 2,149 sample tests of aquatic products that had not yet reached the market, of which 99.2% were found to be compliant. In addition, there

[87] https://www.ampeid.org/documents/taiwan-province-of-china/veterinarian-act/
[88] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC170112/
[89] https://www.aphia.gov.tw/en/ws.php?id=6133
[90] https://food.ec.europa.eu/document/download/a2661e60-c1cc-4b0f-98bc-ee5edcf17c9cen?filename=csvet-med-residuesanimal-imports-non-eubrochureen.pdf

were 12,210 sample tests of aquatic products on sale in wholesale fish markets, of which 99.9% were found to be compliant (MOA 2024).

Communications with MOA confirm that local government and Fisheries Agency inspectors conduct sampling visits and inspections of aquaculture farms every year; the sampling rate is over 5% (Ministry of Agriculture January 2025 pers comm). A key purpose of these visits is to check that animal drugs are being used in compliance with regulations and to survey the on-site environment (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). The results of these inspections, which are published monthly on the Fisheries Agency website, indicate that compliance rates continue to be high. For example, from a total of 804 farms inspected between March and August 2024, all were found to be compliant.[91]

The Animal Drug Residue Standards, with which farm operators must be compliant, are available on the website of Taiwan's Food and Drug Administration (FDA).[92] These standards, which are shown in Table 2, have been formulated in accordance with the provisions of Paragraph 2 of Article 15 of the Food Safety and Sanitation Act.[93] Of note, in 2019, Taiwan's FDA completely banned the use of sulfa drugs in fish aquaculture (Chang et al. 2020).

Traceability: Food safety and hygiene

A barcode traceability scheme for domestically consumed and produced seafood products (farmed and wild caught) was launched in 2016; this scheme, which is titled the Traceability Aquatic Products Retrospective System, is supported by the Operational Code for Traceability Management of Aquatic Products Production regulation.[94] This scheme is free for successful applicants, who can apply through an online portal hosted by the Fisheries Agency.[95] Once approved, participants are given a traceability barcode that they can use on their packaging, which allows consumers to check the provenance of their purchase. According to the regulation that governs the scheme, producers validated by this scheme are subject to both regular and irregular inspections to affirm the veracity of their declarations. The regulation also stipulates that random product quality inspections will be conducted to ensure compliance with domestic food safety and hygiene as well as aquatic and animal drug-related regulations, the results of which will be published online on the Taiwan Agriculture and Food Traceability (TAFT) System website.[96] (Note that all farms are subject to drug residue testing, whether or not they are part of this scheme.) If any drug usage is detected that does not meet the fishery and animal drug use regulations, including the detection of impermissible residual

[91] https://www.fa.gov.tw/list.php?theme=Unlisted_aquaculture_Report
[92] https://consumer.fda.gov.tw/Law/VeterinaryDrugList.aspx?nodeID=519&k=魚&p=1
[93] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=L0040001
[94] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181344
[95] https://www.fishqrc.org.tw
[96] https://taft.moa.gov.tw/mp-2.html

Table 2: Animal drug residue standards for Taiwanese farmed fish (Source: Food and Drug Administration ([FDA]). The FDA notes that if any of the drugs listed in the table are not animal drugs approved for domestic animal production by the Ministry of Agriculture, then they are only applicable to imported animal products.* **Scientific name of drug**	**Chinese name**	**Residual body parts**	**Species**	**Residual allowable amount (ppm)**
Amoxicillin	**Amoxicillin**	**muscle**	**fish**	**0.05**
Ampicillin	**Ampicillin**	**muscle**	**fish**	**0.05**
Chlortetracycline, Oxytetracycline and Tetracycline	**Chlorotetracycline, Hydroxytetracycline and Tetracycline**	**muscle**	**fish**	**0.2**
Deltamethrin (insecticide)**	Deltamethrin	muscle	Beef, sheep, chicken, salmon	0.03
Doxycycline	**Deoxyhydroxytetracycline**	**muscle**	**fish**	**0.01**
Erythromycin	**Erythromycin**	**muscle**	**fish**	**0.2**
Eugenol (anesthetic extracted from essential oil of clove)**	Eugenol	muscle (including skin)	fish	0.05
Florfenicol	**Chloramphenicol**	**muscle (including skin)**	**fish**	**1**
Flumequine	**Fluoride sterilization**	**muscle (including skin)**	**fish**	**0.5**
Kitasamycin	**Beilinomycin**	**muscle**	**fish**	**0.05**
Lincomycin	**Lincomycin**	**muscle**	**fish**	**0.1**
Ormetoprim	Omedap	Muscle, liver, kidney, fat	Chicken, turkey, duck, catfish, salmon	0.1
Oxolinic acid	**Oxalinic acid**	**muscle (including skin)**	**fish**	**0.05**
Spiramycin	**Stamycin**	**muscle**	**fish, shrimp**	**0.2**
Sulfadimethoxine	Sulfadimethoxine	muscle	fish, shrimp	0.1
Sulfamonomethoxine	Sulfamethoxine	muscle	fish, frogs	0.1
Thiamphenicol	Chloramphenicol	muscle	fish	0.05
Tricaine Methanesulfonate/MS-222 (anesthetic)**	Tricaine mesylate	muscle (including skin)	fish	0.01
Trichlorfon (insecticide)**	**Trichloroform**	**muscle**	**fish**	**0.01**

* Note that all drugs highlighted in **blue** are not authorized for use in the production of tilapia in Taiwan, even though they may be authorized for other aquaculture products or imported products.

** Note that all the drugs listed are antibiotics except for Eugenol and Tricaine Methanesulfonate (MS-222), which are anesthetics, and Deltamethrin and Trichlorfon, which are insecticides.

amounts of approved drugs,[97] then the applicant's use of the traceability barcode will be suspended. Note that, to search the TAFT database, either the producer's name or their identifying traceability number must be entered; because a search cannot be conducted for a particular species, it was not possible to determine the number of tilapia producers that subscribe to this scheme.

Veterinary Diagnosis and Treatment Services: Promoting Responsible Chemical Use
Also of relevance to this criterion, government-funded disease inspection clinics offer free veterinary services, and all treatments are recorded in a centralized database (see Criterion 7—Disease for more on this topic). These inspection stations were established in the 1990s and play an important role in promoting effective fish health management across the aquaculture sector, and they have been instrumental in educating farmers about the proper application and usage of veterinary drugs (Chen 2017).

Gaps in Compliance and Border Rejections
The management measures described would appear to offer a robust method of limiting access and monitoring and tracking drug usage; however, there may be additional on-farm drug use that goes undocumented, because farmers are also able to buy medicines directly from pharmacies without a prescription (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). By allowing veterinary drugs to be purchased this way, without professional oversight and diagnosis, there is a potential for these drugs to be administered inappropriately. Furthermore, such on-farm drug usage is not officially documented—even though, in accordance with the law, it is assumed that the total amount of veterinary drugs used each year across all aquatic and terrestrial farming sectors must be documented by authorities, because veterinary drug manufacturers and importers are required to compile and submit such data to municipal authorities twice per year.

Also, despite the government's program of drug residue testing, note that a number of border rejections have been documented in the United States in recent years. Between 2018 and 2022, the United States rejected Taiwanese tilapia shipments for drug residues on ten occasions: two in 2019, two in 2020, and six in 2021; no rejections were recorded in 2018 or 2022. During the same period, there were no documented instances of EU border rejections of Taiwanese tilapia (FAO 2023).

<u>A Note on Antimicrobial Resistance and the World Health Organization</u>
As reported by the World Health Organization (WHO), antimicrobial resistance (AMR) continues to present one of the greatest global health threats to humanity; in 2019, 5 million deaths were attributed to AMR.[98] Therefore, the use of antimicrobials in aquaculture is of particular relevance to this criterion. The WHO's priorities for different antimicrobial classes and their categories are shown in Figure 17.

[97] https://www.fda.gov.tw/ENG/lawContent.aspx?cid=16&id=306
[98] https://www.who.int/news/item/08-02-2024-who-medically-important-antimicrobial-list-2024

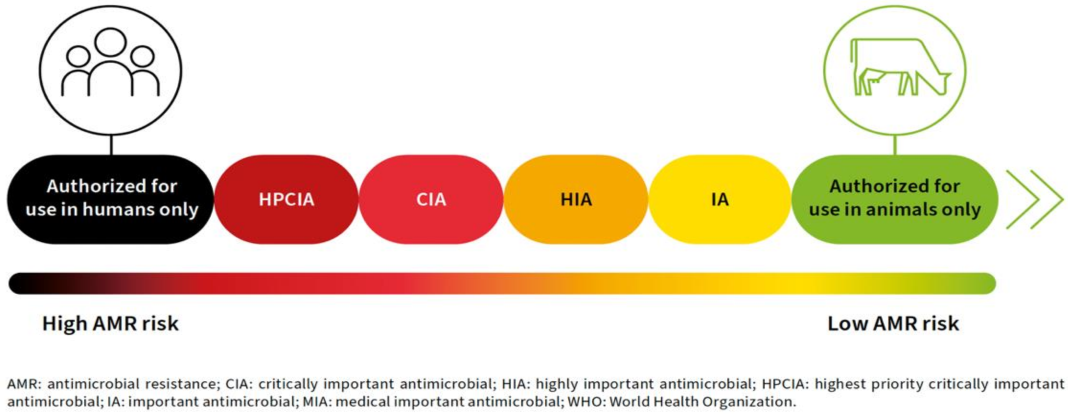

Figure 17: Priorities of antimicrobial classes in the World Health Organization's list of medically important antimicrobials (WHO MIA List) (WHO 2024).

AMR develops when bacteria, viruses, fungi, and parasites evolve to resist antimicrobial medicines, which in turn heightens mortality risks and the spread of disease, and makes infections more challenging to treat. This outcome occurs in all sectors involved in food production, not only in aquaculture (Haenen et al 2023); however, it is notable that a study examining antibiotic resistance in Asia from 2000 to 2019 found that around 33% of antibiotics used in aquaculture had resistance levels surpassing 50% (Guo et al. 2024). To foster the responsible and optimal use of antimicrobial medicines across human and animal health sectors and to help safeguard their efficacy, the WHO maintains a list of medically important antimicrobials for human medicine (WHO MIA List). This list categorizes antimicrobials based on their significance to human medicine and their associated AMR risks, providing a valuable resource for policymakers, regulators, and healthcare professionals to make informed decisions and ensure the prudent use of antimicrobials. Of note, in line with global efforts spearheaded by the United Nations (which does not recognize Taiwan,[99] so neither does WHO), Taiwan has implemented a National Action Plan to help combat AMR (Haenen et al 2023) (Tseng et al. 2014).

It should be noted that the term "antibiotic" specifically refers to substances that target bacteria, while the term "antimicrobial" encompasses a broader range of substances that can target various microorganisms, including bacteria, viruses, fungi, and parasites. In essence, all antibiotics are antimicrobials, but not all antimicrobials are antibiotics.[100]

<u>Drugs Permitted for Use in the Production of Tilapia in Taiwan</u>

Antibiotics

Different antibiotics demonstrate distinct activity spectrums: some are active mainly against gram-negative bacteria, some are more active against gram-positive bacteria, such as streptococcus, the disease of most concern to the tilapia sector in Taiwan, whereas others have a broader spectrum of activity against bacterial pathogens (TFS 2013). As noted, data concerning the specific types and quantities of drugs used on tilapia farms in Taiwan were not identified; however, Table 3 shows the

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[99] https://worldpopulationreview.com/country-rankings/countries-that-recognize-taiwan
[100] https://microbiologysociety.org/membership/membership-resources/outreach-resources/antibiotics-unearthed/antibiotics-and-antibiotic-resistance/what-are-antibiotics-and-how-do-they-work.html

drugs that are permitted for use, per Article 3 of the Guidelines for the Use of Animal Drugs, Annex 1: Aquatic Animal Drugs.[101] [102] In total, the list of approved drugs includes 11 antibiotics and 1 insecticide.

Table 3: Drugs permitted for use in the production of tilapia in Taiwan and their method of application (Source: Guidelines for the Use of Animal Drugs, Annex 1: Aquatic Animal Drugs), including the respective WHO Categories for antimicrobials (Source: WHO 2024).

Aquatic Animal Drug	Administration & Dosage	Usage in Perciformes	Withdrawal Period (Day)	WHO Category*
Amoxicillin	Oral 40 mg/kg/day, continuously for 3 to 5 days	Broad-acting antibiotic. In fish, mainly used in the treatment of *Streptococcus* or photobacterium.	5	HIA
Ampicillin	Oral 20mg/kg/day, continuously for 3 to 5 days	Broad-acting antibiotic. In fish, mainly used in the treatment of streptococci or *Pasteurella* infections.	5	HIA
Doxycycline	Oral 50 mg/kg/day, continuously for 3 to 5 days	Broad-acting antibiotic. In fish, mainly used in the treatment of streptococcal infections.	20	HIA
Erythromycin	Oral 50mg/kg/day, continuously for 3 to 5 days	Medium wide-acting antibiotic. In fish, mainly used in the treatment of streptococcal infections.	30	CIA
Florfenicol	Oral 10mg/kg/day, continuously for 3 to 5 days	Broad-acting antibiotic. In fish, mainly used in the treatment of motile *Aeromonas*, *Edwardsiella*, *Streptococcus*, or photobacterium infections.	15	HIA
Flumequine	Oral 20mg/kg/day, continuously for 3 to 5 days	Antibacterial effect against gram-negative bacteria. In fish, mainly used for treatment of photobacterium, *Aeromonas*, and *Edwardsiella*.	8	HPCIA
Kitasamycin	Oral 80 mg/kg/day, continuously for 3 to 5 days	Treatment of bacterial infections in fish diseases	20	CIA
Lincomycin	Oral 40 mg/kg/day, continuously for 3 to 5 days	Treatment of streptococcal infections in Perciformes (except eels)	10	HIA
Oxolinic acid	Oral 20 mg/kg/day, continuously for 3 to 5 days	Treatment of bacterial infections in Perciformes, Salmoniformes, and Anura	30	HPCIA
Oxytetracycline	Oral 50 mg/kg/day, continuously for 3 to 5 days	Treatment of *Aeromonas*, *Vibrio*, or *Salmonella* infections in fish diseases	30	HIA
Spiramycin	Oral 40 mg/kg/day, continuously for 3 to 5 days	Treatment of streptococcal infections in Perciformes (except eels)	30	CIA

[101] https://law.moj.gov.tw/LawClass/LawGetFile.ashx?FileId=0000247098&lan=C
[102] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=L0040026

Trichlorfon (organophosphate insecticide)	Medicated bath at 0.2 to 0.5 ppm once a week, continuously for 4 weeks	Treatment of parasites on the body surface or outside the gills in Anguillariformes, Perciformes, and Cypriniformes	5	N/A

* WHO Categories: CIA: critically important antimicrobial; HIA: highly important antimicrobial; HPCIA: highest priority critically important antimicrobial; IA: important antimicrobial; MIA: medical important antimicrobial.

Other classes of veterinary medicines: Insecticides, Antiparasitics, Antifungals
As shown in Table 3, which includes all drugs approved for use in the production of tilapia in Taiwan, there are 11 approved antibiotics and 1 insecticide; no antiparasitic or antifungal drugs are included. The one approved insecticide is trichlorfon, an organic phosphorus pesticide that is commonly used in many countries for a range of pest control applications, including to control various parasitic infections in aquaculture and agriculture. The approved method of application for tilapia farmers in Taiwan is included in Table 3. Of note, because of concerns regarding neurotoxicity, the Taiwanese government has prohibited the use of organophosphorus insecticides in aquaculture, except trichlorfon (Chang et al. 2020). Further, according to the MOA website, there is a ten-year policy in place to cut pesticide use in Taiwan in half and, since 2017, pesticide manufacturers and sellers must record pesticide import and sales data, and regularly report these data to the competent authority. Also, each sales record must include information about the buyer, to facilitate any follow up that is deemed necessary by authorities.[103]

Note that vaccines and hormones are not presently used by the tilapia sector in Taiwan, so these chemicals are not discussed in this criterion. Hormones are commonly used for the purpose of sex reversal in tilapia culture (Hoga et al. 2018); however, as discussed further in Criterion 8: Source of Stock (*Production of all male tilapia*), YY male tilapia technology is used in Taiwan rather than hormones.

<u>Documented Chemical Use on Tilapia Farms and Their Ecological Impact</u>
Aside from communications with experts, which indicate that antimicrobials and pesticides are seldom used, it is challenging to understand the extent to which chemicals and veterinary drugs may or may not be used by the Taiwanese tilapia sector, because specific data on this topic do not appear to be publicly available. But comparative data from other tilapia farming nations in the region are available.

Proxy data indicate antibiotic use is moderate in tilapia production
Although data to characterize antibiotic usage (frequency and total amount) in Taiwanese tilapia farming are not readily available, a survey study by Rico et al. (2013) provides valuable insights into chemical use within the tilapia sector across China and Thailand. It reveals that chemical use in tilapia farming is moderate in these regions, with significant reliance on probiotics and feed additives. In China, tilapia farms utilize medicinal herbs and mineral premixes along with a moderate use of antibiotics and disinfectants. In Thailand, there is a notable emphasis on probiotics, with a high percentage of farms incorporating them into their production systems. Although this study does not provide specific data on the Taiwanese tilapia sector, it offers a useful proxy for understanding typical chemical use patterns in tilapia farming, suggesting that moderate chemical inputs with a greater focus on feed additives and probiotics are common management practices across these key aquaculture-producing countries.

Reported antibiotic usage in Taiwanese tilapia farming

[103] https://eng.moa.gov.tw/ws.php?id=2505540

Similar to the farms surveyed by Rico et al. (2013), communications with farmers in Taiwan indicate that probiotics are routinely used within the tilapia sector as a means of boosting the immune systems of fish (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). In addition, both the government and academic institutions have actively supported and trained farmers in using probiotics to enhance water quality, achieving notable improvements (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm). Experts comment that chemical therapeutants are used infrequently; however, when they are applied, the ones most commonly employed are amoxicillin, florfenicol, oxytetracycline, and oxolinic acid (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). A brief review of the known ecological impacts of these antibiotics follows. Note that, although these four antibiotics are all commonly used globally in aquaculture (Pepi & Focardi 2021) and are commonly used in aquaculture in various European countries (Rico et al. 2019), amoxicillin and oxolinic acid are not permitted for use in U.S. aquaculture.[104]

Ecological impacts of antibiotics most commonly used by tilapia farmers in Taiwan
Kovalakova et al. (2020) comment that the environmental impact of amoxicillin is relatively low in comparison to other antibiotics, but that more research is needed to fully understand its environmental hazards. Regarding oxytetracycline, these authors note that this antibiotic can have significant environmental impacts, particularly in terms of chronic exposure and the potential for the development of antibiotic resistance, and that more research is needed on these effects as well as the impact that it may have on aquatic organisms when it is mixed with other antibiotics. The broad-spectrum antibiotic florfenicol is exclusively used in veterinary medicine and is one of the most widely used antibiotics in global aquaculture; it is a synthetic analogue of chloramphenicol and has become a replacement for this drug. Florfenicol has the potential to induce antibiotic resistance in bacteria, disrupt microbial communities, inhibit the growth of algae, and impair physiological functions in various organisms, including invertebrates. Florfenicol is also persistent in the environment because of its stability, and researchers note that further research is required to gain a comprehensive understanding of these impacts and to develop effective mitigation strategies (Guo et al. 2024) (Trif et al. 2023) (Zhang et al. 2022). Oxolinic acid, a quinolone antibiotic that is commonly used in aquaculture, can also have a negative impact on the environment. It can persist in water and resist degradation, especially in natural water environments. This persistence can contribute to the development of antibiotic-resistant bacteria and have toxic effects on aquatic organisms. In addition, the presence of oxolinic acid in aquatic environments can disrupt natural microbial communities (Louros et al. 2020).

[104] https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs

As with antibiotic usage, it is unclear to what extent the tilapia sector in Taiwan may use trichlorfon—the only insecticide that is approved for use in tilapia production—although communications with experts do not identify this as a chemical typically used by the sector. The following is an overview of this chemical's known environmental impacts. The WHO's Environmental Health Criteria report on trichlorfon, which assesses environmental concentrations and human exposure, asserts that trichlorfon does not pose a health risk for the general population. Regarding its impact on environmental organisms, evidence suggests that trichlorfon is moderately toxic to fish and birds, and moderately to highly toxic to aquatic arthropods. This supports the recommendation that this insecticide should not be sprayed over water bodies or streams (WHO 1992). Note that in the U.S., trichlorfon was originally registered for use in 1955, when it was approved for application as an insecticide across a range of vegetable, fruit, and field crops, as well as on livestock, ornamental and forestry plants, agricultural facilities, and residential areas, and for managing parasites in fish within specified aquatic settings. In 1995, a safety review was conducted that considered all previous data submitted since 1984. It was decided that trichlorfon could still be used in certain situations, such as on golf course turf, home lawns, and in ornamental and bait fish ponds to control insects, but not for domestic food production (EPA 2001). Although there are no registered agricultural or other food/feed uses for trichlorfon in the U.S., it is still used in some other countries as a pour-on treatment for cattle. This use is classified as a food use in the U.S.; therefore, imported beef and beef by-products are required to comply with the established permissible level (maximum residue limit) for trichlorfon residues (EPA 2009), but this advice does not appear to extend to seafood imports.

Modeling chemical emissions in Taiwanese tilapia farming

Although no evidence or lack thereof about the subsequent environmental fate of chemicals used on Taiwanese tilapia farms was noted in the literature, one study was identified that sought to estimate the monthly averaged emission rates of oxytetracycline (OTC) used by the wider aquaculture sector in Taiwan. These estimates were based on certain models that used factors such as data concerning overall sales of antibiotics, which were wholly applied to aquaculture, although the authors noted that these therapeutants could also have been used in other applications, such as for domestic pets and in the rearing of chickens, pigs, and cows. The study acknowledged limitations, such as potential overestimation of emission rates, limited data for model validation, and the exclusion of time-varying emission rates and other influencing factors, and the authors recognized that this factor may have led to over-estimations in their findings. But they noted that the results of their modeling were consistent with similar studies in other countries. Overall, the study found a high risk of tetracycline resistance (tetR) gene selection in aquaculture ponds, with variable risks in rivers depending on the region and season, with the highest concentrations found in the Lanyang river basin (in the northeast) and the Agongdian river basin (in the south) (Lu et al. 2021). In addition to the Lanyang and Agongdian river basins, this study considered the river basins of five other rivers: the Potzu, Tsengwen, Yenshui, and Tungkang, which are in southwestern Taiwan where the majority of tilapia are farmed, and the Kaoping, one of Taiwan's longest rivers, which spans Kaohsiung City and Pingtung County in southern Taiwan, where some tilapia production also occurs.

Potential for antibiotic leaching to occur from Taiwanese tilapia ponds

When used in aquaculture settings, antibiotics are most frequently administered in feed; however, because sick fish often suffer from a loss of appetite, this can result in antibiotics from medicated feed dispersing into the pond water rather than reaching their intended target. Overall, it has been estimated by researchers that 75% of the antibiotics administered via medicated aquafeeds enter the aquatic environment as a result of leaching from unconsumed food as well as excretion by the cultured species (Debnath et al. 2023). Although no documented evidence of this being attributable to tilapia farming in

Taiwan was identified, the widespread detection of antibiotic residues in aquatic environments, from various sources, has been documented elsewhere. For instance, oxytetracycline and sulfamethoxazole have been detected in rivers in China at concentrations ranging from 174.9 ± 266.9 ng/L to 741.85 ng/L, while ciprofloxacin has been recorded in surface water in India at levels up to 635 ng/L (Debnath et al. 2023).

But the minimal discharge pond systems used by Taiwanese tilapia farmers would appear to significantly mitigate this potential risk. As discussed in Criterion 2—Effluent, because of water shortages, daily exchange rates are minimal (< 1%) and farmers typically use one or two adjacent ponds as reservoirs; this closed-loop system minimizes external water exchange, and water is infrequently discharged from farms. Consequently, the potential for chemicals to enter the surrounding environment from Taiwanese pond farms is considerably lower compared to regions where frequent water exchanges are standard practice.

<u>Discussion of Chemical Use on Taiwanese Tilapia Farms, According to Available Data</u>
Taiwan's regulatory framework for veterinary medicine in aquaculture focuses on controlling drug access, sale, and usage, as well as monitoring chemical residue limits in harvested fish. The Veterinary Drugs Control Act and the Veterinarian Act oversee drug quality, veterinary practices, and compliance with prescription-only drug use. These regulations prohibit prophylactic drug use, mandate that drugs be administered only after a veterinarian's diagnosis, and require documentation of drug name, dosage, application method, and withdrawal period. In addition, manufacturers and importers must report drug sales biannually, while government-funded clinics provide free veterinary services and record treatments in a centralized database.

Despite these comprehensive measures, farmers can evidently bypass veterinarian requirements by purchasing drugs directly from pharmacies, risking inappropriate drug use. Although compliance with residue testing appears high, recent U.S. border rejections of Taiwanese tilapia for drug residues highlight the potential regulatory enforcement limitations. Although these rejections are not definitive evidence of on-farm misuse, they underscore the risks in the absence of robust usage data.

As discussed further in Criterion 7—Disease, tilapia are generally considered resilient to disease, and the mortality rate of tilapia in Taiwan is between 65% and 95%. Thus, it would appear that the demand and usage of veterinary medicine may be relatively low, which is also supported by a review of proxy data from other tilapia producing nations. But without data to support this, it cannot be assumed. Even so, experts comment that antibiotics are seldom used, and when they are, the veterinary drugs most commonly employed are amoxicillin, florfenicol, oxytetracycline, and oxolinic acid. These are all considered highly important antimicrobials by WHO, except oxolinic acid, which is considered critically important. Without further data to describe the frequency and volume with which these drugs are administered, a precautionary approach to the scoring of this criterion is warranted. But tilapia ponds discharge water infrequently, which significantly reduces the likelihood of chemicals leaching into the surrounding environment. This factor must be carefully balanced against the uncertainties surrounding enforcement and data limitations.

Conclusions and Final Score
Taiwan has implemented a robust regulatory framework for veterinary medicine use, incorporating prescription requirements, residue testing, and compliance mechanisms. But gaps in enforcement, such as the ability for farmers to bypass prescriptions and recent U.S. border rejections, indicate areas for improvement. Determining the extent of chemical interventions across Taiwan's 2,000+ tilapia farms

remains challenging due to a lack of specific data, although proxy data from other tilapia farming nations suggest moderate chemical usage across the sector. Experts report that when chemical interventions are applied, the most commonly used drugs are amoxicillin, florfenicol, oxytetracycline, and oxolinic acid. Although these drugs are categorized as highly important or critically important antimicrobials by WHO, their reported infrequent use and the high compliance rates in residue testing somewhat temper concerns.

The key factor driving the score is the production characteristic of low discharge in Taiwanese tilapia farms. These farms typically operate with minimal daily water exchange (< 1%), because they need to conserve water in resource-limited regions. This low discharge rate significantly limits the potential release of chemicals into the surrounding environment. According to the Seafood Watch Standard for Aquaculture, production systems with infrequent or limited water discharge align with the guidance provided for a low–moderate concern score. Although data limitations necessitate a precautionary approach, the infrequent discharge of water provides a significant mitigation measure, reducing the potential for environmental chemical impacts. Consequently, Criterion 4—Chemical Use is scored a 6 out of 10, reflecting a low–moderate level of concern for chemical use in Taiwan's tilapia sector.

Criterion 5—Feed

Impact, unit of sustainability and principle

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

Feed parameters	Value	Score
F5.1a Feed Fish Efficiency Ratio (FFER)	0.260	
F5.1b Source fishery sustainability score		6
F5.1: Wild fish use score		7
F5.2a Protein INPUT (kg/100 kg fish harvested)	51.930	
F5.2b Protein OUT (kg/100 kg fish harvested)	14.000	
F5.2: Net Protein Gain or Loss (%)	–73.041	2.000
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	20.507	5.000
C5 Feed Final Score (0–10)		**5.450**
Critical?	NO	**YELLOW**

Criterion 5 Summary

Although detailed data on the specific composition of tilapia feeds used in Taiwan are sparse, the available information indicates that feeds contain low levels of fishmeal and fish oil, and primarily consist of crop ingredients. Communications with experts in the Taiwanese tilapia sector inform that economic feed conversion ratios range between 1.6 and 2.0, so an average eFCR of 1.8 has been used in the various feed calculations. A substantial usage of by-products sourced from tuna fisheries for fishmeal results in a low Feed Fish Efficiency Ratio (FFER) of 0.26, indicating that 0.26 MT of wild fish are required to produce the fishmeal needed to grow 1 MT of tilapia. Marine ingredient source fisheries are moderately sustainable, yielding a Factor 5.1: Wild Fish Use score of 7 out of 10. Data from Taiwanese feed companies show that the average weighted feed protein content for a typical on-growing diet is 28.85%. Given a whole tilapia protein content of 14% and an eFCR of 1.8, there is evidently a significant net loss of protein, which is calculated to be slightly over 73%, which results in a Factor 5.2: Net Protein Gain or Loss score of 2 out of 10. The feed footprint, calculated as the embedded climate change impact (kg CO_2-eq) of the feed ingredients, is 20.51 kg CO_2-eq per kg of farmed tilapia protein, which results in a score of 5 out of 10 for Factor 5.3: Feed Footprint. Factors 5.1, 5.2, and 5.3 combine to give a Criterion 5—Feed final score of 5.45 out of 10.

Justification of score

Feed Ingredients and Inclusion Levels

Although there are evidently numerous suppliers of tilapia aquafeeds in Taiwan, it is challenging to obtain data regarding the specific ingredients used, particularly because of the proprietary nature of such information. Therefore, the following is an aggregation of the data supplied by two domestic feed mills for on-growing diets, with an equal weighting applied to each (Table 4).[105] This weighting also takes into account the types of feed produced by either feed mill; one supplier solely produces extruded pellets, whereas the other produces 85% extruded pellets and 15% moist pellets.

Table 4: Composition of a typical tilapia on-growing diet compiled from aggregated data provided by two Taiwanese feed producers.

Ingredient	Aggregated inclusion level (%)
Fishmeal (from whole fish)	3.1
Fishmeal (from by-products)	3.1
Fish oil (from whole fish)	0.5
Fish oil (from by-products)	0.0
Distillers dried grains with solubles (DDGS)	11.0
Rice bran	11.0
Soybean meal	34.6
Wheat flour	22.0
Poultry by-product meal	6.2
Pork by-product meal	6.2
Vitamins and minerals/other	2.3
Total	**100.0**

Economic Feed Conversion Ratio

The feed conversion ratio is the ratio of feed given to an animal per weight gained, measured in mass (e.g., an 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 is used in the ensuing calculations.

Globally, FCRs vary significantly among small- and medium-scale tilapia farms due to several key factors, not least of which is the type of feed being used. Extruded feeds offer significant advantages over steam-pelleted or compressed sinking feeds, including complete gelatinization of polysaccharides, improved digestibility and stability, and the complete removal of anti-nutritional factors, which together provide better overall feed utilization and growth rates (El-Sayed 2020). Temperature also has a significant effect on FCRs; studies indicate that optimal growth and feed efficiency for Nile tilapia is achieved within a temperature range of 27–32 °C, which may vary for other tilapia species. Healthier fish also produce more favorable FCRs because they can convert feed more efficiently, and this will also result in higher survival rates. Water quality and nutrition are also of great relevance: increased crude protein, dissolved oxygen, and optimal pH levels significantly reduce FCRs and enhance growth rates. Higher initial stocking rates will also result in a more favorable, lower FCR (Mengistu et al. 2020).

105 Market share insight was not available so both suppliers are considered equally.

Based on 2018 production data and compound feed usage, Tacon et al. (2022) estimated the global eFCR for tilapia to be 1.7, whereas Mengistu et al. (2020), with specific reference to pond farming of tilapia, found that FCRs ranged between 1.5 and 2.5 in the systematic literature review that they conducted. Likewise, communications with experts in the Taiwanese tilapia sector indicate that there is considerable variation, with local eFCRs varying between 1.6 and 2.0 (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm), whereas some individual farmers in Taiwan report an eFCR of 1.67 (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). Considering all of these, an average eFCR of 1.8 has been selected as representative of the industry overall; this value is the average of eFCR values reported in personal communications and is in alignment with the other references cited.

Factor 5.1: Wild Fish Use

Factor 5.1 combines an estimate of the quantity of wild fish used to produce farmed tilapia in Taiwan with a measure of the sustainability of the source fisheries.

Factor 5.1a: Feed Fish Efficiency Ratio (FFER)

As shown in Table 5, the weighted average inclusion levels of fishmeal and fish oil used in on-growing diets are estimated to be 6.2% and 0.5%, respectively. Fishmeal inputs are sourced from both whole fish and by-products, in equal amounts, whereas the small amount of fish oil used is sourced from whole fish. Whole fish inputs are from Peruvian anchovy (*Engraulis ringens*), which is a whole-fish reduction fishery, whereas fisheries by-products are sourced from albacore tuna (*Thunnus alalunga*) caught in the Indian Ocean; of note, these albacore by-products are MarinTrust certified.[106] As stated previously, these data are based on information provided by two domestic feed mills; other feed manufacturers in Taiwan may use different species compositions or sources.

A detailed description of the calculation process used to determine the FFER value shown in Table 5 is provided in the Seafood Watch Standard for Aquaculture (in the Standard, see Appendix 3—Additional guidance for the Feed Criterion—Scenario 1: Single Feed Type—Equation 1). Standard yield values for fishmeal and fish oil have been applied: these are 22.5% and 5%, respectively (Tacon & Metian 2008).

[106] https://www.marin-trust.com/sites/marintrust/files/approved-raw-materials/THA19%20Albacore%20tuna%20in%20FAO%2061%2071%20Byproduct%20Surveillance%20July%202024_Final.pdf

Table 5: Parameters used and their calculated values to determine the use of wild fish in feeding tilapia farmed in Taiwan.

Parameter	Data
Fishmeal inclusion level (total)	6.2
Fishmeal inclusion level from whole fish	3.1
Fishmeal inclusion level from by-product[107]	3.1
Fishmeal yield	22.5
Fish oil inclusion level (total)	0.5
Fish oil inclusion level from whole fish	0.5
Fish oil inclusion level from by-product	0.0
Fish oil yield	5%
Economic Feed Conversion Ratio	**1.8**
FFER fishmeal	0.26
FFER fish oil	0.18
Assessed FFER	**0.26**

Using an eFCR of 1.8 and applying the standard yield values for fishmeal and fish oil, the marine inputs used to grow tilapia in Taiwan equate to an FFER of 0.26 for fishmeal and 0.18 for fish oil; the former is used as the assessed FFER because it is the higher of the two. Therefore, from first principles it can be determined that 0.26 MT of wild fish must be caught to supply the fishmeal required to grow 1 MT of tilapia, so the score for Factor 5.1a: Feed Fish Efficiency Ratio is calculated to be 0.26 out of 10.

Factor 5.1b: Sustainability of the Source of Wild Fish

This factor evaluates the sustainability of the fisheries supplying fishmeal and fish oil for Taiwan tilapia on-growing diets. The species and fisheries provided from the feed manufacturers for fishmeal and fish oil from whole fish is Peruvian anchovy (*Engraulis ringens*) and by-products are sourced from albacore tuna (*Thunnus alalunga*) caught in the Indian Ocean. The FishSource scores for Peruvian anchovy[108] are ≥ 6 for management strategy, manager's compliance, current stock health, and future stock health, whereas for fisher's compliance the score is ≥ 8. Together, this results in a fishery sustainability score of 6 out of 10 for Peruvian anchovy. All sourced albacore tuna (*Thunnus alalunga*) are caught from the Indian Ocean and are MarinTrust certified,[109] and equate to a score of 4 out of 10.

Combined, these various marine inputs, their associated inclusion levels, and Seafood Watch scores result in a Factor 5.1b score of 5.9, which is rounded to 6. Further details of the mechanics of this calculation can be viewed in the Seafood Watch Standard for Aquaculture (in the Standard, see Appendix 3—Additional guidance for the Feed Criterion—Factor 5.1b: Sustainability of the Source of Wild Fish).

In conclusion, with low fishmeal and fish oil inclusion levels, a significant amount of which is from by-products, the score for Factor 5.1b: Sustainability of the Source of Wild Fish is 6 out of 10. When combined, the Factor 5.1a and Factor 5.1b scores result in a final score for Factor 5.1 of 7 out of 10.

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[107] Note that 5% of the by-product fishmeal inclusion (i.e., inclusion level × 0.05) is included in the FFER calculations.

[108] https://www.fishsource.org/stock_page/1383

[109] https://www.marin-trust.com/sites/marintrust/files/approved-raw-materials/THA19%20Albacore%20tuna%20in%20FAO%2061%2071%20Byproduct%20Surveillance%20July%202024_Final.pdf

Factor 5.2: Net Protein Gain or Loss

This factor is a measure of the net protein efficiency of the fish farming process based on the feed protein inputs and the harvested fish protein outputs. Aggregating the data provided by the feed companies, the average feed protein content of a typical tilapia on-growing diet is 28.85%; when combined with the eFCR of 1.8, the total protein input per MT of tilapia production is calculated to be 519.3 kg. Next, considering the protein output of harvested tilapia, which is 14% (i.e., 140 kg protein per MT of tilapia), there is a considerable net protein loss of 379.3 kg, which is slightly over 73%. This warrants a Seafood Watch Score of 2 out of 10. Further details concerning this calculation can be reviewed in the Seafood Watch Standard for Aquaculture (in the Standard, see Appendix 3—Additional guidance for the Feed Criterion: Factor 5.2: Net protein gain or loss—Equation 8).

Table 6: The parameters used and their calculated values to determine the protein gain or loss in the production of farmed Taiwanese tilapia.

Parameter	Data
Protein content of feed (%)	28.85
Protein content of whole harvested species (%)	14
Economic Feed Conversion Ratio	1.8
Total protein INPUT per MT of farmed species (kg)	519.3
Total protein OUTPUT per MT of farmed species (kg)	140
Total protein LOSS per MT of farmed species (kg)	379.3
Net protein loss (%)	–73.041
Seafood Watch Score (0–10)	2

Factor 5.3: Feed Footprint

Factor 5.3: Feed Footprint is an approximation of the embedded global warming potential (GWP: 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[110] to estimate the GWP of 1 MT 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 the worst listed value for that ingredient is applied; this approach is intended to encourage data transparency and provision. But 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. The detailed calculation methodology can be found in the Seafood Watch Aquaculture Standard (in the Standard, see Appendix 4—Factor 5.3: Feed Footprint). 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. Table 7 shows the results of the embedded global warming potential of each ingredient, while the following text describes the methods used to match the Taiwanese tilapia feed ingredients with the available ingredients from the GFLI database.

Fishmeal and Fish Oil

- No tuna products or tuna by-products are listed in the GFLI database; therefore, the average value was calculated using closely matched ingredients (i.e., mackerel by-products).
- For Peruvian anchoveta, the GFLI database has a matching entry, which was selected.

[110] http://globalfeedlca.org/gfli-database/gfli-database-tool/

Terrestrial Crop Ingredients (grains, rice bran, soybean, and wheat flour)

- For soybean meal, since the origin is unknown, an average value between the global average value (GLO) and the worst listed value for this ingredient has been applied.
- For wheat (wheat flour), since the origin is unknown, the global average value (GLO) has been applied, which is the worst listed value for this ingredient.
- For rice bran, the origin of which is Taiwan, the value for China has been used as an approximate equivalent, since there was no value for Taiwan listed in the GFLI database.
- For distillers dried grains with solubles (DDGS), the average European value (RER) was selected as the best fit for this ingredient, because it is the only entry for this item listed in the GFLI database.

Terrestrial Animal By-Products

- Poultry by-product meal is not listed in the GFLI database; therefore, the value for poultry meal has been substituted as an approximate equivalent, with the country selected being the European value (RER).
- Pork by-product meal is not listed in the GFLI database; therefore, the value for pork meal has been substituted as an approximate equivalent with the country selected being the European value (RER).

Other

- For this category, the average European value (RER) for minerals, additives, and vitamins has been selected because it is the only entry for this item listed in the GFLI database.

As shown in Table 7, the estimated embedded GWP of 1 MT of tilapia feed is 1,595.02 kg CO_2-eq. Considering a whole harvested farmed tilapia protein content of 14% and an eFCR of 1.8, it is estimated that the feed-related GWP of 1 kg of farmed tilapia protein is 20.51 kg CO_2-eq. This results in a score of 5 out of 10 for Factor 5.3: Feed Footprint.

Table 7: Estimated embedded global warming potential of 1 MT of tilapia feed used in Taiwan.

Feed ingredients (≥ 2% inclusion level)	GLFI ingredient name used for calculations	Ingredient inclusion%	kg CO_2 eq/ MT feed
Fishmeal (from whole fish)	Fishmeal, from anchoveta, at processing/PE Economic S	3.1	19.36
Fishmeal (from by-products)	Fishmeal, from mackerel by-products, at processing/NO Economic S	3.1	10.35
Fish oil (from whole fish)	Fish oil, from anchoveta, at processing/PE Economic S	0.5	3.66
Distillers dried grains with solubles (DDGS)	Wheat distillers grains dried, at processing/RER Economic S	11.1	92.2
Rice bran	Rice bran meal, at processing/CN Economic S	11.1	39.15
Soybean meal	Soybean meal (solvent), at processing/GLO Economic S	34.8	1,164.07
Wheat flour	Wheat flour, at processing/GLO Economic S	22.2	167.21
Poultry by-product meal	Animal meal, poultry, at processing/RER Economic S	5.9	47.06
Pork by-product meal	Animal meal, pig, at processing/RER Economic S	5.9	31.82
Vitamins and minerals/other	Total minerals, additives, vitamins, at plant/RER Economic S	2.3	20.15
	Sum of total	**100.00**	**1,595.02**

Conclusions and Final Score

Although detailed data on the specific composition of tilapia feeds used in Taiwan are sparse, the available information indicates that they contain low levels of fishmeal and fish oil and primarily consist of crop ingredients. Communications with experts in the Taiwanese tilapia sector inform that economic feed conversion ratios range between 1.6 and 2.0, so an average eFCR of 1.8 has been used in the various feed calculations. A substantial usage of by-products sourced from tuna fisheries for fishmeal results in a low Feed Fish Efficiency Ratio (FFER) of 0.26, indicating that 0.26 MT of wild fish are required to produce the fishmeal needed to grow 1 MT of tilapia. Marine ingredient source fisheries are moderately sustainable, yielding a Factor 5.1: Wild Fish Use score of 7 out of 10. Data from Taiwanese feed companies show that the average weighted feed protein content for a typical on-growing diet is 28.85%. Given a whole tilapia protein content of 14% and an eFCR of 1.8, there is evidently a significant net loss of protein, which is calculated to be slightly over 73%, which results in a Factor 5.2: Net Protein Gain or Loss score of 2 out of 10. The feed footprint, calculated as the embedded climate change impact (kg CO_2-eq) of the feed ingredients, is 20.51 kg CO_2-eq per kg of farmed tilapia protein, which results in a score of 5 out of 10 for Factor 5.3: Feed Footprint. Factors 5.1, 5.2, and 5.3 combine to give a Criterion 5—Feed final score of 5.45 out of 10.

Criterion 6—Escapes

Impact, unit of sustainability and principle

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

Escape parameters	Value	Score
F6.1 System escape risk	4	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		4
F6.2 Competitive and genetic interactions		6
C6 Escape Final Score (0–10)		**5**
Critical?	NO	**YELLOW**

Criterion 6 Summary

Given the open nature of tilapia ponds in Taiwan and the potential for flooding to occur in culture areas, there is clearly a risk of tilapia escaping from farms. Although water exchange activities often present a significant escape pathway in other aquaculture settings, this is less of a concern in Taiwan, where farms discharge water infrequently due to water conservation practices. Escape risks are further mitigated by the implementation of best practices to minimize escapes, including the use of screens on inlet and outlet water pipes. Government subsidies also help mitigate escape risk by encouraging measures on farms such as increasing the height of embankments around ponds and making improvements to drainage systems. While the Seafood Watch Standard for Aquaculture considers ponds with low daily water exchange rates (0–3%) and minimal flood risk to pose a low to moderate escape risk, the low-lying areas where tilapia are farmed in Taiwan remain vulnerable to periodic flooding, thereby increasing the likelihood of escapes. Accordingly, the Factor 6.1: Escape risk for tilapia farms in Taiwan is assessed as moderate, which warrants a score of 4 out of 10.

Considering the potential competitive and genetic interactions (Factor 6.2) that may arise as a result of farmed tilapia escaping, these species are characterized by their robust physiological adaptability and prolific reproductive capacity; these traits have enabled tilapia to successfully acclimate to the many diverse environments into which they have been introduced worldwide. Although nonnative to Taiwan, resident tilapia populations have thrived here in natural environments since they were introduced in the 1940s. Advancements in YY male tilapia technology mean that the tilapia stocked in Taiwanese ponds are now predominantly male, so any escapes that occur nowadays will mostly be of male fish. As is the case in many other countries, tilapia have become an integral part of the local Taiwanese fish fauna found in brackish and freshwater environments.

Nevertheless, it is evident that the escape of cultured tilapia in Taiwan does present potential ecological risks, such as competition with wild species for habitat and food resources. In accordance with the Standard, and considering that tilapia have been fully ecologically established in Taiwan for many decades—due to introductions initially made for aquaculture and intentional release—Factor 6.2 is assessed as presenting a low to moderate risk in terms of potential competitive and genetic interactions, which results in a score of 6 out of 10 for Factor 6.2. Overall, Factors 6.1 and 6.2 combine to give a final score of 5 out of 10 for Criterion 6—Escapes.

Justification of score

Historical Introduction of Tilapia in Taiwan

Although tilapia are native to Africa and the southwestern Middle East, since the 1930s they have been introduced into many areas of the world in which they are nonnative. These introductions have occurred for a number of reasons, including for aquatic weed control, for recreational angling, and for aquaculture (Bonham 2022) (El-Sayed 2006) (Canonico et al. 2005). Estimates indicate that at least 140 countries have introduced various species of tilapia for aquaculture (Deines et al. 2016). Thus far, Nile tilapia, which is by far the world's predominantly farmed species of tilapia, is documented to have been introduced into 114 countries, including within Africa, and most of these introductions have been for aquaculture and fisheries enhancement. While tilapia have brought social and economic benefits to many of these nations, many have also documented a variety of adverse ecological and socioeconomic impacts from these introductions. El-Sayed & Fitzsimmons (2023) comment that the dispersal of tilapia into natural ecosystems from irrigation and aquaculture facilities is almost inevitable, so appropriate management measures must be implemented to mitigate the potential adverse effects.

Taiwan's first recorded introductions of tilapia were in 1944 and 1946, when a number of Mozambique tilapia were brought from Indonesia and Singapore, respectively. The *Taipei Times* comments that by the autumn of 1946, millions of tilapia were already being maintained in multiple locations across southern Taiwan. But in 1947, a flood led to the unintended release of many of these fish, which found their way into other farms, and local farmers began cultivating them.[111] These fish were subsequently bred, and their offspring stocked into numerous open aquatic systems, such as lakes and ponds. Soon thereafter, they became widely distributed throughout the country's natural waterways.[112] Over the next few decades, other species of tilapia were also brought into Taiwan and stocked, including Nile tilapia, which was introduced in 1966 (De Silva et al. 2004) (Kuo 1984) (Chuen & Huang 1981) (Chen 1954).

Factor 6.1: Escape Risk

Escape Risk and Mitigation

Production System Risk
The degree of escape risk inherent in any aquaculture operation is dependent on a range of factors, although a prime driver of such risk is how open a production system is to the environment; in this regard, floating cages and net pens present the highest degree of risk, followed by ponds, then flow-through raceways, partial recirculating systems, and finally closed recirculating systems (Senanan & Bart 2014). The ponds used to culture tilapia in Taiwan are evidently open to the environment, so there is an inherent risk of escape events occurring. Escape risk is further amplified by water exchange activities; however, as discussed in Criterion 2—Effluent, Taiwanese tilapia farmers discharge water infrequently. Because of water shortages, farmers collect rainwater to augment their water supply, which is

[111] https://www.taipeitimes.com/News/feat/archives/2017/04/30/2003669672
[112] https://pansci.asia/archives/95701

circulated between ponds and reused, with some ponds serving as reservoirs to address water shortages. While daily exchange rates are minimal (< 1%), this exchange typically does not involve any discharge into the external environment. During pond harvesting, water is transferred to adjacent ponds via underground pipes, and the emptied pond is left to dry and sterilize before being refilled for restocking (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Therefore, despite pond production systems being inherently at risk of escapes, the low-to-zero discharge rate helps to minimize the perceived system escape risk.

Flood Risk Relative to the Location of Farms

The probability of escapes is also influenced by the location of a farm (Senanan & Bart 2014). As discussed in Criterion 3—Habitat, tilapia production in Taiwan predominantly occurs in southwestern coastal regions. Because the interior of Taiwan is dominated by a large, high-relief mountain range, with the majority of the lowlands lying west of the range, the amount of land suitable for farming is limited; hence, fish ponds are typically situated near each other. The topographic gradient of the southwest region is also low, and fish farms in this region are primarily located near the coast, typically extending no more than 10–15 km inland (Hung et al. 2018). Of note, 88% of aquaculture land—not specifically for tilapia—is described by MOA as being located on flatlands (MOA 2024). Combined with the typhoons and heavy rainfall that typically occur each summer, severe flooding can occur in some areas during the summer months (Imani et al. 2021). To put this in context, Teng et al. (2006) commented that, over the last century, Taiwan had been affected by 350 typhoons and over 1,000 storms, resulting in significant flooding. Land subsidence in these low-lying areas exacerbates the impact of flooding when it occurs (Imani et al. 2021). Conversely, drought is a problem for farmers in some years (Cheng et al. 2022), such as in 2021, when no typhoons were recorded.[113] Overall, given the rainfall patterns, land subsidence, and the location of farms (flatlands, in riparian zones), it appears that tilapia farms are at risk of flooding.

Farm Practices and Biosecurity

Despite the flood risk presented by typhoons and storms, tilapia farmers in Taiwan view these events as critical opportunities to address chronic water shortages, by collecting heavy rainfall to restore their pond water levels. But if a farm is already at full capacity before a storm, gradual water discharge over the two to three days preceding a typhoon may be necessary to prevent flooding. These measures are taken to prevent fish escapes, ensuring that water levels remain manageable during severe weather events (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm).

The likelihood of escapes occurring is also dependent upon stocking densities, management, and maintenance practices, as well as the design of the system, particularly the implementation of escape barriers (Senanan & Bart 2014). Losses from escapes evidently incur considerable financial losses for farmers, so it is in their best interests to do their utmost to prevent them. Discussions with experts confirm that best management practices are typically employed by farmers to prevent such occurrences. Tilapia farms are equipped with barriers, such as screened water pipes, to prevent fish escaping from ponds. Also, a height differential is maintained between pond banks and pond water levels to further reduce the risk (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm).

Government initiatives to prevent fish escapes during adverse weather

[113] https://www.bbc.co.uk/news/world-asia-56798308

The government has significantly aided fish farmers in preparing for bad weather events by establishing agricultural meteorology stations in aquaculture areas, which provide real-time weather data and early warnings about extreme conditions. This proactive approach allows farmers to implement timely preventive measures, such as reinforcing pond structures and securing nets, to prevent fish from escaping during storms or heavy rainfall. In addition, the COA's disaster early warning platform and "weather and agricultural disaster prevention app" provide crucial information and guidance, enabling farmers to safeguard their operations effectively. These initiatives help to support the resilience of fish farms against adverse weather, minimizing the risk of fish escaping and helping farmers to maintain operational stability (MOA 2024).

Further, the government regularly implements workshops to teach farmers how to prevent fish from escaping (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm), which is also noted in the ASC audit reports that are available for the sector.[114] The government also provides subsidies to farmers to improve drainage systems[115] and to raise the height of embankments around their ponds to enhance river basin management[116]—both of which help to reduce escape risk (for more on these government incentives, see Criterion 3—Habitat, *Regulations regarding farm registration and subsidies*). Experts comment that, by encouraging higher embankments, this policy has successfully reduced the occurrence of escape events (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Escape Events and/or Evidence of Escapes/Recaptures

As noted, tilapia were introduced into Taiwan in 1944. Further introductions were made in the 1960s, 1970s, and 1980s (De Silva et al. 2004) (Kuo 1984); since then, tilapia have become naturalized in Taiwan and are now a popular sportfish with recreational anglers.[117] [118] Even though some escaped farmed tilapia are likely caught in this way, this cannot be considered a concerted effort to remove farmed escapes from the wild. Although farmers implement protocols to help minimize the risk of escapes, it is evident that they still occur, as is evidenced in news reports that document both aquaculture and agricultural losses in the wake of particularly acute weather events.[119] [120] [121] [122] Even so, experts note that under normal circumstances, escapes are rare. But extreme weather events, including typhoons and floods, may occasionally overwhelm the safeguards that are in place, leading to fish escaping from farms. Experts comment that these incidents have rarely occurred over the last 5 years (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm).

Factor 6.1: Final Score and Risk Conclusion

While the Seafood Watch Standard for Aquaculture considers ponds with low daily water exchange rates (0–3%) and minimal flood risk to pose a low to moderate escape risk (a score of 6), tilapia farms in

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[114] https://asc-aqua.org/find-a-farm/
[115] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181706
[116] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC181379
[117] https://news.orvis.com/fly-fishing/exploring-taiwan-on-the-fly
[118] http://www.taiwanangler.com/journal/tag/tilapia
[119] https://www.aquafeed.com/newsroom/news/aquaculture-losses-from-typhoon-morakot-worst-in-18-years/
[120] https://thefishsite.com/articles/damage-to-aquaculture-sector-totals-nt470-million
[121] https://www.usnews.com/news/world/articles/2023-08-05/heavy-rains-wreak-havoc-in-central-taiwan-in-wake-of-typhoon
[122] https://edition.cnn.com/2023/09/02/asia/typhoon-haikui-landfall-taiwan-intl-hnk/index.html

Taiwan are also located in flood-prone coastal areas (score of 0 or 2). Farmers do implement extensive preventative measures, including early warning systems, screened water pipes, maintained height differentials, and government-supported infrastructure improvements. In addition, experts indicate that escapes have been rare over the last 5 years, with incidents primarily occurring only during extreme weather events rather than being due to system failures. Therefore, an intermediate score of 4 (moderate risk) is deemed most appropriate because it best reflects both the inherent vulnerabilities of the geographic location and system type, while acknowledging the well-considered management practices, infrastructure, and systematic approach to risk management that have been implemented. This score recognizes that, while the farms face genuine environmental risks, these are being actively and effectively managed through multiple layers of protection and oversight. Accordingly, Factor 6.1: Escape Risk for tilapia farms in Taiwan is assessed as moderate, which warrants a score of 4 out of 10.

Factor 6.2: Competitive and genetic interactions

Both the characteristics of the farmed stock and the receiving waterbody have a significant bearing on the potential impact of aquaculture escapes (Senanan & Bart 2014). Although tilapia have historically been introduced into many tropical and subtropical regions—both intentionally and accidentally—in many instances, these introductions took place without any prior scientific assessment of the natural aquatic ecosystems where these introductions were made. As a result, an assessment of the environmental impacts related to such introductions can often only be inferred, and are also challenging to disassociate from other contemporaneous anthropogenic alterations that may have occurred (Bonham 2022).

Characteristics of Farmed Stock

Tilapia have a high physiological tolerance to a wide range of variable environmental parameters as well as a high reproductive capacity, and these characteristics have allowed them to adapt and thrive in the wide spectrum of environments into which they have been introduced worldwide (Bonham 2022) (Cassemiro et al. 2018) (El-Sayed 2006) (Boyd 2004) (SRAC 2005) (Pullin et al. 1997). It is relevant to note here that, in recent decades, the tilapia grown on Taiwanese farms are predominantly male, which is beneficial from a husbandry and production perspective; this has become possible by the ongoing development of YY male tilapia technology in Taiwan (for more information, see Criterion 8X—Source of Stock, *Production of all male tilapia*).

Interactions of Farmed Tilapia Escapes with Established Wild Populations

Historical records from MOA discuss the deliberate stocking of tilapia into lakes in the 1940s, which at the time was described as a great achievement.[123] From the early days of their initial introductions, tilapia were cultured in various open systems including earthen ponds, irrigation canals, reservoirs, and paddy fields: practices that made their establishment in natural waterways inevitable (El-Sayed & Fitzsimmons 2023) (Gu al. 2022). At the time, the establishment of tilapia populations in natural waterways was not viewed as an ecological concern but rather as a beneficial extension of aquaculture development, reflecting an era when environmental impacts were given little consideration. These introductions resulted in the naturalization of tilapia in both brackish and freshwater systems across Taiwan, meaning that tilapia are now a common and well-established component of local flora and fauna—as is the case in many other countries where they have been introduced (El-Sayed 2020). Given that Taiwan's resident tilapia are nonnative, genetic interactions are not a primary concern; however, the competitive impacts they exert on native species must still be considered.

[123] https://kmweb.moa.gov.tw/subject/subject.php?id=16628

Ecological Risk of Escapes

Perceptions of the ecological impact of tilapia introductions, whether intentional or accidental, vary widely among societies, researchers, and decision-makers and hinge on the intended objectives of these introductions. While one perspective emphasizes the adverse ecological effects on native aquatic environments, with over 75% of published research supporting the notion of negative impacts, an opposing viewpoint underscores the significance of social and economic benefits from these fish introductions, such as improved food security—despite evidence of ecological consequences (El-Sayed 2020). In addition, a more nuanced perspective suggests that the impacts of tilapia introductions are contentious and inconclusive, leaving room for debate on whether these negative impacts do in fact occur (El-Sayed, 2020).

In this regard, it is notable that the CABI[124] [125] Invasive Species Compendium entry for Nile tilapia in Taiwan lists its invasive status as "unrecorded" (Bonham 2022), which perhaps indicates that feral tilapia populations in Taiwan are not considered especially ecologically problematic. In alignment with this view, it is noteworthy that no data pertaining to the ecological impacts of escaped farmed tilapia in Taiwan were identified in a literature review for this factor. Also, sector experts note that tilapia is already a common fish in Taiwan's natural environment (rivers, seas, and wild areas) and that it is not considered a problem species (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Even so, it is interesting to note the comments in a recent news article, which notes that, "In most of Taiwan's waterways, we see the dominance of non-native, pollution-tolerant species such as tilapia, striped snakehead and Amazon sailfin catfish," the last of which is described as "extremely invasive."[126] Similarly, a Taiwanese news article from two decades ago states that: "In Taiwan, tilapia is . . . found in aquatic environments all over the island. In recent years, the introduction of foreign species has attracted the notice of Taiwanese, causing them to worry about damage to native species . . . Tilapia is an extremely territorial species that drives out other species. However, due to its high economic value, everyone happily accepted it" (TPM 2004).

Although no data regarding the impact of farmed tilapia escapes in Taiwan were identified, it is evident that the potential ecological risks of aquaculture escapes on receiving environments are varied. These risks include competition with wild species for crucial resources such as territory, feeding, and breeding sites. Escaped tilapia may also alter habitats by grazing on vegetation, releasing nutrients through excreta, and engaging in nest-building activities. Moreover, there is a risk that escapees may introduce and spread various pathogens and parasites to wild fish. Because tilapia are not native to Taiwan, they do not present a genetic risk to populations of wild conspecifics, and the literature notes that, because they are nonpredatory, the likelihood of adverse ecological effects from tilapia preying on other organisms is minimal (Senanan & Bart 2014). Tilapia feed on a quite low trophic level and are generally considered to be herbivorous detrivorous, or planktivorous, although many species also display omnivorous feeding habits (Canonico et al. 2005), consuming small aquatic animals such as crustaceans and insects. But in some environments, the presence of invasive Nile tilapia has been shown to destabilize local food webs, despite the low trophic level they occupy, such as in the Dongjiang River (part of China's Pearl River system) and in a northeastern Brazilian reservoir, as reported by Shuai et al. (2023).

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[124] Centre for Agriculture and Bioscience International (CABI) is an international, inter-governmental, not-for-profit organization

[125] https://knowledge4policy.ec.europa.eu/organisation/centre-agriculture-bioscience-internationalen

[126] https://www.taipeitimes.com/News/feat/archives/2022/03/09/2003774445

Factor 6.2: Final Score and Risk Conclusion
The Seafood Watch Aquaculture Standard considers that, in instances where farmed stocks are nonnative and they became fully ecologically established in the production region as a result of aquaculture > 10 years ago, there is a low–moderate risk, which results in a score of 6 out of 10. This scenario aligns with the situation in Taiwan, where tilapia have become fully established in natural environments since they were first introduced eight decades ago. Therefore, the score for Factor 6.2 is assessed as 6 out of 10.

Conclusions and Final Score
Since tilapia were introduced into Taiwan in the 1940s, aquaculture escapes and intentional releases have led to the establishment of resident populations throughout the country. Although water conservation practices on tilapia pond farms reduce water exchange-related escape risks, periodic flooding remains a significant concern. Mitigation measures, such as screens on water pipes and embankment improvements encouraged by government subsidies, help to reduce this risk. Despite these efforts, the low-lying geography increases the likelihood of escapes during floods. In accordance with the Seafood Watch Standard, this warrants an Factor 6.1 score of 4 out of 10, which accounts for both the evident flood risk and the low water exchange rates typically implemented by farmers.

Although no data were identified to enable an evidence-based evaluation of the ecological risks of farmed tilapia escapes in Taiwan, potential impacts include competition for resources with wild species, habitat alteration, and pathogen spread. Tilapia are characterized by their high physiological tolerance and reproductive capacity, both of which are attributes that make them able to adapt to and thrive in many different environments, worldwide. Since their introduction to Taiwan eight decades ago, tilapia have become part of the local fish fauna. In more recent times, farmed tilapia stocks in Taiwan are primarily male, due to advancements made in YY male tilapia technology; hence, any escaped tilapia will also predominantly be male. Considering these elements, the score for Factor 6.2 is 6 out of 10, reflecting the long-standing ecological establishment of nonnative tilapia in Taiwan from aquaculture and stocking activities that commenced 80 years ago, well exceeding the “more than a decade” criterion guidance outlined in the Standard. Factors 6.1 and 6.2 combine for a final score of 5 out of 10 for Criterion 6—Escapes.

Criterion 7—Disease, Pathogen, and Parasite Interactions

Impact, unit of sustainability and principle

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

Disease Risk-based assessment	Score	
C7 Disease Score (0–10)	**6**	
Critical?	NO	YELLOW

Criterion 7 Summary

In most global aquaculture settings, the impact of disease spillover from fish farms into the wider environment is poorly understood; this is also the case in Taiwan. Because of a lack of data available on this aspect of tilapia production in Taiwan, this criterion has been assessed using the Seafood Watch risk-based assessment, which comprises an assay of the different types of diseases experienced on farms and their prevalence with a review of the measures that are in place to prevent and contain them.

Though tilapia are generally considered to be resilient species, production intensification in recent years has led to an increase in disease events across the global sector. Bacterial diseases have had a particularly significant impact on worldwide tilapia production, especially streptococcosis, which is estimated to be responsible for ≈90% of the mortalities experienced on Taiwanese tilapia farms. An emergent viral disease, tilapia lake virus disease (TiLVD), has also caused significant mortalities worldwide but has had minimal impact in Taiwan to date. This demonstrates the strength of the existing disease management system in place, including robust biosecurity measures, effective surveillance, and timely management of outbreaks, which help mitigate the risk and impact of new diseases. Overall survival rates for tilapia in Taiwan, from stocking to harvest, are in the range of 65–95%.

A key factor in the assessment of this criterion is that Taiwanese tilapia farmers are keenly focused on conserving water because of ongoing shortages. The average daily water exchange rate is minimal (< 1%), and most water exchange occurs internally between ponds rather than leaving the farm. The main water source used by farmers is rainwater, which is collected and circulated between ponds, with one or two ponds often functioning as reservoirs. Water is only occasionally discharged into public drainage canals; for example, to prevent overfilling before a typhoon. This low-discharge farm practice significantly mitigates the risk of pathogen transfer from tilapia farms to the external environment.

To manage fish health issues, the government has established regional fish disease control stations in fish farming areas; these provide farmers with complimentary medical examination services, enabling them to promptly respond to any disease concerns as they arise. This is an important tool that helps to minimize the potential for disease outbreaks on farms, and a centralized database is used to track all cases. A supporting regulatory framework is in place to prevent the occurrence and spread of infectious animal diseases and to ensure that fish diseases are appropriately diagnosed, treated, and documented by veterinarians. Regional aquaculture associations also play an important role in disease management.

According to the Seafood Watch Standard for Aquaculture, a score of 6 is justified in situations where fish health management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm level, and the production systems may discharge water once per production cycle. Therefore, a low–moderate score has been assessed for this criterion, resulting in a final score of 6 out of 10 for Criterion 7—Disease.

Justification of score

Globally, limited research has been conducted on the dynamics of disease transmission from aquaculture facilities to surrounding ecosystems, and the potential impact of this spillover on wild fish populations remains poorly understood (Bouwmeester et al. 2021). Such data are also lacking in the context of tilapia farming in Taiwan, and data concerning the prevalence and types of disease affecting wild fish species were not identified. Because the disease data quality and availability is moderate–low (i.e., a Criterion 1—Data score of 5 out of 10 for the disease category), the Seafood Watch risk-based assessment methodology was utilized to assess this criterion.

Tilapia exhibit a high degree of resilience to water quality variations and stressors, and have generally been considered less susceptible to infectious diseases in comparison to many other aquaculture species (Debnath et al*.* 2023) (Liao et al. 2020) (Liping & Fitzsimmons 2011) (Boyd 2004). Even so, in recent years, as global production of tilapia has intensified, so have disease concerns, particularly from the emergence of new diseases. Tilapia are susceptible to infection by various genera of virus, bacteria, fungi, and protozoa, although bacterial diseases are particularly noted for their significant impact on the global tilapia sector (Abdel-Latif et al. 2020). Although bacterial and fungal infections in tilapia are often mitigated through antibiotic treatments, there is limited knowledge regarding therapeutic and containment strategies for waterborne and water-related viral infections in these species (Debnath et al*.* 2023) (Chen et al. 2022) (Yang et al. 2018) (Bacharach et al. 2016).

Communications with experts indicate that the prevalence of disease in the Taiwanese tilapia sector is fairly low, and overall survival rates from stocking to harvest are in the range of 65–95% (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). The following is an overview of the various diseases that affect global tilapia production, with a particular focus on those that have affected the Taiwanese tilapia sector in recent years.

<u>Overview of diseases that affect global tilapia production</u>

Viral Pathogens

Before 2009, viral diseases were not documented as presenting a significant husbandry challenge to global tilapia production (Bacharach et al. 2016). But this changed with the emergence of tilapia lake virus (TiLV), which has since garnered considerable attention for the high level of mortalities it has caused in many countries—both in wild and farmed tilapia (Lakshmi et al. 2023) (Jansen et al. 2019) (Chen et al. 2022) (Aich et al. 2022). While TiLV

Table 8: Summary of viral diseases that affect tilapia (Machimbirike et al. 2019).

Agent	Taxonomy	Genome	Tilapine Host	Affected Stage/Mortality	Published Geographical Distribution	References
Infectious pancreatic necrosis virus (IPNV)	**Birnaviridae, genus *Aquabirnavirus***	dsRNA, two segments, segment (A) 3.1–3.6 kb, segment (B) 2.8–3.3 kb	*Tilapia mossambicus*, *Oreochromis niloticus*	Surveillance examinations of selected species and stocks. Age not specified. No clinical outbreaks.	Taiwan, Kenya	Hedrick et al. 1983; Mulei et al. 2018
Viral nervous necrosis (VNN)	**Nodaviridae, genus *Betanodavirus***	Positive sense ssRNA, two segments, genome size 4.5 kb	*Oreochromis niloticus*	Genomic determination in tilapia seed, tilapia larvae. Mortality ranges from 20% to 100%.	Indonesia, France, Thailand	Prihartini et al. 2015; Bigarré et al. 2009; Keawcharoen et al. 2015
Tilapia larvae encephalitis virus (TLEV)	**Herpesviridae, Herpes virus-like virus**	6.4–7.2 kb capped positive-sense monopartite RNA, three segments	*Oreochromis aureus*	Laboratory-reared tilapia larvae with mortalities above 90%	Israel	Shlapobersky et al. 2010
Bohle virus	**Iridoviridae, genus *Ranavirus***	150–170 kb double-stranded DNA	*Oreochromis mossambicus*	Tilapia fry affected during field outbreak, up to 100% mortalities	Australia	Ariel and Owens, 1997
Iridovirus-like agent	**Iridoviridae, genus unknown**	Not sequenced	*Oreochromis niloticus*	Concurrent infections and mortalities in fry and disease symptoms in adult fish	Canada	McGrogan et al. 1998
Infectious spleen and kidney necrosis virus (ISKNV)	**Iridoviridae, genus *Megalocytivirus***	111–112 kb single, linear double-stranded DNA	*Oreochromis niloticus*, red hybrid tilapia (*O. niloticus x O. mossambicus*), red tilapia	Adult female (ovary), fertilized eggs, fry stages, fingerlings. Mortality 50–75%.	U.S. Midwest, Thailand	Subramaniam et al., 2016; Suebsing et al., 2016; Dong et al., 2015b
Lymphocystis disease virus (LCDV)	**Iridoviridae, genus *Lymphocystivirus***	102.6–209 kb dsDNA	*Tilapia amphimelas*, *T. esculenta*, *T. variabilis*, *Haplochromis* sp.	Juvenile tilapia and mature *Haplochromis* sp., no mortalities recorded	North Tanzania	Paperna, 1973
Tilapia lake virus (TiLV)	**Proposed as Tilapia tilapinevirus, genus *Tilapinevirus* (Orthomyxovirus-like)**	Negative-sense RNA, 10 segments, genome size 10.323 kb	*Oreochromis niloticus*, hybrid tilapia, red tilapia, red hybrid tilapia, *Sarotherodon galilaeus*, *Tilapiazilli*, *Oreochromis aureus*, *Tristamellasimonis intermedia*, wild black tilapia	Fingerlings and juveniles, adult fish, fertilized eggs, yolk-sac fish, fry. Mortality up to 90%.	TiLV has been reported in 13 countries across three continents: Asia, Africa, South America	

still predominates in literature pertaining to viral challenges affecting global tilapia production, an additional seven viral agents that cause disease in tilapia have been scientifically recorded: infectious pancreatic necrosis virus (IPNV); nervous necrosis virus (NNV); tilapia larvae encephalitis virus (TLEV); and the Iridovirus infections, namely Bohle iridovirus (BIV); infectious spleen and kidney necrosis virus (ISKNV); Lymphocystivirus; and iridovirus-like infection (Machimbirike et al. 2019). A summary of these eight viral diseases, including the species and regions affected, is provided in Table 8.

Tilapia Lake Virus Disease

Commencing in the summer of 2009, significant mortalities were observed in both wild and farmed hybrid tilapia in various regions of Israel, but at the time the reason was unknown. The causative agent was later identified in 2014 and named tilapia lake virus (TiLV), also known as syncytial hepatitis of tilapia (SHT) or tilapia tilapinevirus. Subsequently, tilapia lake virus disease (TiLVD) spread and was later reported in other countries across Asia, Africa, and the Americas, where it has affected both farmed and wild tilapia—sometimes resulting in quite high mortalities in the range of 80–90% (Kembou-Ringert et al. 2023) (Debnath et al. 2023) (Aich et al. 2022) (Surachetpong et al. 2020) (El-Sayed 2020) (Machimbirike et al. 2019) (Yang et al. 2018). Of note, the spread of TiLVD is thought to have originated from the absence of efficient control measures for the intra- and inter-continental movements of live tilapia for aquaculture (Machimbirike et al. 2019). The rise in the number of countries identifying TiLV in their tilapia populations, along with its detection in archived samples, implies that TiLV may have existed as a latent pathogen for several years before its discovery in 2014 (Jansen et al. 2019).

TiLVD is a notifiable disease, so outbreaks must be reported to the World Organization for Animal Health (WOAH, previously OIE)[127]; these outbreaks are subsequently recorded in the World Animal Health Information System (WAHIS) database.[128] Thus far the disease has not had a significant impact on the tilapia sector in Taiwan, although two minor outbreaks of TiLVD have been reported, as described in the following.

The first instance of TiLVD in Taiwan was reported in 2017 when the disease emerged in Taoyuan City[129] in the north. After the virus had been detected on 1 farm, 46 other tilapia farms within a 5-km radius with related drainage systems were put under surveillance. Samples from each farm in the surveillance area were tested by the National Reference Laboratory, Animal Health Research Institute (AHRI), and eight of these were confirmed positive for the presence of TiLV. But mortalities occurred only on the farm initially affected, where a mortality rate of 6.4% was observed; epidemiological comments on the WAHIS database note that these mortalities were considered to be caused by a secondary bacterial (*Francisella*-like bacteria) infection (WOAH 2024) (Surachetpong et al. 2020). The second TiLVD event was reported in 2022 on one farm in the Tucheng District of New Taipei City, also in the north. Only one farm was affected, and the mortality rate observed was 6.25%, which again was considered to be caused by a coinfection of TiLV and a bacterial infection (*Francisella* sp.). The WAHIS database notes that "No other cases of the same or similar diseases have been reported from other fish farms in Taiwan, as of January 5, 2023." This is echoed in discussions with in-country experts, who comment that viral diseases are not a significant concern for tilapia farmers in Taiwan; indeed, no other disease events for Taiwanese tilapia are noted in the WAHIS database at present.

Bacterial Pathogens

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[127] https://edis.ifas.ufl.edu/publication/FA213
[128] https:// is.woah.org/#/home
[129] https://www.intrafish.com/aquaculture/taiwan-steps-up-measures-to-contain-tilapia-lake-virus/2-1-109170

An overview of the bacterial pathogens that affect global tilapia production is provided in Table 9.

Table 9: Common bacterial disease agents, symptoms, and related treatment protocols for tilapia (El-Sayed 2020).

Agent	Species (Location)	Disease Symptoms	Treatment Protocols	References
Aeromonas hydrophila	*O. n* (China)	Erosion of skin and dorsal fin, body surface filled with blood, high mortality		Wang and Xu (1985)
	O. n (China)	Slow movement, caudal fin rot, swimming near water surface, poor appetite, mortality		Liu et al. (1993)
	O. n (Philippines)	Skin lesion, ulceration, fin rot, body discoloration, mouth sore, eye opacity, exophthalmia, dislodged eyeball, sluggishness		Yambot (1998)
Aeromonas jandaei and *Aeromonas veronii*	*O. n* (Thailand)	Mass mortality, dark body, abnormal swimming, loss of appetite, hemorrhage, and liver blood congestion		Dong et al. (2017a)
Aeromonas sobria	*O. n* (China)	Fin rot, mass mortality, skin darkening, ascites with abdominal swelling, hemorrhagic blots on liver, lack of feeding		Li and Cai (2011)
Pseudomonas sp.	*O. n* (Japan)	Fine white nodules in the spleen; abscesses in the swim bladder; exophthalmia; dark body; nodular lesions and focal necrosis in the liver, spleen, kidney, and gills; inflamed swim bladder; abscesses in the eyes, spleen, and swim bladder		Miyashita (1984). Miyazaki et al. (1984)
Vibrio sp.	*O. s* (Kuwait)	Lethargy, dark body color, dermal necrosis, high mortality		Saeed (1993)
Vibrio vulnificus	Hybrid (Taiwan)	Dark coloration, lethargy, skin hemorrhage and ulceration, liver splenomegaly and hemorrhagic lesions and septicemia		Chen et al. (2006)
Streptococcus sp.	*O. n* (USA)	Hyperemic gills, diffused epithelial tissue proliferation, lesions, dermal hemorrhage		Bowser et al. (1998)
	O. n (Taiwan)	Hemorrhage, exophthalmia, corneal opacity, dark coloration, abscess of trunk muscles	Erythromcin, Doxycycline	Tung et al. (1987)
	O. n x *O. a* (Saudi Arabia)	Erratic swimming, melanosis, exophthalmia, hemorrhage around the jaws and base of pectoral and pelvic fins, ascetic fluid in the abdominal cavity		Al-Harbi (1994)
Streptococcus iniae	*O. n* (USA)	Darkening skin pigments, bottom swimming, rising and falling, side swimming, losing appetite		Evans et al. (2000)
	O. n (USA)	Dark skin pigmentation, abdominal distention, hemorrhage, erythema, eye lesion, lethargy, reduction or cessation of feeding, circular swimming, side swimming	Oxytetracycline (75–100mg/kg feed)	Darwish and Griffin (2002)
	O. n (USA)	Loss of orientation, exophthalmia, corneal opacity, petechia around the mouth and anus, fluid accumulation in the peritoneal cavity	Tetracycline, Oxytetracycline; Sulfadimethoxine-ormitroprim (5:1)	Perera et al. (1994)
Streptococcus dysgalactiae	*O. m* (Brazil)	High mortality, anorexia, lethargy, tachypnoea, and skin darkness		Neto et al. (2011)

Agent	Species (Location)	Disease Symptoms	Treatment Protocols	References
Staphylococcus epidermis	*O. a* (Taiwan)	Lesions of spleen and kidney; apoptosis in lymphocytes and macrophages, brain, liver, gonads, mesentery, stomach, intestines and skeletal muscles		Huang et al. (2000)
Mycobacterium marinum	*O. n* x *O. m* x *O. a* (USA)	Small visceral granulomas, high epithelial macrophages and peripheral lymphocytes		Wolf and Smith (1999)
Mycobacterium fortuitum and *Mycobacterium marinum*	*O. n* (Mexico)	Body deformity; hemorrhage; exophthalmia; ulcers in head, mouth, and skin; multiple granulomas with thick capsules on spleen, liver, and stomach		Lara-Flores et al. (2014)
Flexobacter columnaris	*O. n* (USA), *Tilapia* sp. (Korea)	Respiratory disorder, fin erosion, body discoloration, lesion in muscles and skin, heavy mucus secretion	Oxytetracycline, Tetracycline, Chloramphenicol, Amikacine, Erythromycin, Kanamycin	Roberts and Sommerville (1982), Chun and Sohn (1985)
Edwardsiella tarda	*Oreochromis* spp. (Colombia)	Mortality, granulomatous inflammation, hemorrhage, necrotic meningitis, encephalitis, vasculitis with fibrinoid necrosis of the blood vessel walls; lesions in the brain, liver, kidney, spleen, and pancreas		Iregui et al. (2012)
Edwardsiella ictaluri	*O. n* (Chile)	Multifocal nodulation of the spleen, head kidney; hepatomegaly and inflammatory infiltrates in the spleen, head kidney, and liver		Soto et al. (2012b)
Yersinia ruckeri	*O. n* (Egypt)	Mortality, hemorrhages on mouth, fin and skin, hemorrhagic gastroenteritis and congestion of the internal organs		Eissa et al. (2008)

O. a = Oreochromis aureus; *O. m = Oreochromis mossambicus*; *O. n = Oreochromis niloticus*; *O. s = Oreochromis spilurus*; *T. z = Tilapia zillii*; *S. g = Sarotherodon galilaeus*.

Tilapia are susceptible to infection by various gram-positive and gram-negative bacteria, including those species belonging to genera such as *Vibrio*, *Aeromonas*, *Citrobacter*, *Edwardsiella*, *Flavobacterium*, *Pseudomonas*, *Mycobacterium*, and *Streptococcus*, although some types of bacteria (such as *Aeromonas* and *Pseudomona*) may also be present on healthy fish. Many bacterial diseases are multifactorial and are typically triggered by stress factors, such as suboptimal environmental conditions like poor water quality, which creates a chance for opportunistic bacteria to infect fish and induce disease (Haenen et al. 2023) (Chen et al. 2022). The following is a review of the bacterial pathogens that have affected the Taiwanese tilapia sector in recent years, of which *Streptococcus* is the primary cause of mortalities.

Streptococcosis

Streptococcosis is a disease caused by *Streptococcus* spp., a genus of gram-positive, nonmotile bacteria belonging to the family Streptococcaceae. *Streptococcus* spp. are noted as being among the main bacterial pathogens that affect tilapia, particularly *S. agalactiae*[130] and *S. iniae* (TFS 2024) (Debnath et al. 2023) (MacKinnon et al. 2023) (Chen et al. 2022) (Sudpraseart et al. 2021) (TFS 2006), both of which have affected tilapia aquaculture in Taiwan (Liao et al. 2020) (Gong et al. 2017), and both of which may be zoonotic (Haenen et al. 2023). The first case of streptococcosis to be reported by an aquaculture facility was in the mid-1950s in Japan; subsequently, the disease spread and is now considered to be a significant fish disease worldwide, affecting most principal cultured species (Liao et al. 2020). Conversations with farmers and experts in Taiwan indicate that streptococcal infection is also the disease of most concern to its tilapia sector (Taiwan Fisheries Research Institute November 2023 pers comm) (Wang Yifeng, General Manager of Kouhu Fisheries, September 2023 pers comm). Because this disease affects large-sized fish, its economic impacts are particularly severe (TFS 2006).

As a result of its significant impact on global aquaculture, streptococcus is one of the industry's most widely studied pathogens, especially regarding tilapia production. Streptococcosis outbreaks can be addressed with antibiotics when administered early in the disease; however, oral administration of antibiotics in feeds can pose challenges because of infected fish losing their appetite. As a consequence of these limitations, bespoke vaccines for this disease have been developed (Debnath et al. 2023) (Irshath et al. 2023) (El-Sayed 2020); however, uptake of these by fish farmers in Asia has been limited, and vaccines are typically not used by tilapia producers in Taiwan (ACAP 2022). This is particularly the case due to cost considerations, because tilapia is a relatively low-value fish (Taiwan Fisheries Research Institute November 2023 pers comm).

Researchers in Taiwan and elsewhere have observed that the infection rate of streptococcosis is more strongly associated with factors such as intensive farming, elevated water temperature (particularly during summer), and water quality, rather than the mere presence of the pathogen (TFS 2024) (Haenen et al. 2023) (Liao et al. 2020). Of note, *Streptococcus* spp. commonly occur in water and can also be isolated from healthy fish (Liao et al. 2020). Although tilapia mortality rates in Taiwan fluctuate from year to year, the majority are typically attributable to streptococcosis, which accounts for an estimated 90% of all mortalities within the sector (Taiwan Fisheries Research Institute November 2023 pers comm).

[130] https://hatcheryfm.com/news/editors-picks/hatchery-outlook-2024-fish/

While streptococcosis is the primary disease of concern to tilapia farmers in Taiwan, accounting for the majority of mortalities, other notable bacterial pathogens that impact fish health are *Aeromonas* and *Vibrio* spp. (Taiwan Fisheries Research Institute November 2023 pers comm).

Aeromoniasis

Aeromonas spp. are widely distributed in freshwater environments and are recognized as infectious and opportunistic organisms; thus, when stress factors are present on fish farms, the presence of these pathogens can give rise to the disease, aeromoniasis. *Aeromonas hydrophila* is particularly identified as a primary pathogenic bacterium in tilapia culture, which not only leads to significant mortality and diseases in cultured fish but also poses similar threats to wild fish, resulting in substantial losses of both. Fish suffering from aeromoniasis may experience both acute and chronic diseases, such as hemorrhagic septicemia, skin ulcers, and enteritis. Aeromonas coinfections with other bacteria are key factors in tilapia mass mortalities, and coinfections with TiLV have also been documented. Antibiotics are generally used to treat such infections on tilapia farms (Haenen et al. 2023) (MacKinnon et al. 2023).

Vibriosis

Fish vibriosis is characterized as a systemic infection caused by various *Vibrio* spp., which include *V. harveyi*, *V. parahaemolyticus*, *V. alginolyticus*, *V. anguillarum*, and *V. vulnificus*; the latter is the major pathogenic *Vibrio* spp. Vibriosis is commonly linked to brackish and marine aquaculture, making tilapia cultured in these environments susceptible (Haenen et al. 2023). *V. vulnificus*, which is widely present in marine and brackish water, was first isolated and documented on tilapia farms in Taiwan by Chen et al. (2006). Interestingly, these outbreaks only occurred on farms operating in freshwater and low-salinity environments (< 10 ppt), whereas higher salinity farms in the vicinity were unaffected. While vibriosis can manifest differently depending on the host and bacterial species, the acute form consistently presents as a septicemia, which causes mortalities, particularly in immunocompromised hosts (Haenen et al. 2023).

Francisellosis

Francisellosis is also recognized globally as one of the major diseases that affect tilapia, both farmed and wild, and its occurrence has been documented in Taiwan (Haenen et al. 2023). As noted, coinfection with *Francisella* spp. was identified in both instances of TiLVD that have thus far been detected in Taiwan.

Other conditions/Diseases of note: Parasitic and fungal diseases of tilapia/Coinfections

The literature and expert communications indicate that parasitic and fungal diseases are not significant constraints to Taiwan's tilapia sector, though tilapia are susceptible to such diseases. In contrast to bacterial and viral infections, which require species-level identification to ascertain the most appropriate treatment, it is usually sufficient to identify parasites at the genus-level (Islam et al. 2023).

Table 10: Common parasitic diseases, symptoms, and related treatment protocols for tilapia (El-Sayed 2020).

Agent	Species (Location)	Disease Symptoms	Treatment Protocols	References
Ichthyophthirius multifiliis	*O. m.*, *O. a*, *T. z*, *O. m* x *O. n* (USA)	Low growth, white spots on fins and epidermis		Lightner et al. (1988)
	O. m fry (UK)	High mortality		Subasinghe and Sommerville (1986)
	O. m (USA)		0.5 mg/L $KMnO_4$, single dose	Straus and Griffin (2001)
Trichodina	*O. n* (Cameroon)	Loss of escape reaction, scraping against tank walls, rapid opercular movement, jumping out of water	1: formalin bath, 250 ppm for 35–49 minutes. 2: $KMnO_4$, 5 ppm for 10–15 minutes	Nguenga (1988)
	O. m., *O. a*, *T. z*, *O. m* x *O. n* (USA)	Gill hyperplasia, eroded fins, epidermal ulcers, high mortality		Lightner et al. (1988)
Paratrichodina africana	*O. n* (Brazil)	Lesions in the gills, epithelial hyperplasia, desquamation and mononuclear and eosinophilic infiltrate		Valladão et al. (2013)
Epistylis sp.	*O. n* males (Brazil)	Inflammation, higher lymphocyte number, lower neutrophil numbers, erosions on the head and lateral line		Valladão et al. (2014)
	O. n (Vietnam)	Massive mortality in nursery stage		Lua et al. (1999)
Myxobolus ovariae	*O. n*, *S. g* (Nigeria)	Inflammatory reaction, resorption of ovary tissue, replacing gonads tissue with the spores, gonadal atrophy and low GSI	Culling infected fish, water filtration to eliminate the spores	Okaeme et al. (1989)
Myxobolus sp.	*Oreochromis* sp. (Mexico)	White nodules in the gills, dark skin, exophthalmia, loss of appetite, increased abdominal volume, congestion and thickening of intestines		de Ocampo and Camberos (1998)
Cryptobia branchialis (Costia)	*O. m* (USA)	Thick mucus on gill surface, swelling of gill filaments, reduction of respiratory lamellae and hypertrophy of respiratory epithelium	Use formalin baths	Kuperman et al. (2002)
Dactylogyrus sp.	*O. n* (Cameroon)	Rapid opercular movements, opercula held open, thickened edges of gills and destruction of branchial epithelium	1: A single dose of formalin (250 ppm for 35–40 min). 2: Two repeated doses of $KMnO_4$, 5 ppm for 10–15 minutes	Nguenga (1988)
Alitropus typus	*O. n* (Thailand)	50–100% mortality		Chinabut (2002)
Renocila thresherorum	*T. z* (Egypt)	Eroded gill filaments, degenerative lesions including destruction, detachment, hyperplasia and fusion of the primary and secondary gill lamellae		Ali and Aboyadak (2018)
Lamproglena sp.	*O. n* (Ethiopia, Kenya, Uganda)	Gill damage, epithelial sloughing off and thick mucus secretion		Florio et al. (2009), Akoll et al. (2012a)
Acanthogyrus sp.	*O. n* (Philippines)	Decreased hematocrit volume and RBC, increased WBC, proliferation of lymphocytes and eosinophilic granulocytes, lesions and exfoliation of the mucosal layer		Pallet et al. (2016)

Agent	Species (Location)	Disease Symptoms	Treatment Protocols	References
O. a = Oreochromis aureus; *O. m = Oreochromis mossambicus*; *O. n = Oreochromis niloticus*; *O. s = Oreochromis spilurus*; *T. z = Tilapia zillii*; *S. g = Sarotherodon galilaeus*.				

Common parasitic diseases that affect the global tilapia sector are shown in Table 10, whereas common fungal diseases are shown in Table 11. Parasitic and fungal infections do not appear to be a notable concern for tilapia farmers in Taiwan, but as elsewhere, they may be implicated in coinfections, whereby different pathogens can infect the same host simultaneously, thereby amplifying their pathogenic impact and increasing the host's susceptibility and the likelihood of a disease outbreak occurring. Researchers also note the role that ectoparasites often play in the development of coinfections: when a host becomes infested with ectoparasites, this provides an opportunity and point of entry for a second, or multiple, coinfecting pathogen(s). Numerous studies have been conducted to investigate the prevalence of coinfections involving bacteria, parasites, fungi, and viruses in various species of tilapia. But as of yet, there is limited understanding of the mechanisms of pathogenicity and interactions among pathogens in the context of coinfections. Researchers also note that treatment is frequently targeted solely at the apparently dominant pathogen and other disease agents are often overlooked, thereby diminishing the potential effectiveness of such treatments. Interestingly, coinfections may sometimes reduce disease severity compared to single pathogen infections (Islam et al. 2023) (Buchmann 2022) (Abdel-Latif et al. 2020). Coinfections have also been documented in wild populations of tilapia in Africa (Abdel-Latif et al. 2020).

Table 11: Common fungal diseases, symptoms, and related treatment protocols for tilapia (El-Sayed 2020).

Agent	Species (Location)	Disease Symptoms	Treatment Protocols	References
Saprolegnia parasitica	*O. n* (Egypt)	Cotton-like growths on the skin and fins, listlessness, erratic swimming, and rising near water surfaces or resting on the bottom	Potassium permanganate and hydrogen peroxide	Zahran et al. (2017), Sherif and Abdel-Hakim (2016)
Branchiomyces	*O. n x O. m*, *O. n x O. a* (Israel)	Damage of gill tissue, high mortality		Paperna and Smirnova (1997)
Branchiomyces demigrans	*O. n* (Egypt)	Massive mortality, gill tissue damage, rapid movement of gill operculum, hyphae and spores embedded in gill tissues	Clotrimazole and clove oil	El-Bouhy et al. (2014)
O. a = *Oreochromis aureus*, O. m = *Oreochromis mossambicus,* O. n = *Oreochromis niloticus*, O. s = *Oreochromis spilurus*, T. z = *Tilapia zillii*, S. g = *Sarotherodon galilaeus.*				

Mitigating disease spread from tilapia farms: regulations, practices, and impacts

On-Farm Disease Spillover and Related Potential Impacts on Wild Species

Because the ponds used by tilapia farmers in Taiwan are open systems, the potential exists for on-farm diseases to spill over into the surrounding environment, particularly when culture water is discharged. Open pond systems are also vulnerable to the entry of pathogens and parasites from the local environment, which may be introduced by multiple vectors, such as fry, feed, wildlife, and incoming water. Such introduced pathogens and parasites could, in turn, become amplified in the pond and then be retransmitted into the environment via effluents, with the potential to negatively affect wild species in the vicinity. But this is a challenging aspect of farming to monitor and quantify, both in Taiwan and elsewhere.

Concerning parasites, Shinn et al. (2023) comment that, while tilapia harbor a diverse array of parasites, many of which have been translocated during global fish movements, there is no evidence of introduced tilapia parasites having an adverse impact on native fish populations. But as Islam et al. (2023) note, aside from exception cases in which mass mortality has been caused in wild fish populations due to parasitosis, it is generally challenging to assess the impact of parasitic disease on natural fish populations, because predators and scavengers tend to remove diseased and dying fish promptly. This is evidently also the case when wild fish succumb to viral, bacterial, and fungal diseases, which makes the monitoring of such diseases in wild populations particularly challenging. This underscores the need for a risk-based assessment approach to evaluate potential spillover impacts. Therefore, the following sections consider the regulatory landscape as it pertains to disease management, as well as relevant farm practices.

Regulatory Framework and Management of Aquaculture Diseases in Taiwan

The Statute for Prevention and Control of Infectious Animal Diseases,[131] which is under the remit of the Ministry of Agriculture (MOA), is the regulatory tool enacted to prevent the occurrence, transmission, and spread of infectious animal disease. Though this statute specifically mentions tilapia, it applies to a broad spectrum of animals. It covers the preventative measures that must be adhered to and stipulates that the owners and keepers of animals must report to the animal health inspection authorities if their animals are suffering from, or are suspected of suffering from, infectious animal diseases or if their animals die of unknown causes. The statute also stipulates the control procedures and requirements to be followed in the event of an epidemic. Additional provisions concerning quarantine measures, loss compensation, and penalties for violations, etc., are specified.

The Veterinarian Act[132] regulates the veterinary profession in Taiwan: it specifies the qualifications required to practice veterinary medicine as well as the legal requirements for operating a veterinary animal care facility. Article 10 stipulates that a practicing veterinarian must not issue a diagnostic certificate or write a prescription without personally performing the diagnosis and/or treatment, nor should they issue an inspection certificate without personally conducting the inspection. Article 12 states that a practicing veterinarian shall make entries about the diagnosis, treatment, and/or inspection in the corresponding medical record or inspection record when conducting diagnosis, treatment, or inspection; and that for each visit, the treatment date, physical conditions, and diagnostic results, as well as prevention, medication used, and treatment performed must be recorded. As stipulated in Article 13, if a veterinarian is alerted to a notifiable infectious animal disease, they must give farmers instructions about the disinfection and quarantine methods to be implemented, and identify and report the species, name of the disease, and the name and address of the owner or caregiver to the local competent authority within 24 hours.

The Animal Health Inspection Division (AHID), a department under the MOA, plays a pivotal role in the supervision of animal health inspections and disease prevention, and it also oversees veterinary

[131] https://www.ampeid.org/documents/taiwan-province-of-china/statute-for-prevention-and-control-of-infectious-animal-diseases/
[132] https://www.ampeid.org/documents/taiwan-province-of-china/veterinarian-act/

medicines and their usage (for more information, see Criterion 4—Chemicals). In addition, the division works to enhance animal disease diagnosis capabilities and develops disease control techniques.[133]

Farm-Level Biosecurity Practices and Control Measures
Although tilapia pond farms in Taiwan are evidently open systems and there is a risk of pathogen transfer from ponds to the external environment, a key factor that must be considered while assessing this risk is that farmers discharge water infrequently. Because of water shortages, farmers practice water conservation, resulting in minimal discharge from their farms. The average daily water exchange rate is typically less than 1%, mainly to compensate for evaporative loss, and most water exchange occurs between the farmers' own ponds rather than leaving the farm. Farmers primarily rely on rainwater, which they collect and circulate between ponds using underground pipes, with one or two ponds often serving as reservoirs. Water is only discharged to public drainage canals occasionally, such as before a typhoon to prevent overfilling. This practice significantly reduces the risk of diseases spreading from tilapia farms to the external environment.

As noted, ponds are also vulnerable to the entry of pathogens and parasites from the external environment, such as from fry, feed, wildlife, or incoming water. As will be discussed further in Criterion 10X—Introduction of Secondary Species, fry are raised and transported in sterilized water, meaning that fry are an unlikely pathogen vector; this is also the case with the feeds used, because these comprise formulated diets. Although farmers can, when advised, access municipal water supplies, their primary water source is rainwater collected directly on the farm. Regarding wildlife that interacts with the farm, farmers generally perceive predation by wildlife on their farms as minimal, with small fish being the primary targets (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). Some farmers use bird netting during the fingerling stage to prevent losses, though it is typically removed once fish reach a certain size. But many farmers do not find such measures necessary (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & May 2024 pers comm).

To manage fish health issues, every county and city government in Taiwan has established an aquatic animal disease inspection station in fish farming areas, a practice that dates to the late 1990s (Cheng 2017). These facilities, which are staffed by licensed veterinarians, provide farmers with complimentary medical examination services. An online Treatment and Diagnosis System (TDS) is used to manage cases and record data. Combined with ongoing analysis of climatic factors, this helps to minimize the potential for disease outbreaks in Taiwan's tilapia sector (Liao et al. 2020). Communications with experts indicate that veterinary inspection stations are located near farms, so farmers only need to transport sick fish a short distance (a 5–30 minute drive) to obtain such services. Free water quality analysis is also available to farmers at these government facilities through regional fish disease control stations (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Communications with farmers indicate that probiotics are routinely used, with the aim of boosting the immune system of fish. In addition, if farmers observe any sick fish, they promptly remove them from the pond and seek veterinary advice. Together, these measures help to contain and prevent the spread of on-farm diseases (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). The effectiveness of these measures is evidenced by the swift containment of tilapia lake virus (TiLV) outbreaks in Taiwan in 2017 and 2022. Mortalities were limited to a single farm on both occasions, reflecting the robustness of national biosecurity measures. As noted on the website of the Aquaculture

[133] https://www.aphia.gov.tw/en/ws.php?id=6133

Development Association (ADA), regional aquaculture associations also play an important role in disease management by facilitating the collection of disease data collection, collaborating with epidemic prevention units, and working with scholars and experts to provide training on disease awareness, prevention, and treatment to farmers.[134]

Overall, though tilapia pond systems in Taiwan may be susceptible to some pathogen introductions, particularly via wildlife interactions, the regulations and farm practices in place appear to significantly reduce the risk of pathogens and parasites being amplified on fish farms and retransmitted to local wild species. Infrequent water discharge practices, driven by water conservation needs, greatly reduce the risk of pathogen release into the external environment. Accessible veterinary services, disease monitoring systems, and farmer training further strengthen disease management. Together, these proactive strategies mitigate risks and demonstrate a robust framework for maintaining fish health and minimizing environmental impacts.

Conclusions and Final Score

In Taiwan, as is generally the case elsewhere, the impact of disease spillover from aquaculture ponds into the wider environment is poorly understood, which necessitates the implementation of a risk-based assessment for this criterion. Although no data were identified to quantify the impact of disease spillover from tilapia farms in Taiwan on wild species in adjacent environments, it is evident that on-farm diseases do occur—notably streptococcosis, which accounts for approximately 90% of the mortalities experienced. Even so, the sector has a fairly high survival rate of 65–95%, indicating that disease pressure from streptococcosis is relatively low.

Pond systems are, by design, open to the environment, which means that pathogens and parasites can both be introduced from the surrounding environment and can also be discharged back into it, with the inherent risk of negatively affecting wild species. But the low-discharge practices that characterize tilapia farms in Taiwan significantly mitigate the risk of pathogen transfer from culture ponds to the external environment. This risk is further reduced by the regulatory provisions that are in place, the provision of complementary and accessible veterinary services, disease monitoring systems, and farmer education programs. Together, these measures form a robust framework for managing fish health while mitigating environmental risks and supporting biosecurity.

According to the Seafood Watch Standard for Aquaculture, a score of 6 is justified in situations in which fish health management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm level, and the production systems may discharge water once per production cycle. Therefore, a low–moderate score has been assessed for this criterion, resulting in a final score of 6 out of 10 for Criterion 7—Disease.

[134] https://www.fish1996.com.tw/service.html

Criterion 8X: Source of Stock—Independence from Wild Fish Stocks

Impact, unit of sustainability and principle

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

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

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0–10)		**0.0**
Critical?	NO	**GREEN**

Criterion 8X Summary

Tilapia species have been farmed since ancient times, and today they are one of the world's most abundantly cultured finfish. Their dominance in aquaculture has been made possible due to the many favorable characteristics that they exhibit, allowing them to be easily domesticated and propagated in captivity. But before breakthroughs in monosex culture techniques, a significant constraint to the sector's development was tilapia's trait of early sexual maturation. This tended to result in uncontrolled spawning events occurring in production ponds, which caused overcrowding, stunted growth, and suboptimal culture conditions. Since the mid-20th century, researchers in Taiwan have been at the forefront of R&D efforts to refine and improve tilapia propagation and culture techniques, including the development of broodstock programs. These endeavors have enabled the production of specific strains of tilapia in Taiwan that are well suited to local culture conditions. Because the tilapia sector in Taiwan has no reliance on wild tilapia stocks, the score for Criterion 8X—Source of Stock is 0 out of 10.

Justification of score

As discussed in the Introduction, tilapia were introduced to Taiwan in the 1940s. The first species of tilapia to be introduced and cultured was Mozambique tilapia (*Oreochromis mossambicus*), followed shortly by a number of tilapia species including Nile tilapia (*Oreochromis niloticus*). Taiwan soon became a global leader in tilapia production, as evidenced by historical FAO production statistics (FAO 2025). By the mid-1980s, Taiwan initiated international sales of farmed tilapia, becoming the first country to do so (Bonham 2022).

Historical evidence shows that Nile tilapia was already being farmed in Egypt more than 3,500 years ago (Teletchea 2019), which is testimony to its ease of reproduction and survival. Tilapia possess many natural traits that make them well suited for aquaculture, such as a high physiological tolerance to a wide range of environmental conditions, but a significant early constraint to development of this sector in modern times was this species' trait of early sexual maturation. Because tilapia naturally reproduce at a young age, often before reaching a marketable size, this typically led to uncontrolled spawning in production ponds, which resulted in overcrowding and stunted growth, as well as other challenges related to suboptimal culture conditions. Consequently, the primary focus of early tilapia research was methods to control reproduction (Wohlfarth & Hulata 1981); global breakthroughs achieved in this area of research resulted in tilapia production rising exponentially toward the end of the 1980s (Teletchea 2019). As Taiwan's aquaculture technologies advanced, new tilapia strains and hybrids were developed to enhance specific traits such as high fecundity, rapid growth, cold resistance, and tolerance to saltwater conditions (Wohlfarth & Hulata 1981).

Fisheries Research Institute

Taiwan's Fisheries Research Institute (FRI), which dates to 1913, has played a significant role in the development of the aquaculture sector in Taiwan. Of particular importance to the tilapia sector is the Freshwater Aquaculture Research Center (FARC), one of six separate research centers that operate under FRI. FARC engages in numerous R&D activities, including the refinement of tilapia culture techniques.[135] FARC's stated mission is:

- Conservation and breeding of freshwater species.
- Development of propagation and culture techniques for freshwater species.
- Studies on the prevention and cure of diseases affecting freshwater species.
- Studies on the nutritional requirements and artificial feeds for freshwater species.
- Collection, storage and utilization of genetic information from freshwater species.
- Extension for the propagation and culture techniques of freshwater species.
- Selling fry of freshwater species to farmers.

The FRI website lists a number of FARC's ongoing research and development activities, including a project to improve tilapia breeding techniques, that seek to:

- Breed excellent pure or hybrid strains of tilapia.
- Produce all-male tilapia.
- Breed pure-red, red tilapia.
- Analyze the genetic variation of tilapia populations using biotechnological methods.

GIFT Tilapia and Hybrid Tilapia: The Two Major Tilapia Strains that are Cultured in Taiwan

As noted in the Introduction, in FAO statistics, all of Taiwan's tilapia production is generically recorded in the category "Tilapias nei" (not elsewhere included), even though farmers in Taiwan typically refer to their stocks as Nile tilapia. In fact, there are two major types of tilapia that are farmed in Taiwan, which are referred to as commercial strains rather than specific species. One of these is a strain of Nile tilapia referred to as GIFT, which is an acronym for Genetically Improved Farmed Tilapia.

The GIFT tilapia strain accounts for approximately 60% of tilapia production in Taiwan (Taiwan Fisheries Research Institute November 2023 pers comm). GIFT was developed through a pioneering selective breeding program that was launched in 1988 by WorldFish and partners in the Philippines. The initial GIFT population was established with a mix of wild Nile tilapia from Egypt, Ghana, Kenya, and Senegal, along with farmed Nile tilapia from Israel, Singapore, Taiwan, and Thailand. Employing a systematic breeding method inspired by successful salmon and trout programs in Norway, the GIFT method involved rearing full-sibling families of fish in separate enclosures, tagging them with microchips, and transferring them to communal ponds where growth rates could be monitored, compared, and tracked. By the conclusion of the initial project in 1997, six generations of GIFT had been developed, resulting in an improved strain that grew up to 85% faster than the fish used at the start of the breeding program. Of note, the primary purpose of the GIFT project was to produce a fast-growing and adaptable strain of

[135] https://en.tfrin.gov.tw/ws.php?id=58

tilapia suitable for both small-scale and commercial aquaculture, with the aim of helping to address global poverty and hunger[136] (Teletchea 2019).

The balance of tilapia production in Taiwan is mostly a commercial strain referred to as hybrid tilapia, which is a cross between Nile tilapia females and blue tilapia males (*Oreochromis aureus*) (Taiwan Fisheries Research Institute November 2023 pers comm). Favorable characteristics noted for this strain are improved survival at lower temperatures as well as a higher percentage of male offspring (Thodesen et al. 2013). Some farmers also produce hybrid red tilapia, although this accounts for only a small percentage of total production (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Also, Taiwan produced the world's first red tilapia in the late 1960s by crossing a mutant reddish-orange female Mozambique tilapia with a standard male Nile tilapia (Lutz 2021) (SRAC 2005) (Modadugu & Acosta 2004).

Production of all male tilapia

For decades, the practice of mixed-sex culture has been widely implemented by tilapia producers in many countries; however, during the last two decades, the focus has shifted significantly to monosex culture, whereby sex reversal techniques are used to produce either all male or all female fish (El-Sayed 2020). But tilapia male monosex cultures are the norm because males exhibit much higher growth rates than females (Teletchea 2019). One advantage of monosex tilapia culture is that farmers can control the negative impacts of uncontrolled spawning on production. Monosex culture of tilapia encourages rapid growth rates and efficient feed utilization, improves tolerance to variable environmental conditions, reduces aggression, helps achieve uniformity in size at harvest, and promotes disease resistance (El-Sayed 2020).

One method that has been used extensively to influence sexual determination in aquaculture is hormonal sex reversal. But this practice has attracted much criticism because of the potential for the hormones used to enter the food chain and the environment. For example, the hormone methyltestosterone, which is commonly employed in this procedure, is recognized as a carcinogen with the potential to cause liver damage or disrupt normal reproductive functions in both humans and animals. In the late 1990s, the United States made the sex reversal of tilapia a licensed procedure, and in Europe, the direct use of hormones was banned outright (El-Sayed 2020) (Teletchea 2019) (Hartley-Alcocer & Bink 2014) (Penman & McAndrew 2000).

Taiwan initially used hormones to facilitate sex reversal in tilapia fry; however, as Taiwan's technology in this field advanced, this approach was replaced with hybridization techniques and YY male tilapia technology (Taiwan Fisheries Research Institute November 2023 pers comm). The production of all-male XY populations of Nile tilapia from YY males has been described by some authors as the most successful sex-reversal and breeding program to date in the global tilapia sector, and the one with the most favorable economic outcome for farmers (Hartley-Alcocer & Bink 2014). Taiwan's ongoing research into YY male technology, which is now in its 12th year of development, is able to reliably produce fry that are 95–97% males (Taiwan Fisheries Research Institute November 2023 pers comm).

The technology developed at FARC is then disseminated to the commercial tilapia hatcheries, where closed-cycle broodstock produce fry that supply Taiwan's tilapia sector. Though some farmers may keep a few broodstock onsite for their own experimentation, virtually all the tilapia fry stocked by farmers in

[136] https://worldfishcenter.org/project/genetically-improved-farmed-tilapia-gift

Taiwan come from just six large-scale hatcheries,[137] which focus exclusively on fry production (Taiwan Fisheries Research Institute, November 2023 pers comm).

Conclusions and Final Score

Taiwan has been a leader in the development of tilapia propagation and culture techniques since the mid-20th century. At present, two commercial strains of tilapia are farmed in Taiwan: the GIFT strain and a local hybrid produced by crossing Nile tilapia and blue tilapia. Because the tilapia sector in Taiwan does not rely on wild tilapia stocks, the score for Criterion 8X—Source of Stock is 0 out of 10.

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[137] A 2019 industry publication noted that GaoZheng Tilapia Breeding Company was producing 50% of Taiwan's tilapia fry (Source: Aqua Culture Asia Pacific Magazine—Volume 15 Number 4 July/August 2019, p. 20) https://issuu.com/aquacultureasiapacific/docs/aq19138_aquaculture_julaug19_fa_lr

Criterion 9X—Wildlife Mortalities

Impact, unit of sustainability and principle

- *Impact: mortality of predators or other wildlife caused or contributed to by farming operations*
- *Sustainability unit: wildlife or predator populations*
- *Principle: 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.

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0–10)		0.0
Critical?	NO	GREEN

Criterion 9X Summary

Tilapia farming in Taiwan primarily occurs on the western coastal plain, which is an important habitat for waterbirds particularly because Taiwan is a stopover point on the East Asian–Australasian Flyway from the Arctic to New Zealand. Both migratory and local species of bird rely on the nation's wetlands, including artificial wetlands such as aquaculture ponds, so the main species of wildlife—and primary predators—on tilapia farms are birds, particularly egrets. The level of predation is generally perceived as minimal by farmers, and only small-sized fish are targeted. Some farmers install bird netting during the fingerling stage to prevent fish loss, typically removing it when fish reach a certain size, although many farmers do not feel the need for such measures. There are no specific requirements for the monitoring or reporting of wildlife interactions on tilapia farms. Thus, specific data on the frequency of these interactions and any related wildlife mortalities are lacking.

Wildlife protection regulations in Taiwan prohibit the hunting and killing of vulnerable species, and though permits can be granted for hunting general wildlife in specific circumstances, such activities are typically not permitted on pond farms. Penalties for illegally harming wildlife are strictly enforced, ensuring that both vulnerable and general wildlife species are safeguarded. Although Taiwan has many wetlands, including two of international importance, artificial wetlands have long been an integral part of the landscape and play a significant role in supporting high bird diversity and abundance. Despite the lack of data on mortalities, academic studies highlight the positive role of aquaculture ponds in providing habitat for birds and discuss how these habitats can be managed more proactively for the benefit of avian visitors; note that these literature sources do not report any instances of bird harm occurring on fish farms. Considering these factors, the risk of wildlife mortalities occurring on tilapia pond farms in Taiwan as a result of farming activities would appear to be quite low, so the final score for Criterion 9X—Wildlife Mortalities is 0 out of –10.

Justification of score
Because the wildlife mortalities data quality and availability is moderate–low (i.e., the score for the Wildlife Mortalities category in Criterion 1—Data is 5 out of 10), the Seafood Watch risk-based assessment methodology has been used.

Fish farms are often associated with a local increase in the abundance and diversity of wildlife, with birds and mammals frequently observed preying on aquaculture stocks. But the literature notes that there are limited data available on the consequences of these interactions. To assess the range of research that has been undertaken on this topic, Barrett et al. (2019) conducted a global review and meta-analysis of empirical studies examining interactions between aquaculture activities and vertebrate wildlife. Overall, these researchers concluded that such documented interactions are primarily driven by the presence of wild fish aggregations around sea cages and shellfish farms, and to a lesser extent by birds, while there are comparatively less references to other taxa.

As further noted by Barrett et al. (2019), the predation of birds on pond farms is well documented, and studies show that aquaculture sites tend to have a greater overall diversity of bird species than reference sites. But these authors commented that the variability in bird abundance responses across these studies makes it challenging to conclusively determine the impact on bird diversity. The main factor that likely draws organisms to most aquaculture systems is the presence of food, whether through direct predation on fish stocks or through an indirect food source such as spilled feed, waste, and deceased animals (Barrett et al. 2019). Communications with tilapia farmers in Taiwan indicate that birds are the main wildlife encountered on pond farms, although dogs and cats are also common visitors. Of these, only birds predate on live fish, whereas cats and dogs may seek out any dead fish (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

It is worth reiterating that the interior of Taiwan is dominated by forested mountains; consequently, the majority of the population lives on the western coastal plain. Thus, the western coastal region is where most human activity occurs, including aquaculture, which predominantly occurs in the southwest. The website of Taiwan's Forestry and Nature Conservation Agency (FNCA)[138] states that, though the island supports a diverse array of flora and fauna, the majority of its wildlife inhabits the sparsely populated mountains, while the lowlands, particularly the coasts, serve as important habitats for seabirds and wildlife. Notably, Taiwan's location along with its diversity of habitats make it is an important stopover point for migratory birds. The island is also home to over 650 bird species, which include 27 endemic species.[139] Although Taiwan makes up just 0.02% of the Earth's land area, its unique geographical and environmental conditions contribute to its rich biodiversity. Over 50,000 species, accounting for 2.6% of global species diversity, have been documented in Taiwan.[140]

<u>Wildlife Protections/Control</u>
According to the FNCA,[141] Taiwan's protected areas cover approximately 1,210,600 ha, representing about 19% of its land area, excluding overlapping and sea areas. These protected areas are managed in alignment with international conservation standards set by the International Union for Conservation of Nature (IUCN) categories (UNEP-WCMC 2024). To ensure the protection of its diverse habitats and

[138] https://conservation.forest.gov.tw/EN/0000075
[139] https://theworldsrarestbirds.com/birds/birds-in-taiwan/?utmcontent=cmp-true
[140] http://www.swan.org.tw/docdir/NYBK1V0WIX.pdf
[141] https://conservation.forest.gov.tw/EN/0001640

species, Taiwan has numerous regulations in place.[142] The following provides an overview of those most relevant to the tilapia sector in terms of this criterion's principle: preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

<u>*Governance*</u>

Wildlife Conservation Act

The Wildlife Conservation Act[143] was established in 1989 to uphold wildlife conservation, protect biodiversity, and maintain ecosystem balance. Article 8 stipulates that any development, construction, or land use activity should not compromise the original function of the ecosystem and must be carried out in a manner that minimizes impact on the respective area. Furthermore, Article 8 mandates that prior approval must be obtained from the competent authority to undertake any development activity within a designated important wildlife habitat. According to the Wildlife Conservation Act, general wildlife and protected species are classified differently and have different levels of protection.

- General Wildlife: General wildlife refers to all wildlife that are not classified as protected species. The law does not provide specific details about the protection measures for general wildlife; however, it can be inferred that general wildlife is not subject to the same level of protection as protected species. Hunting of general wildlife is allowed under certain conditions and is contingent upon obtaining a permit from local authorities or contracted organizations or groups. Local authorities are responsible for designating hunting areas and species, and these designations must be approved by the National Principal Authority (NPA) and publicly announced.

- Protected Species: Protected species include endangered species, rare and valuable species, and other conservation-deserving wildlife. These species have a higher level of protection compared to general wildlife. The Wildlife Conservation Advisory Committee is responsible for determining which animals belong to the category of protected species. The NPA is responsible for compiling and announcing the Schedule of Protected Species. The law prohibits the disturbance, abuse, hunting, killing, trading, exhibition, display, ownership, import, export, raising, or breeding of protected species, unless under special circumstances recognized in this or related legislation. Academic research or educational purposes and special circumstances approved by the NPA are some examples of exceptions to the prohibition.

In summary, the Wildlife Conservation Act provides more stringent protection measures for protected species compared to general wildlife. Protected species are subject to a complete ban on hunting, killing, trading, and other forms of utilization, except under specific circumstances. Offenses committed against protected species may result in penalties ranging from fines to imprisonment, depending on the offenses' severity. General wildlife, on the other hand, can be hunted under certain conditions and is not subject to the same level of protection as protected species. This act stipulates that a permit is required for hunting.

Animal Protection Act

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[142] https://www.fao.org/faolex/country-profiles/general-profile/see-more/en/?iso3=TWN&countryname=Taiwan%20Province%20of%20China&area=Wild%20species%20and%20ecosystems&link=aHR0cDovL2Zhb2xleC5mYW8ub3JnL2NnaS1iaW4veG1sLmV4ZT9kYXRhYmFzZT1mYW9sZXgmYW1wO3NlYXJjaF90eXBlPXF1ZXJ5JmFtcDt0YWJsZT1hbGwmYW1wO3F1ZXJ5PUFSRUE6V0IgQU5EIENDOlRXTiBBTkQgVDpBTEwgQU5EIFJFUEVBTEVEOk4gQU5EIFNVUEVSUzpOIE5PVCBSTzpZIEFORCBaOihMIFIgTSkgTk9UIFo6UCZhbXA7c29ydF9uYW1lPUBzcHJmV0ImYW1wO2xhbmc9eG1sZiZhbXA7Zm9ybWF0X25hbWU9QFhTSE9SVCZhbXA7cGFnZV9oZWFkZXI9RVhNTEgmYW1wO3BhZ2VfZm9vdGVyPUVYTUxG

[143] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC155541

Although the Animal Protection Act[144] specifically provides protection to domesticated animals, not wildlife, it is worth noting here because it extends protection to dogs and cats, as well as other pets and commercially reared animals. This law expressly forbids the harming, harassment, or mistreatment of such animals. Recent amendments include Section 14(1), which governs the capturing of animals. Under Taiwanese law, the use of traps, firearms (except for tranquilizer guns), poison, or corrosive substances to capture animals is now completely prohibited. Offenders are subject to a fine up to TWD75,000 (USD2,350 at the time of writing).[145] In addition, the government has a stated commitment to improving the management of stray animals.[146]

Farm Practices
As noted, farmers comment that birds are the principal wild predator encountered on tilapia pond farms. Even so, birds only predate on small-sized fish, so the amount of predation is reportedly minimal, and many farmers do not feel the need to use any deterrents (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm). Those that do wish to implement measures to prevent predation install bird netting over the pond during the fingerling stage; this helps to prevent the loss of small fish, and the netting is removed when fish reach around 60–80 g. Experts note that the most common avian visitors to pond farms are egrets, and that farmers are not permitted to shoot at or set traps to capture these animals. Furthermore, Taiwan, which has many designated wetland areas, is home to several rare bird species protected under the Wildlife Conservation Act; interfering with or harming these species is considered a serious offense, and the detection of such activities would result in imprisonment (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March & May 2024 pers comm). Regarding farm-level governance measures, communications with farmers indicate that there are no specific monitoring or reporting requirements in place with respect to on-farm wildlife interactions (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

Wildlife Species Population Status
The literature notes that, globally, the abundance of waterbirds is in decline due to the widespread loss and degradation of natural wetlands, which are being rapidly reclaimed, degraded, and fragmented. This decline in natural wetlands contrasts with the expansion of artificial wetlands such as aquaculture ponds and rice paddies, the development of which has often resulted in the conversion of natural habitats. Consequently, understanding how waterbird communities adapt to changing wetland landscapes and whether artificial wetlands can effectively replace lost natural habitats for waterbirds are critical concerns in conservation efforts (Bai et al. 2018). Thus, it is relevant to understand the history of artificial wetland development in Taiwan to better understand the impact that tilapia farms may have upon the status of predators or other wildlife attracted to farm sites, particularly birds, which have been identified as the main type of wildlife that interacts with fish ponds in Taiwan.

For more than 250 years, agriculture in Taiwan has depended on irrigation ponds to gather rainwater for irrigating rice paddies and terraces; hence, these artificial wetlands have been an integral part of the landscape for a considerable time. But by 1993, almost 36% of these ponds had been filled to accommodate local urban and industrial growth, and the literature notes that this decline in irrigation ponds has not been offset by an increase in fish ponds (Chen et al. 2019). It is notable that studies that consider interactions between birds and aquaculture ponds in Taiwan are primarily focused on how

[144] https://law.moj.gov.tw/Eng/LawClass/LawAll.aspx?pcode=M0060027
[145] https://www.hkalpo.com/newsandblogs/breakthrough-of-animal-protection-act-in-taiwan
[146] https://eng.moa.gov.tw/ws.php?id=9166

artificial ponds can best be managed to provide benefits to birds (Wang et al. 2020) (Tu et al. 2020) (Hsu et al. 2019) (Bai et al. 2018). The literature notes that aquaculture ponds and salt pans in Taiwan have a significantly positive effect on bird numbers and the variety of species present (Tu et al. 2020).

In Taiwan, both migratory and local species of bird rely on its wetlands and other aquatic ecosystems. Migratory waterbirds follow annual routes known as flyways. There are nine major flyways globally, including the East Asian–Australasian Flyway (EAAF) that spans from the Arctic to New Zealand and covers 22 countries, including Taiwan. The EAAF hosts more than 50 million migratory waterbirds from over 250 populations, including 36 globally Threatened and 19 Near Threatened species.[147] The decline of waterbird populations along the EAAF is primarily due to the loss of natural wetlands, while artificial wetlands like aquaculture ponds and rice paddies have expanded.

Although artificial wetlands generally support fewer waterbird species and individuals compared to natural wetlands, in densely populated areas where natural coastal lands are scarce, artificial wetlands have become essential habitats for waterbirds at high tide. A study conducted in Taiwan's Changhua County, which is a significant stopover and wintering site along the EAAF, found that waterbird richness and abundance were notably high in artificial wetlands, particularly during high tide when these habitats were the only refuge available (Bai et al. 2018). These finding are similar to those of another study conducted in Tainan, the region where most tilapia is farmed; researchers here suggested that pond aquaculture can enhance habitat for wild birds if farmers follow a practice of seasonal adjustments during production. This involves drawing down water levels in the ponds during certain periods to create resource pulses, concentrate prey, and provide accessible feeding habitats for waterbirds, particularly waders and shorebirds, while maintaining fish production in aquaculture ponds (Wang et al. 2020).

Of note, Taiwan has 60 wetlands (Ramsar Citizen 2024), including 2 wetlands of international importance that are located in Tainan: the Zengwun Estuary Wetland (Figure 18) and the Sihcao Wetland, the latter of which exhibits the highest amount of biodiversity along Taiwan's coastline. These wetlands are considered globally important for bird conservation and provide habitat for various bird species, including the endangered black-faced spoonbill; more than half the world's black-faced spoonbill population migrates to these two wetlands to overwinter (Imani et al. 2021). Taiwan's conservation efforts regarding this species appear to

[147] https://www.eaaflyway.net/the-flyway/

Figure 18: Aerial view of the Zengwun Estuary Wetland, one of Taiwan's two designated wetlands of international importance (photo credit: Taiwan Ministry of the Interior—MOI 2018).

be having a positive impact: the international black-faced spoonbill census for 2023 counted a record 6,603 of these iconic waterbirds, 64% of which overwintered in Taiwan.[148] Note that no data were identified concerning the number of mortalities that may occur on farms, or the overall risk of entanglement or other accidental mortality of wildlife on Taiwanese tilapia farms.

Conclusions and Final Score

In Taiwan, interactions between wildlife and tilapia farms are primarily limited to birds, which predate on small-sized fish; rare and migratory birds may occasionally be involved but egrets are the main avian visitors encountered. Although specific data on the frequency of these interactions are lacking, farmers generally perceive bird predation as being minimal and often do not take any preventative actions, although some farmers may install netting during the early fish growth stage.

There is a lack of data concerning the occurrence of wildlife mortalities on tilapia farms or the overall risk of accidental wildlife deaths from farm activities; furthermore, there are no regulatory requirements for the monitoring or reporting of wildlife interactions on farms. But both vulnerable and general wildlife species are protected by law: the hunting and killing of vulnerable species is strictly prohibited, and though a permit to hunt general wildlife may be approved in certain circumstances, this is typically not an activity that would be permitted on a tilapia farm. The law imposes penalties for illegal harm to wildlife, and enforcement of these measures is stringent, according to experts.

[148] https://www.taipeitimes.com/News/feat/archives/2023/04/26/2003798621

Although there is a lack of data concerning mortalities, it is notable that numerous academic studies were identified that discuss the ecosystem services provided by aquaculture ponds and how they can best be managed for the benefit of wildlife. The absence of any references to wildlife being killed or harmed on pond farms indicates that it is not something that commonly occurs.

The Seafood Watch Standard for Aquaculture considers the risk of impacts to wildlife to be low in instances when effective management practices for the nonharmful exclusion of wildlife are in place, and deliberate lethal wildlife control is not used or permitted. Considering the preceding information, and in accordance with this criterion's principle, this description is a good fit for the situation in Taiwan regarding wildlife interactions on tilapia pond farms. Thus, the final score for Criterion 9X—Wildlife Mortalities is 0 out of –10; i.e., zero deduction.

Criterion 10X—Introduction of Secondary Species

Impact, unit of sustainability and principle

- *Impact: movement of live animals resulting in introduction of unintended species*
- *Sustainability unit: wild native populations*
- *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.

Escape of secondary species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	10	
F10Xb Biosecurity of source/destination	0.0	
C10X Escape of secondary species Final Score	**0.0**	**GREEN**

Criterion 10X Summary

The Taiwanese tilapia sector does not require any international or trans-waterbody live animal shipments. Thus, no deduction is applicable, and the score for Criterion 10X—Introduction of secondary species is 0 out of –10.

Justification of score

The Seafood Watch Standard for Aquaculture states that Criterion 10X, which is defined as an exceptional criterion, will not be relevant to the majority of aquaculture production, yet it can be a concern for those production practices where it is relevant. The Standard further notes that, though conducting a complete analysis of the biological diversity of the source and the destination of animal or other material movements is impractical, a reasonable effort to determine the degree of distinctiveness of the ecosystems/environments in question should be made. The following considers the relevance of this criterion to the Taiwanese tilapia sector.

Factor 10Xa: International or trans-waterbody live animal shipments

As discussed in Criterion 8—Source of Stock (*Production of all male tilapia*), virtually all the tilapia fry stocked by farmers in Taiwan come from just six large-scale hatchery and broodstock facilities, which focus exclusively on fry production. These commercial hatcheries implement technology that has been developed by the Freshwater Aquaculture Research Center (FARC), which is one of six separate research centers that operate under Taiwan's Fisheries Research Institute (FRI). These hatcheries are located in the southwest of Taiwan in the regions of Chiayi, Tainan, and Pingtung, near the principal tilapia producing regions (see Figure 5 in the Introduction).

Although a detailed survey of the watersheds in production areas versus hatchery areas has not been conducted, information concerning the wider hydrological network in Taiwan provides some valuable insights that assist in evaluating this criterion. There are 151 rivers in Taiwan, but only 9 possess a basin area exceeding 1,000 km², which indicates that Taiwan's rivers are short and swiftly flowing. These rivers share similar climatic, geographical, and hydrological conditions, characterized by high sediment yield and concentration, warm climate, significant rainfall, and steep riverbed slopes (Luo & Liu 2016) (McCabe 2011) (Kao & Milliman 2005). These conditions reduce the likelihood of distinct ecological profiles developing across these river systems compared to regions with longer, slower-flowing rivers, because rapid water flow and frequent disturbance events tend to homogenize habitats and reduce the establishment of diverse ecological niches.

This hypothesis is further supported by McCabe (2011), who comments that, in faster-moving rivers, disturbances like high-water events can significantly reduce the abundance of certain organisms. Although riffle areas, where water flows quickly over shallow, rocky sections, tend to have diverse macroinvertebrate communities, the overall biodiversity is generally lower in these fast-moving sections compared to slower-moving areas, where deeper pools support more diverse fish communities. Thus, the speed of the water flow and the type of habitat play crucial roles in determining the biodiversity of river ecosystems. Along with the geographic clustering of hatcheries and production areas, which are relatively near one another, this would appear to diminish the potential for ecological distinctiveness between source and destination water bodies.

In addition to the shared hydrological characteristics of its rivers, Taiwan's compact geography and high population density (Hwang 2003) would appear likely to collectively minimize the potential for significant ecological differentiation between watersheds. This hypothesis is reinforced by the absence of any identified data contradicting these conclusions during an extensive review and literature search.

Although domestic hatcheries produce virtually all the tilapia fry stocked on farms, a small amount of fry may also be produced by farmers themselves, because some keep a few broodstock onsite for personal experimentation (Taiwan Fisheries Research Institute November 2023 pers comm). These practices are limited to individual experimentation by a small number of farmers and do not represent the standardized production practices or pose a significant risk with regard to this criterion. Because the production of tilapia in Taiwan is not considered to be reliant on trans-waterbody movements of fish, the score for Factor 10Xa is 10 out of 10 (i.e., no deduction).

Factor 10Xb: Biosecurity of source/destination

As noted in the Standard, if aquaculture production does not rely, to any degree, on trans-waterbody movements of animals or materials, if it is considered that there is no risk of movement of secondary species, and if the score for Factor 10Xa is 10 of 10, then Factor 10Xb does not need to be completed.

Conclusions and Final Score

The tilapia sector in Taiwan does not rely on trans-waterbody or international live animal movements. Consequently, no deduction is warranted, and the score for Criterion 10X—Introduction of Secondary Species is 0 out of –10.

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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 standard and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Standard document for a full explanation of the standards, calculations and scores.

Criterion 1—Data	
Data Category	**Data Quality**
Production	7.5
Management	7.5
Effluent	5.0
Habitat	5.0
Chemical Use	5.0
Feed	5.0
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	5.0
Escape of secondary species	10.0
C1 Data Final Score (0–10)	**6.591**
	Yellow

Criterion 2—Effluent	
Risk-based assessment	
2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	28.850
eFCR	1.800
Fertilizer N input (kg N/ton fish)	0.000
Protein content of harvested fish (%)	14.000
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	83.088
N output in each ton of fish harvested (kg)	22.400
Waste N produced per ton of fish (kg)	60.688

2.1b Production System discharge	Data and Scores
Basic production system score	0.240
Adjustment 1 (if applicable)	–0.080
Adjustment 2 (if applicable)	0.000
Adjustment 3 (if applicable)	0.000
Boundary adjustment (if applicable)	0.000
Discharge (Factor 2.1b) score (0–1)	0.160
Waste discharged per ton of production (kg N ton^{-1})	9.710
Waste discharge score (0–10)	9.000
2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	5
2.2b Enforcement of effluent management measures	3
2.2 Effluent management effectiveness	6.000
C2 Effluent Final Score (0–10)	**8**
Critical?	No

Criterion 3—Habitat	
F3.1 Habitat conversion and function	**Data and Scores**
F3.1 Score (0–10)	7
F3.2 Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measures	4
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	4.800
C3 Habitat Final Score (0–10)	**6.267**
Critical?	No

Criterion 4—Chemical Use	
All-species assessment	**Data and Scores**
Chemical use initial score (0–10)	6
Trend adjustment	0
C4 Chemical Use Final Score (0–10)	**6**
Critical?	No

Criterion 5—Feed	
5.1 Wild Fish Use	
5.1a Feed Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	3.100
Fishmeal from by-products, weighted inclusion %	3.100
By-product fishmeal inclusion (@ 5%)	0.155
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.500
Fish oil from by-products, weighted inclusion %	0.000
By-product fish oil inclusion (@ 5%)	0.000
Fish oil yield value, weighted %	5.000
eFCR	1.800
FFER Fishmeal value	**0.260**
FFER Fish oil value	**0.180**
Critical (FFER > 4)?	No
5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	5.941
Critical source fisheries?	No
SFW “red” source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW red and FFER ≥ 1)?	No
Final Factor 5.1 Score	**7.400**
5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	28.850
Protein INPUT kg/100 kg harvest	51.930
Whole body harvested fish protein content	14.000
Net protein gain or loss	–73.041
Species-specific Factor 5.2 score	**2**
Critical (Score = 0)?	No
Critical (FFER > 3 and 5.2 score < 2)?	No

5.3 Feed Footprint	Data and Scores
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	**20.507**
Contribution (%) from fishmeal from whole fish	1.214
Contribution (%) from fish oil from whole fish	0.229
Contribution (%) from fishmeal from by-products	0.649
Contribution (%) from fish oil from by-products	0.000
Contribution (%) from crop ingredients	91.700
Contribution (%) from land animal ingredients	4.945
Contribution (%) from other ingredients	1.263
Factor 5.3 score	**5**
C5 Final Feed Criterion Score	**5.5**
Critical?	**No**

Criterion 6—Escapes	Data and Scores
F6.1 System escape risk	4
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	4.000
F6.2 Invasiveness score	6
C6 Escape Final Score (0–10)	**5.0**
Critical?	No

Criterion 7—Disease	Data and Scores
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0–10)	**6**
Critical?	No

Criterion 8X—Source of Stock	Data and Scores
Percent of production dependent on wild sources (%)	0
Initial Source of Stock score (0–10)	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

Criterion 9X—Wildlife Mortalities parameters	Data and Scores
Single species wildlife mortalities score	0
System score if multiple species assessed together	n/a
C9X Wildlife Mortalities Final Score	**0**
Critical?	No

Criterion 10X—Introduction of Secondary Species	Data and Scores
Production reliant on trans-waterbody movements (%)	0
Factor 10Xa score	10
Biosecurity of the source of movements (0–10)	0
Biosecurity of the farm destination of movements (0–10)	0
Species-specific score 10X score	0.000
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**0.000**
Critical?	n/a

Appendix 2—Historical Context: Aquaculture Sector Development in Taiwan

Development of the Aquaculture Sector in Taiwan between the 1940s and 1990s

Tilapia were introduced into Taiwan in the 1940s, when a number of Mozambique tilapia were brought from Indonesia by the Japanese. A 1954 report published by the Chinese–American Joint Commission on Rural Reconstruction, "The Culture of Tilapia in Rice Paddies In Taiwan," (Chen 1954) notes that: "According to [an] unofficial report, about 6,000 hectares of rice fields and ponds were stocked with Tilapia in 1953 (3,000 hectares of rice paddies and 3,000 hectares of ponds)." Therefore, Tilapia farming was already well established in Taiwan by the 1950s.

By the 1960s, when Taiwan was emerging from the aftermath of World War II and Japanese occupation,[149] aquaculture was recognized as a sector with great potential. With strong support from the government, the industry began to grow significantly between the 1960s and the 1990s (Chang et al. 2020). Historically, Taiwanese agricultural policy gave land-use preference to rice production over aquaculture production, and rice is still considered Taiwan's most important food staple.[150] As a result, tilapia production mainly developed in areas that were unsuitable for agricultural cultivation (Tang & Tang 2006) (TPM 2004). The literature notes that, before the 1980s, the government had taken little notice when fish farmers converted land to fish ponds; hence, during this period some rice paddy fields were also converted for aquaculture, particularly in areas that had good access to groundwater, which farmers accessed by digging wells (Cheng 2017) (Sun et al. 2011). Notably, in Chiayi County, which supplies over 50% of Taiwan's rice, there is a dense network of coastal fish farms, which were originally converted from rice farms during the 1980s (Hung et al. 2018).

During the 1980s, the aquaculture sector in Taiwan flourished, and exports of eel, tilapia, and giant tiger prawns allowed the industry to prosper. But the proliferation of ponds from this economic boom created a much higher demand for water, which resulted in more wells being drilled and more groundwater being abstracted. This led to an array of environmental problems that became particularly evident in the early 1990s, which Tang & Tang (2006) describe as a "tragedy of the commons." One of the most severe impacts of the overextraction and pumping of groundwater was widespread land subsidence; however, with livelihoods at stake and no alternative source of water available to farmers, a hard crackdown on groundwater overexploitation was challenging to enforce without creating societal disharmony (Tang & Tang 2006).

Overview of Land Subsidence and Water Use Issues Exacerbated by Aquaculture Growth

Despite being an island that experiences a higher than average amount of rainfall that is 2.6 times the global average (Lai et al. 2019), Taiwan has a severe shortage of freshwater. This situation is expected to become more acute in the near future as climate change accelerates. This shortage is partly due to the characteristics of Taiwan's rivers, most of which are short and fast-flowing, but also to the alternating cycles of torrential rain and drought (Cheng et al. 2022) (Lai 2019) (Lai et al. 2019) (Sun et al. 2011) (Hwang 2003). This factor has had a significant impact on the course of industrial development, particularly for those sectors that rely most heavily on water resources; these water-dependent industries have also greatly affected Taiwan's hydrologic environment.

Although land subsidence, exacerbated by overextraction of groundwater, has frequently been cited as a key habitat impact of aquaculture development in Taiwan, land subsidence and coastal erosion have been long-standing concerns in southwestern Taiwan, with geodetic surveys documenting such impacts at least as far back

[149] https://theculturetrip.com/asia/taiwan/articles/taiwan-called-republic-formosa
[150] https://eng.moa.gov.tw/ws.php?id=9501

as 1904. The literature notes that this region has undergone significant changes from various coastal engineering works, particularly the construction of seawalls in response to land subsidence (Lin 1996). Land subsidence increases the risk of flooding, and in coastal areas it can also lead to coastal erosion and the salinization of coastal soils and aquifers (Chen et al. 2021) (Hung et al. 2018) (Lin 1996). Though aquaculture has often been referenced as a significant contributor to land subsidence, many other industries have a history of groundwater extraction, making it challenging to track the overall exploitation and use of groundwater in Taiwan (Lai 2019) (Hung et al. 2018). For example, some older literature notes that at least twice as much groundwater was being extracted for agriculture as for aquaculture (Sun 2011). Also, Taiwan's semiconductor sector, which supplies 90% of the world's most advanced computer chips, is heavily reliant on water resources.[151]

As surface water supplies could not meet the growing demand from expanding fish ponds, farmers resorted to drilling progressively deeper wells (Hung et al. 2018) (Tang & Tang 2006). A great deal of the wells that were built to support this expansion were unpermitted and thereby unregistered; the literature notes that, in 1995, 89% of wells being used to extract groundwater—for all activities, not just aquaculture—were unregistered or illegal (Tang & Tang 2006). Tang & Tang (2006) comment that, at this time, well drilling was a common practice because there were no other supporting infrastructure, such as reservoirs and aqueducts, that would enable farmers to gain access to water. Hence, the government's inaction over illegal wells was also partly an acknowledgement of their failure to supply an adequate supply of water to farmers.

This situation did not arise from total inaction by central government. Indeed, the first measures to tackle issues of ground subsidence related to overextraction of groundwater were implemented in 1969 in the Taipei Basin near the capital, and these measures were successful in curtailing subsidence in the region by the 1980s. But when the central government sought to tackle similar issues as they developed in the central and southwestern coastal regions, the situation was more complex, which made it challenging for local authorities to enforce mitigation policies. The reasons were varied and nuanced across different regions, although the literature notes that local government officials were often inclined to be sympathetic to the economic hardship that would beset local farmers if they were prevented from pumping groundwater, rather than pursuing a course of stringent enforcement. As a result, early management measures to address land-subsidence issues were a failure (Tang & Tang 2006). Another important factor is that in southwest Taiwan, the Eurasian Plate subducts beneath the Philippine Sea Plate at the Manila Trench, and this tectonic activity is also contributing to subsidence in the region; however, researchers still attribute most subsidence to human-related activities, suggesting that they account for around 70–82% of subsidence, depending on the area (Tran & Wang 2020).

[151] https://earth.org/the-taiwan-water-shortage-dilemma/

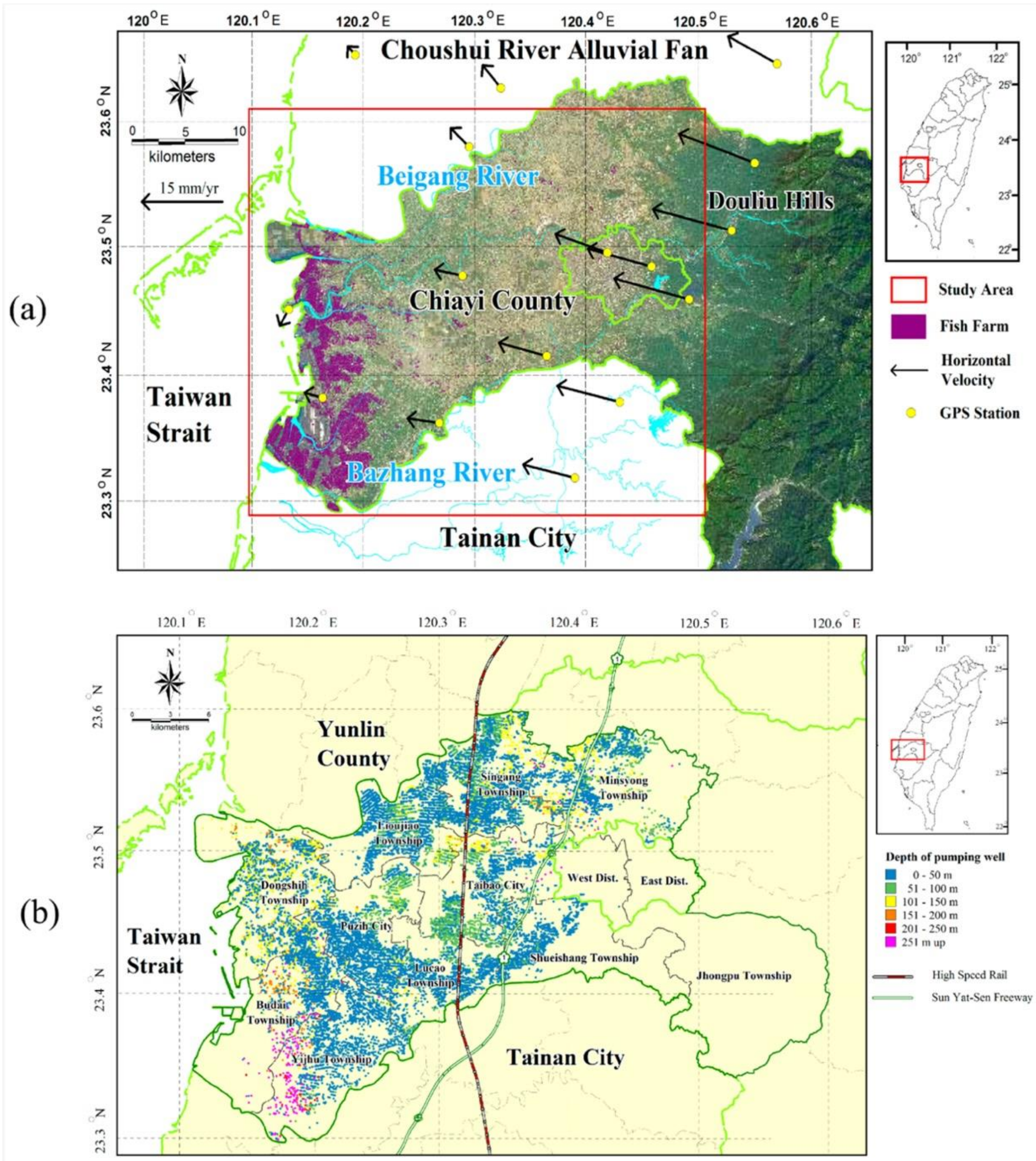

Figure 18: Maps of Chiayi County, Taiwan, highlighting (a) the distribution of fish farms and (b) the locations and depths of groundwater pumping wells. Reproduced from Hung et al. (2018), *Land Subsidence in Chiayi, Taiwan, from Compaction Well, Leveling and ALOS/PALSAR: Aquaculture-Induced Relative Sea Level Rise*. Reproduced with the kind permission of Professor Cheinway Hwang, Department of Civil Engineering, National Yang Ming Chiao Tung University, Taiwan.

To demonstrate the landscape of wells in Taiwan, Figure 19 illustrates the distribution, density, and varying depth of wells that have been drilled in Chiayi County, some of which exceed 250 m deep, and shows the regions where these wells have been used for aquaculture. As can be noted, fish farms are principally distributed near the coast, extending no more than 10–15 km inland. Wells drilled in this aquaculture zone were typically deeper than those found farther inland, where rice plantations predominate.

Policy Interventions Enacted to Mitigate Environmental Impacts of Aquaculture

In an effort to address the environmental concerns posed by the overextraction of groundwater and ground subsidence, the government began to restructure the aquaculture sector in the early 1990s. The Aquaculture Supervision Program, introduced in 1992, established aquaculture zones as well as regional fish farmer development associations. In 1995, the government introduced the Land Subsidence Prevention and Treatment Implementation Program (LSPTIP), which provided subsidies to “retire” unworkable fish ponds and repurpose the land for other uses (Liao & Chen 2008).

A study by Ting et al. (2015) concluded that the LSPTIP strategy successfully reduced ground subsidence and helped to reduce the footprint of inland aquaculture ponds, resulting in a measurable decrease in land subsidence in the aquaculture producing regions of Changhua, Yunlin, Chiayi, Tainan, and Pingtung between 1992 and 2011. But other authors evaluated the impact of the LSPTIP as being more limited, noting that significant changes within the aquaculture industry contributed to a decline in the sector’s groundwater consumption, such as the marked reduction in eel and black tiger shrimp production in the late 1990s, both of which are particularly heavy users of groundwater (Sun et al. 2011). In this regard, it is interesting to note that, according to FAO data (FAO 2025), Taiwan’s total aquaculture output reached its zenith in 2003, when production (excluding aquatic plants) exceeded 350,000 MT. This zenith is closely mirrored if only Taiwanese tilapia production is considered (see Figure 3 in the Introduction), when tilapia production reached almost 90,000 MT in 2004, whereas current production volumes are around just two-thirds of this. Although no data on the number or land area of retired ponds were identified in the literature, this significant reduction in volume of aquaculture production over the last two decades would suggest that there has also been a significant reduction in the areal footprint of pond farms.

Aside from LSPTIP and the introduction of aquaculture zones, various other measures were implemented by the government to help control the sector’s groundwater use, such as discouraging the expansion of freshwater inland culture, tightening enforcement measures regarding the illegal pumping of groundwater, improving the infrastructure that supplies and drains water from farms, promoting brackish-water culture, and developing marine cage culture (Chen & Qiu 2014). Despite efforts to promote mariculture to help reduce the sector’s reliance on freshwater, note that, while the 1990s saw a shift toward the development of marine aquaculture production, by 2010 nearly 90% of Taiwan’s aquaculture production was still taking place in land-based pond farms (Ting et al. 2015) (Sun et al. 2011). But there was a marked increase in the use of brackish water in inland ponds during this period, which helped to reduce the predominance of freshwater production and reduce the aquaculture sector’s overall use of freshwater (Chen & Qiu 2014). By 2023, FAO data show that 9% of Taiwan’s aquaculture was taking place in marine environments, 51% in brackish-water, and 40% in freshwater[152] (FAO 2025).

Reporting in 2019, Taiwan’s Water Resource Agency (WRA) stated that the footprint of significant land subsidence had decreased from 1,529 km^2 in 2001 to 419 km^2. WRA also reported that the occurrence of coastal subsidence had declined and that the primary areas of subsidence were located in the inland areas of Changhua-Yunlin, and further noted that studies had shown a significant correlation between the rate of subsidence and the amount of rainfall (Lai 2019). Note that, to help make up for Taiwan’s water demand shortage, it has implemented a policy of water reclamation, which uses a variety of technologies to recapture water from high water-consuming industries and municipal wastewater treatment plants, although these supplies cannot be used for drinking or in food or pharmaceuticals production (Cheng et al. 2022). This initiative

[152] Note that Taiwan’s production of aquatic plants is minimal, so these percentage values are the same, whether aquatic plants are included or not.

is underpinned by the Reclaimed Water Resources Development Act of 2015.[153] [154] In addition, because water is a highly precious resource, particularly considering the limited groundwater resources, the WRA recommends brackish-water and saltwater as priorities for sources for aquaculture (Huang, Shih-Pin, Water Resources Management Division, Water Resources Agency, MOEA December 2023 pers comm).

Since 2019, the government has also been promoting the “symbiosis of fisheries and solar power,” whereby photovoltaic installations are floated on fish ponds to facilitate the integration of aquaculture and solar power generation. This policy has been introduced to diversify the use of aquacultural lands, reduce overall aquaculture production, and increase power generation on an island that is constrained by land resources, which limit the amount of space available for solar power developments. But a number of problems have arisen among different stakeholders in the implementation of this policy (Hsiao et al. 2021), and it has not been universally embraced by farmers.[155] Even so, many fish farmers have switched to using solar power systems in the last 3 years.

All these policy interventions have done much to mitigate the environmental impacts of aquaculture in Taiwan. In addition, industry experts note that, for the last 7 years or so, it is no longer permissible for fish farmers to dig new wells to access groundwater, and the old wells are mostly not used anymore (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). This shift, driven by government incentives and farmers’ concerns about groundwater safety, has led to farmers adopting alternative practices, particularly the collection, storage, and recycling of rainwater (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm). Notably, rainwater collection in irrigation ponds has been a long-standing agricultural tradition in Taiwan, dating hundreds of years[156] (Hsu et al. 2019).

The government has now also constructed water supply channels in aquaculture zones, and it will announce and inform aquaculture operators from time to time as to when they can draw freshwater; the upstream water source is most often a reservoir. Given Taiwan’s limited water resources, most fish farmers discharge water infrequently, further conserving this vital resource (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Experts further comment that land use in Taiwan is strictly regulated by land classification policies, which make it quite challenging to convert nonaquaculture land into aquaculture land (likewise for agricultural lands), and it would likely not be possible to obtain permission to construct a new pond under the current regulatory framework (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm). To mitigate subsidence issues, water resource authorities have also established groundwater control zones in coastal areas and have significantly limited the ability to obtain water rights (Fisheries Agency December 2024 pers comm). Consequently, the majority of present-day fish farms are located in areas that are now specifically designated for aquaculture, although most of these farms were established in these areas many years ago (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association October 2024 pers comm) (Wang Yifeng, General Manager of Kouhu Fisheries September 2023 pers comm).

[153] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC171950
[154] https://faolex.fao.org/docs/pdf/tw172118.pdf
[155] https://english.ftvnews.com.tw/news/2023813W02EA
[156] https://www.ia.gov.tw/en/culture/articles?a=1943

Appendix 3—Ministry of Agriculture Farmland Resource Use Inventory Survey Map

To assist in the management of land use and related policy making, the Ministry of Agriculture (MOA) maintains a publicly accessible and comprehensive Agricultural and Farmland Resource Use Inventory Survey Map (MOA 2023),[157] which details the locations and area of various agricultural uses, including fish farming, production of crops, livestock, forestry, and leisure/recreational farms. These land use categories can be filtered individually on the MOA survey map to show where each is active. The maps shown in Figures 20–21 have been generated using the MOA survey map with the fish farm filter selected. Together, these provide three different snapshots of the MOA survey map at various geographic scales, which together give an overview of the location and density of aquaculture in Taiwan.

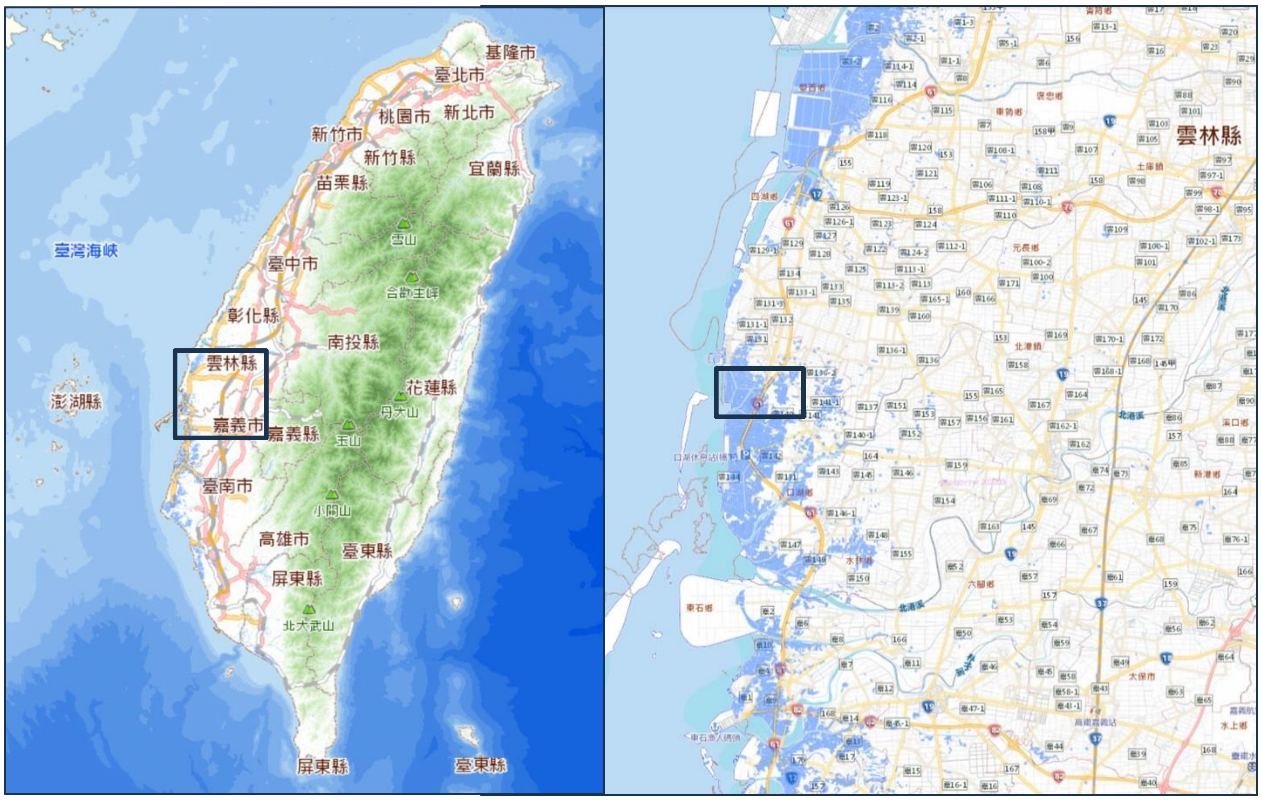

Figure 19: These maps have been generated using the Ministry of Agriculture's agricultural and farmland resource use inventory tool (MOA 2023). Left: Map of Taiwan island showing registered aquaculture facilities highlighted in blue. The square highlighted on this map incorporates part of Yunlin County (top) and Chiayi County (bottom). Right: Higher resolution of the square in the left image, showing all registered aquaculture facilities in the region highlighted in light blue. Note: the square highlighted on the right map is shown in higher resolution in Figure 21.

Although it is not possible to further filter these aquaculture production survey maps to the species level, the source data do show that, across Taiwan, a total of 43,610 ha were available for fish farming in 2023, of which 38,389 ha (88%) were located on flatlands, 131 ha (< 1%) were in a hillside area, and 5,090 ha (11%) were described as being located on nonstatutory agricultural land (MOA 2023) (MOA 2024). These maps clearly show that the majority of Taiwan's aquaculture production occurs in the southwest coastal region, which is also where most tilapia production takes place, most likely within areas defined as flatlands on the survey maps. As

[157] https://map.moa.gov.tw/farmland/survey.html

noted, the Tainan region is Taiwan's foremost tilapia producer; this municipality is also Taiwan's overall largest producer of aquaculture products, with approximately 14,000 ha of fish farms[158] (Chen et al. 2021) (MOA 2023).

The left map in Figure 20, which shows the entirety of Taiwan Island, has been filtered to show all aquaculture facilities, which are denoted in light blue. The right map details the square that is highlighted on the left map; this was randomly selected to demonstrate the functionality of the MOA land use inventory tool and to illustrate farm density, incorporating part of Yunlin County (top) and Chiayi County (bottom). The aquaculture facilities in this area are again denoted in light blue but are shown in much greater detail. Figure 21 zooms in to an even higher resolution, presenting satellite imagery of the box highlighted in the right-hand map in Figure 20. This higher-resolution map clarifies the boundaries of aquaculture facilities in this region. This MOA map resource also contains a number of interactive features, such as the ability to move the map to specified coordinate positions and to zoom the map into a specific cadastral address.

While not specific to aquaculture, the MOA website notes that most farms in Taiwan are small-scale, family-run enterprises with an average size of approximately 1.1 ha. This aligns with findings specific to tilapia farming, where many farms are also described as part of family-run operations (Lee et al. 2023). Likewise, communications with experts indicate that most tilapia farms are small-scale, with the average size estimated between 1.5 to 6 ha, with most in the 1–3 ha range (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm).

Figure 20: This satellite map, which has been generated using the Ministry of Agriculture's agricultural and farmland resource use inventory tool (MOA 2023), shows a close-up view of registered aquaculture facilities (highlighted in blue) in one small part of Yunlin County. Note: this corresponds with the square highlighted on the right-hand map in Figure 20. Note that this tool can also zoom in further on specific cadastral addresses.

[158] https://www.taipeitimes.com/News/taiwan/archives/2022/09/11/2003785134

Appendix 4—Certification and Assurance Schemes for Aquaculture

Although domestic assurance schemes are not formally part of Taiwan's regulatory framework, they are closely aligned to governance efforts, particularly given the government's active role in their promotion and administration. Taiwan's government began restructuring the aquaculture sector in the early 1990s to address emerging environmental concerns. This reform effort laid the groundwork for initiatives such as the Traceable Agricultural Product (TAP) System, established by the Ministry of Agriculture (MOA) in 2007.[159]

The TAP System is a comprehensive framework designed to ensure the safety, quality, and traceability of agricultural products, including aquaculture. Its foundation lies in Taiwan Good Agricultural Practices (TGAP), which were developed based on the European Good Aquaculture Practices (GAP) (Cheng 2017). TGAP standards are sector-specific, with tailored criteria developed to address the unique challenges and requirements of each sector. For aquaculture, these criteria encompass a range of critical areas, including water quality control, feed usage and storage, drug usage and storage, treatment of effluents, pond management, and the maintenance of logbooks to ensure transparency and accountability. Farm operators must adhere to stringent TGAP guidelines, disclose detailed management practices, and undergo verification by independent certification bodies. Consumers can access this information via QR codes or through the Taiwan Agriculture Food Traceability System website.[160]

MOA notes on its website that adoption of the TAP system has steadily increased each year, motivating retail establishments to offer TAP-certified products and encouraging farmers to pursue certification. As of the end of 2020, 2,356 ha of Taiwan's aquaculture ponds were TAP-certified[161]; details can be searched for on the Taiwan Agriculture and Food Traceability System website.[162] Currently, approximately 3% of aquaculture producers are certified under this scheme (Shin-Chang Chen, Secretary-General, Taiwan Fisheries Economic Development Association March 2024 pers comm), although the proportion of these that produce tilapia is unclear.

Shortly after the introduction of TAP, the international Aquaculture Stewardship Council (ASC) certification program was launched and promoted in Taiwan, and several farms became certified[163] [164] (Cheng 2017) (Chen & Qiu 2014). A list of the Taiwanese tilapia farms that are currently ASC certified is available on the ASC website, along with related certification documentation.[165] At the time of writing, approximately 2,000 MT of Taiwanese tilapia is ASC-certified (Hans Van Someren Greve, Aquaculture Stewardship Council, January 2024 pers comm).

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[159] https://taft.moa.gov.tw/cp-1063-1991-de3c9-2.html
[160] https://taft.moa.gov.tw/mp-1.html
[161] https://eng.moa.gov.tw/ws.php?id=2505645
[162] https://taft.moa.gov.tw/mp-2.html
[163] https://taiwantoday.tw/news.php?unit=6&post=11579
[164] https://www.eco-business.com/news/taiwan-tilapia-earns-global-quality-accreditation/
[165] https://asc-aqua.org/find-a-farm/