DEPARTMENT OF AGRICULTURE

Minnesota State Aquaculture Plan

3/14/2025

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This report cost approximately $93,000 to prepare, including staff time, printing, and mailing expenses (MINN. STAT. 3.197).

Executive Summary

This State Aquaculture Plan describes the history, current state, challenges, and opportunities for growth and expansion of aquaculture in Minnesota. It was prepared by the Minnesota Department of Agriculture (MDA) at the direction of the Minnesota Legislature and is informed by the work of Steamboat Road Consulting.

The plan posits that Minnesota is well-positioned to establish itself as a key player in food, baitfish, and sportfish production and marketing, and recommends the following:

Policy and Leadership

1. Under legislative direction, create a Minnesota Aquaculture Working Group.
2. Adopt a comprehensive 10-year Minnesota Aquaculture Plan to provide long-term strategy for growth and sustainability.
3. Strengthen and improve interagency coordination to ensure cohesive policy implementation and resource sharing.
4. Develop policies that support sustainable growth in the aquaculture sector and ensure compliance with environmental, economic, and social standards by streamlining permitting processes and co-locating regulatory rules for all aquaculture sectors.

Research and Information

1. Expand online MDA, Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, and Minnesota Sea Grant resources for aquaculture development to include specific resource content, initiatives, and opportunities.
2. Centralize and enhance access to aquaculture resources and innovations, fostering an environment that supports industry growth and technological advancements by developing outreach programs, extension association positions, etc.
3. Innovate and improve the sustainability and efficiency of dry and live aquaculture feeds by funding research into alternative protein sources feeding strategies. Identify and address scientific and technological challenges that hinder the growth and sustainability of the aquaculture industry.
4. Fund and conduct market research on food fish to better understand and effectively respond to market demands and consumer preferences for food fish in Minnesota's target markets.

Market Development

1. Diversify the aquaculture sector by exploring and developing new markets for unconventional aquaculture products.
2. Enhance the economic impact of aquaculture products through strategic market development and innovative value-addition.

Financial Support and Incentives

1. Establish targeted financial incentives and support to reduce barriers to entry and expansion, facilitating growth of both startup and existing aquaculture operations.
2. Strategically expand aquaculture by identifying and preparing optimal production and research sites that support sustainable practices and economic viability.
3. Promote the use of environmentally and economically sustainable methods to produce fish.

MINNESOTA STATE AQUACULTURE PLAN

JANUARY 2025

PREPARED BY
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Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

Minnesota stands at a significant juncture to develop a robust and sustainable aquaculture industry, poised to stimulate substantial economic growth and provide high-quality protein for a growing global population. Facing a $20.3 billion U.S. seafood trade deficit and critical challenges such as overfishing that threaten marine biodiversity, aquaculture emerges as both an economic opportunity and an environmental necessity. With the strategic deployment of the National Aquaculture Development Plan and cutting-edge technologies, Minnesota is uniquely positioned to harness its vast natural resources and agricultural expertise. This emerging market, supported by focused public-private partnerships and strong industry leadership, offers Minnesota the potential to significantly impact the seafood trade deficit and establish itself as a key player in the U.S. aquaculture industry.

Since 1998, the United States Department of Agriculture (USDA) has systematically measured aquaculture production nationwide through its Census of Aquaculture. This detailed census divides the industry into seven distinct sectors and provides a production breakdown by state, as depicted in Table 1. In 2023, the census reported that total U.S. aquaculture production surpassed $1.9 billion, with the food fish sector accounting for $820 million, indicating its significant contribution to the industry (USDA, 2024).

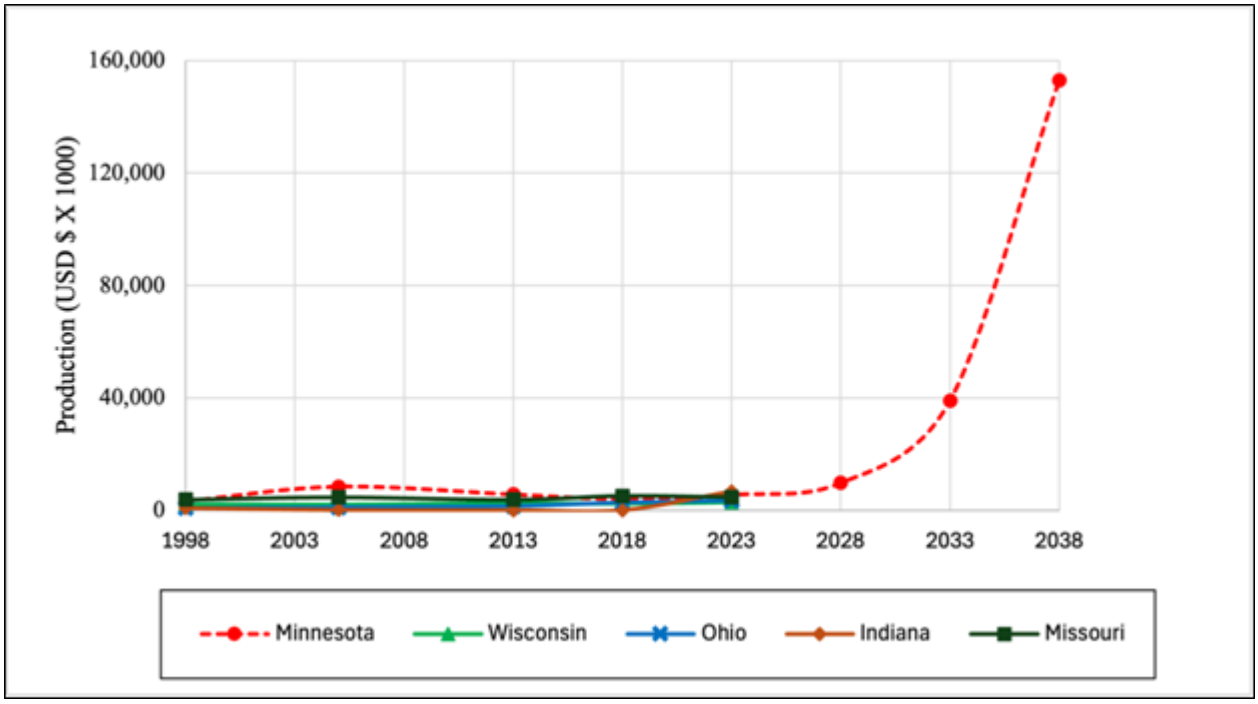
Table 1. *Total U.S. aquaculture production in sales from 1998 – 2023 (x$1,000)*

USDA NASS DATA (Census of Aquaculture)	1998	2005	2013	2018	2023	25 year Growth
Food fish	691,714	672,377	732,147	715,978	819,556	18%
Sport fish	7,390	18,126	23,849	39,350	54,390	636%
Baitfish	37,482	38,018	29,375	32,778	48,125	28%
Crustaceans	36,318	53,381	84,880	100,365	175,746	384%
Mollusks	89,128	203,183	328,567	441,801	575,455	546%
Ornamentals	68,982	51,297	41,485	43,534	77,095	12%
Misc.	46,734	56,003	131,400	141,875	157,655	237%
Total Aquaculture	**978,012**	**1,092,386**	**1,371,707**	**1,515,680**	**1,908,022**	**95%**

Note. Data from USDA (2024)

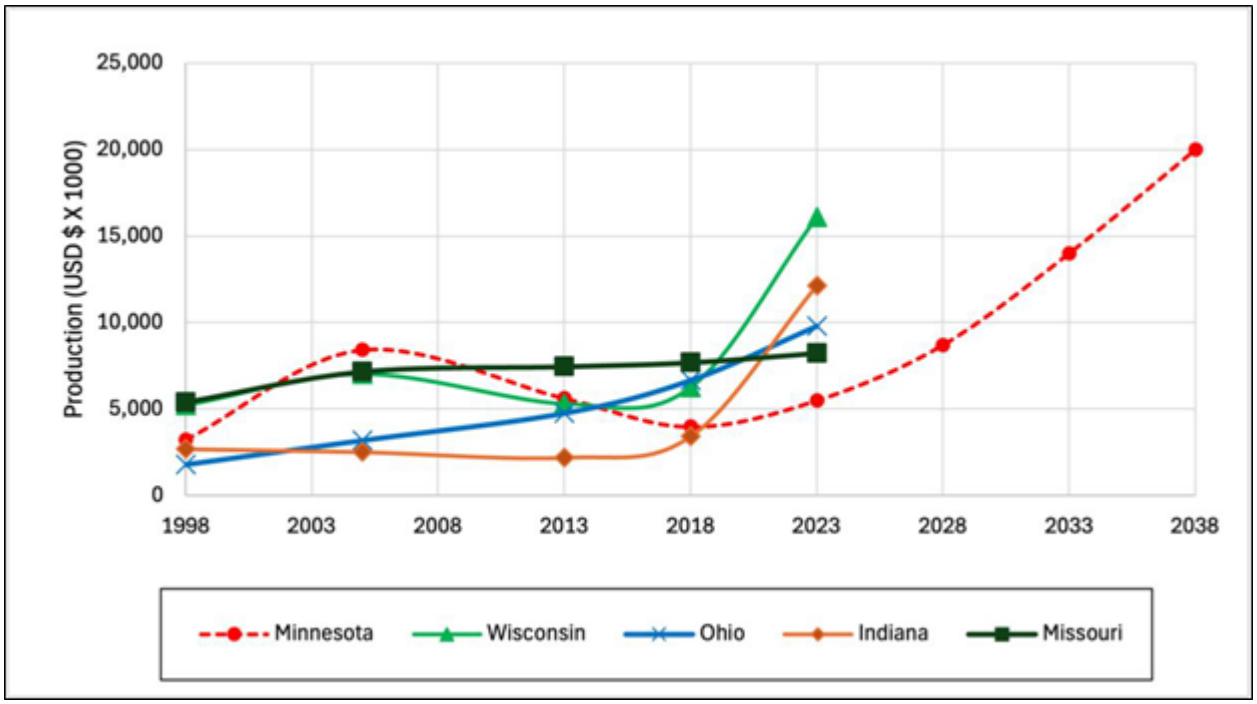
Minnesota's aquaculture industry, traditionally focused on baitfish, sport, and food, generated nearly $5.5 million in 2023, primarily from baitfish and sport fish production (USDA, 2024). Projections indicate that these sectors could grow to $10-$15 million in annual production by the planned 2038 Census of Aquaculture, assuming favorable support from the Minnesota Department of Natural Resources, state legislature and the public. The food fish sector represents the most significant growth opportunity, potentially generating $140 million annually within the same 13-year timeframe. An aggressive growth strategy for food fish, supported by the organic growth in baitfish and sport fish has the potential to generate $153 million of annual revenue in the state (Figure 1). However, achieving this growth would require a dramatic shift in government support, including infrastructure investment, regulatory streamlining, and collaboration between public and private stakeholders. Without this significant shift, food fish aquaculture in Minnesota would only be projected to reach about $7.0 million per year in 13 years, with a total aquaculture production of $20 million per year in all three key sectors (Figure 2).

Figure 1. *Minnesota Total Aquaculture Production Target with Aggressive Growth Strategies (1998 – 2038)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/
Missouri has traditionally been a leader in food fish production in the North Central Region.

Figure 2. *Minnesota Total Aquaculture Production Target with only the Traditional Growth Strategies for food fish (1998 – 2038)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

The USDA reported the 2023 U.S. seafood trade deficit at $20.3 billion, over ten times the value of domestic aquaculture production. Key imports include $6.5 billion in Shrimp, $4.3 billion in Salmon, and $1.2 billion in Tilapia (Tradeimex, 2024). Minnesota can offset a portion of this deficit by targeting domestic production of high-demand species like Atlantic Salmon. Producing just 5% of the U.S. import volume of fresh or chilled Salmon fillets would establish Minnesota as a key player in this sector. This target equates to 10,000 metric tons of Salmon fillet products annually (15,000 metric tons live weight), valued at approximately $128.4 million (Salinas, 2024). Additionally, byproducts such as trimmings and fish racks could contribute another $4.75 million through sales to the pet food industry, for example (Nunes et al., 2022).

The successful expansion of food fish production in Minnesota will depend on adopting advanced technologies such as Recirculating Aquaculture Systems (RAS). RAS technology offers reduced water use, physical isolation from environmental impacts, effluent treatment with nutrient recycling, and water quality control to ensure fish welfare (*Recirculating Aquaculture System*, 2021). However, the high capital investment required for RAS facilities–estimated at $300 million for 15,000 metric tons of live weight production annually–poses a significant barrier. Combined with a working capital requirement of $170 million over two years and a 5 to 7-year timeline to achieve steady-state production, the startup costs have stimulated limited private sector interest in the state[1]. Public-private partnerships (PPP) will be essential to mitigate risk, reduce costs, and grow the industry. Feedback from the private equity side indicates that startup costs and risk mitigation through improved regulations and financial incentives would promote private investment and growth in this sector. An incentive equivalent to 25% of capital investments required for a startup would be sufficient to promote extensive interest in growing aquaculture in the state. These incentives could be achieved through activities like site development, access to water resources, discharge permits, tax incentives, utility contracts, and regulatory streamlining.

This report advocates a dual-strategy approach for the development of Minnesota's aquaculture industry. It recommends a traditional growth strategy for the baitfish, sport fish, and food fish sectors to foster responsible expansion that balances risk and diversifies the industry. In parallel, it suggests a more aggressive strategy for the food fish sector to drive significant long-term economic growth. This aggressive approach focuses on the emerging potential of land-based food fish aquaculture in the U.S., requiring a well-coordinated, state-level strategic plan that harnesses both public and private collaboration. By embracing these strategies, Minnesota can position itself to join the top ten aquaculture-producing states, reduce reliance on imported seafood, enhance national food security, and generate employment opportunities.

The production targets developed in this report for 2038 are ambitious: $7.0 million from baitfish, $6.0 million from sport fish, and $7.0 million from food fish under traditional growth strategies, for a total aquaculture production reaching $20 million annually, with a $24 million investment over 8 years. With aggressive growth strategies for food fish, the target could raise an additional $133 million in annual revenue, requiring an additional $98 million in investments over 8 years. Overall, with the implementation of traditional and aggressive growth measures, the total aquaculture production has the potential to be $153 million annually, with a $122

[1] Estimates by EDA-Aquatic Design Services, LLC. RAS Design Consultant. Estimates consider species, culture time, and biomass prior to generating revenue.

million investment. This expansion would contribute significantly to a sector poised to meet the increasing demand for locally sourced, high-quality seafood while also boosting the economic impact of Minnesota's aquaculture industry.

The Minnesota Aquaculture Action Plan developed at the end of this report outlines a comprehensive strategy to establish Minnesota as a leader in the aquaculture industry. The plan calls for collaborative efforts across government, industry, and academia to develop the infrastructure necessary for sustainable development and to advance the state's aquaculture sectors effectively. Central to the plan are 15 strategic actions categorized into six main areas: Governance and Strategic Planning; Financial Support and Incentives; Research, Development, and Innovation; Market Development and Consumer Engagement; Infrastructure Development and Environmental Management; and Regulatory Compliance and Policy Development. These actions are designed to foster a robust framework for aquaculture that supports economic growth, enhances sustainability, and integrates innovative practices across various aquaculture sectors.

In conclusion, this proposed action plan taps into Minnesota's rich agricultural heritage and abundant natural resources to position the state as a leader in sustainable aquaculture. By focusing on collaborative efforts and strategic partnerships, the plan aims to elevate Minnesota's aquaculture sector to potentially generate an estimated $153 million annually by 2038, while also creating approximately 528 jobs. This proposal highlights the state's potential to transform aquaculture into a significant economic driver, addressing environmental challenges such as overfishing and the seafood trade deficit. If realized, this vision will set Minnesota on a path to realize its potential, establishing it as a benchmark in U.S. aquaculture.

2.0 Introduction and Methodology

This report synthesizes research, stakeholder engagement, and expert analysis to update Minnesota's aquaculture strategy, addressing contemporary challenges and leveraging emerging opportunities. Building upon the foundation established in the 1989 state aquaculture plan, this document reflects significant changes in the sector driven by increased demand for locally sourced food and advancements in sustainable practices.

This report was informed by key insights from a range of important reports and updates, including the Agricultural Utilization Research Institute's 2021 assessment of aquaculture opportunities and challenges (AURI, 2021) and the Minnesota Sea Grant 2017 Food Fish Aquaculture Workshop Synthesis (Moen, 2017) that highlight the need for updated management practices due to ecological and market changes. Legislative changes since 1988 have also significantly influenced policy frameworks, particularly regarding the use of public wetlands and the management of aquatic invasive species. These factors emphasize a sector that is evolving quickly in response to global agricultural trends, driven by urgent needs for food security and environmental sustainability.

Recent stakeholder engagement has captured a broad spectrum of perspectives across the aquaculture industry. Through workshops, interviews, and site visits involving entities such as the Minnesota Department of Natural Resources (MNDNR), USDA, and NOAA Sea Grant, alongside academia and private enterprises, this plan has been crafted to reflect a comprehensive understanding of the sector's dynamics. Notably, the University of Minnesota and industry associations like the Minnesota Aquaculture Association have provided invaluable insights into both the challenges and innovations within the state's aquaculture landscape.

Data from the USDA's National Agricultural Statistics Service (NASS) and additional field research have provided benchmarks that not only gauge the economic impact of aquaculture but also guide strategic development to enhance productivity and sustainability. These collaborative efforts culminated in strategic recommendations that steer Minnesota toward becoming a leader in responsible aquaculture practices.

To maintain clarity in the main content of the report, detailed information about the incentive justifications and growth strategies, roles of federal and state institutions, regulatory frameworks, and aquaculture methodologies can be found in the appendices. These appendices provide insights into the interactions and collaborative efforts necessary for sustaining aquaculture practices. Readers interested in a deeper understanding of these specific areas can refer to the appendices for additional resources.

This action plan is structured to provide stakeholders with an executive summary of critical findings, followed by in-depth analyses across various aquaculture sectors. Designed to serve as a comprehensive roadmap, it facilitates informed decision-making and fosters collaborative efforts to advance Minnesota's aquaculture industry into the next decade.

3.0 Aquaculture Overview

Global Perspective

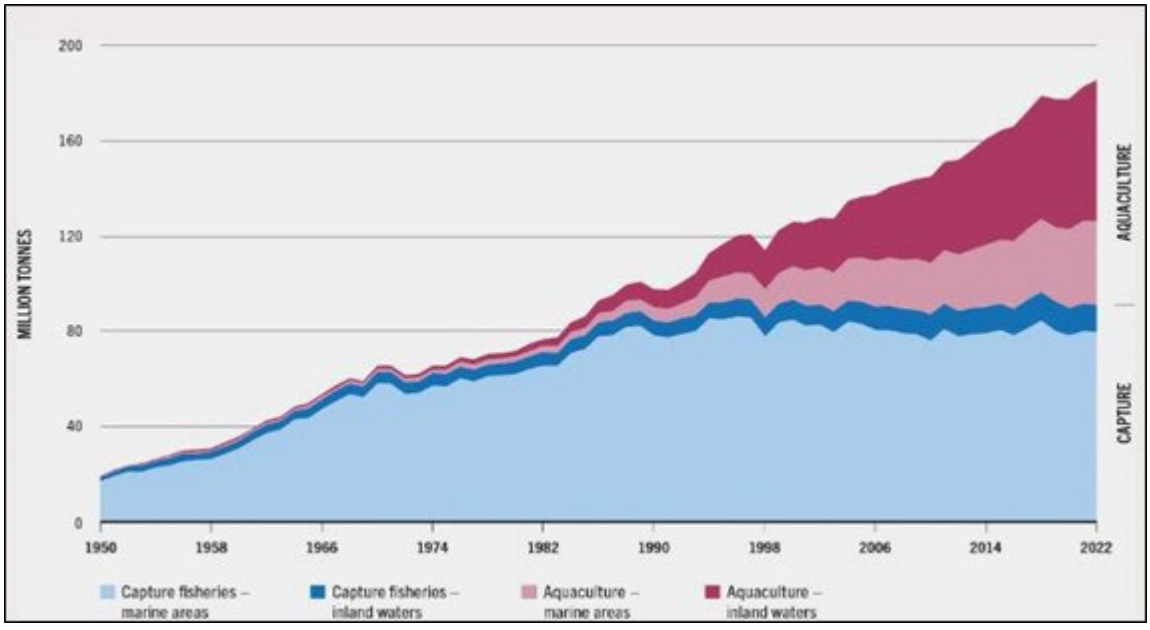
Aquaculture, farming aquatic animals and plants, is the fastest-growing food production sector globally, with an average growth rate of 6.7% over the past three decades (Mair et al., 2023). This growth is driven by increasing seafood demand, declining wild fish stocks, and technological advancements. In 2022, global aquaculture production reached a record of 130.9 million tons, comprised of 94.4 million tons of aquatic animals and 26.5 million tons of algae, at a farm-gate value of $312.8 billion. Aquaculture production of aquatic animals has surpassed capture fisheries for the first time in history and supports over 22 million jobs worldwide (FAO, 2024).

Aquaculture is recognized as an efficient production method of high-quality protein, using fewer natural resources compared to terrestrial livestock. It also provides ecosystem benefits, such as water filtration and carbon sequestration through shellfish and algae farming (MacLeod et al., 2020). Innovations such as recirculating aquaculture systems (RAS) and alternative feed sources are paving the way for sustainable growth despite challenges like environmental impacts, regulatory barriers, and climate change.

Freshwater aquaculture comprises 62.6% of total aquaculture production, highlighting its growing importance in global food security (Figure 3) (FAO, 2024). Minnesota's abundant freshwater resources and potential to expand sustainable aquaculture align with these global trends, positioning the state as a leader in this sector within the North Central region.

For more detailed statistics, trends, and projections, refer to the FAO's "The State of World Fisheries and Aquaculture 2024" (SOFIA) report, which can be found on the FAO website.

Figure 3. *Production of Aquatic Animals from Capture Fisheries and Aquaculture in Marine and Inland Waters (1950-2022)*



Note. Reprinted from "The State of World Fisheries and Aquaculture 2024" by FAO, 2024. https://doi.org/10.4060/cd0683en

Domestic Perspective

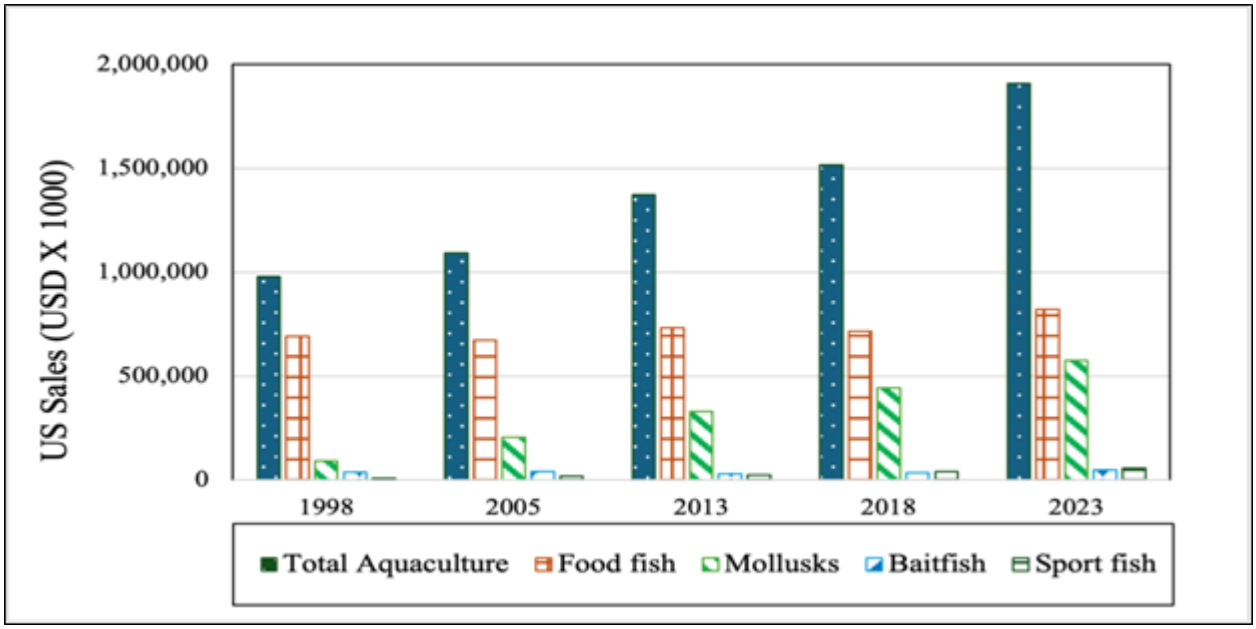
Aquaculture in the U.S. began in the late 19th century with government efforts to raise fish for conservation and recreation (Guinan & Curtis, 2024). Modern commercial aquaculture emerged in the mid-20th century, with the National Aquaculture Act of 1980 marking a significant milestone by promoting private-sector development and sustainable practices (U.S. Congress, 1980).

According to the 2023 Census of Aquaculture, 3,453 farms reported $1.9 billion in sales across all U.S. aquaculture, of which freshwater food fish production – primarily Catfish and Trout – is the leading contributor. However, this data is likely a minimum estimate due to voluntary reporting, especially in states like Minnesota, where few producers participate. While the total U.S. production may be underrepresented in the census, it provides one of the only consistent measures of aquaculture. Overall, U.S. aquaculture makes significant economic and recreational contributions, supporting over 22,000 jobs and generating $3.8 billion in direct and indirect economic output (Kumar et al., 2024)

Minnesota's wealth of freshwater resources and established agriculture infrastructure create unique opportunities to expand sustainable aquaculture practices. By leveraging innovative technologies, such as recirculating aquaculture systems (RAS), the state can reduce the national seafood trade deficit while strengthening its local economy.

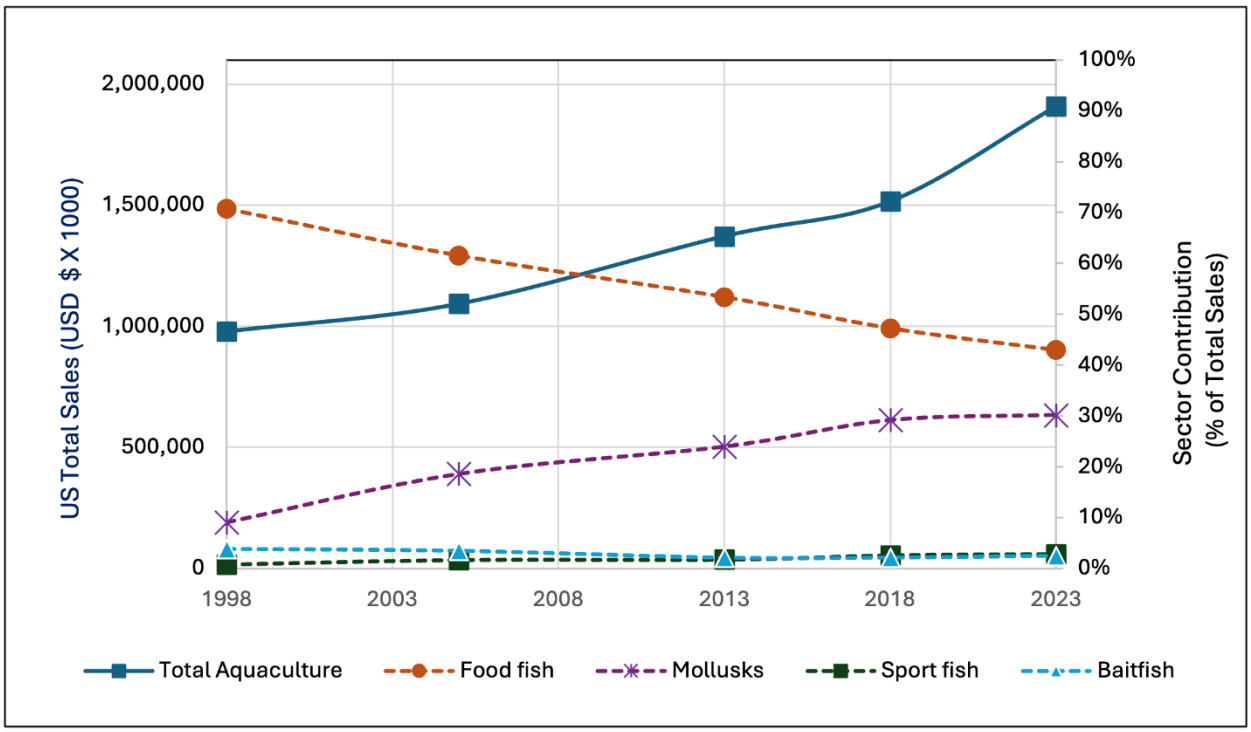
For further details, refer to the USDA 2023 Census of Aquaculture, which provides detailed statistics and trends for U.S. aquaculture.

Figure 4. *U.S. Aquaculture Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

Figure 5. *Total U.S. Commercial Aquaculture Production and Percentage Produced in each Sector (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

National Aquaculture Development Plan

The National Aquaculture Development Plan (NADP), overseen by the National Science and Technology Council's Subcommittee on Aquaculture, provides a strategic framework for expanding U.S. aquaculture while balancing economic, environmental, and social priorities. Its primary goal is to increase domestic seafood production through three key focus areas: aquaculture research, regulatory efficiency, and economic development.

1. **Strategic Plan for Aquaculture Research**
   This plan establishes federal research priorities to support a science-based aquaculture industry that enhances seafood production, creates jobs, and promotes ecological restoration. Key objectives include fostering economic growth while ensuring healthy aquatic ecosystems, advancing aquaculture technologies, and improving animal welfare, product safety, and nutritional value.
2. **Strategic Plan to Enhance Regulatory Efficiency in Aquaculture**
   This strategy focuses on improving federal and state aquaculture regulations' efficiency, predictability, and cost-effectiveness. It aims to streamline permitting and authorization processes, implement a national framework for aquatic animal health, and develop better regulatory management tools.
3. **Strategic Plan for Aquaculture Economic Development**
   This plan outlines federal efforts to support a resilient, competitive, and sustainable domestic aquaculture industry. It aims to expand existing operations, attract new entrants, and strengthen infrastructure, workforce development, and market opportunities. The strategy integrates public-private partnerships to promote climate-ready aquaculture, equitable economic growth, and healthy aquatic ecosystems, ensuring long-term industry viability.

The NADP emphasizes interagency collaboration among NOAA, USDA, and the U.S. Fish and Wildlife Service to promote sustainable practices, enhance permitting processes, and drive innovation. Key strategies include improving aquaculture production technologies, fostering workforce development, and expanding market opportunities for U.S. aquaculture products.

The NADP aligns closely with Minnesota's goals for growing its aquaculture sectors, including baitfish, sport fish, and food fish production. Minnesota can strengthen its aquaculture industry by leveraging federal support for infrastructure investment and regulatory streamlining while contributing to national seafood production goals.

An overview of the NADP can be found here for more detailed information.

North Central U.S. Perspective

The North Central Regional Aquaculture Center (NCRAC) encompasses 12 states, each contributing to the region's aquaculture production. USDA NASS data has been analyzed to assess total aquaculture production, as well as sport fish, baitfish, and food fish sectors. This analysis provides valuable insights into aquaculture achievements across the region, serving as a benchmark for Minnesota's growth strategies.

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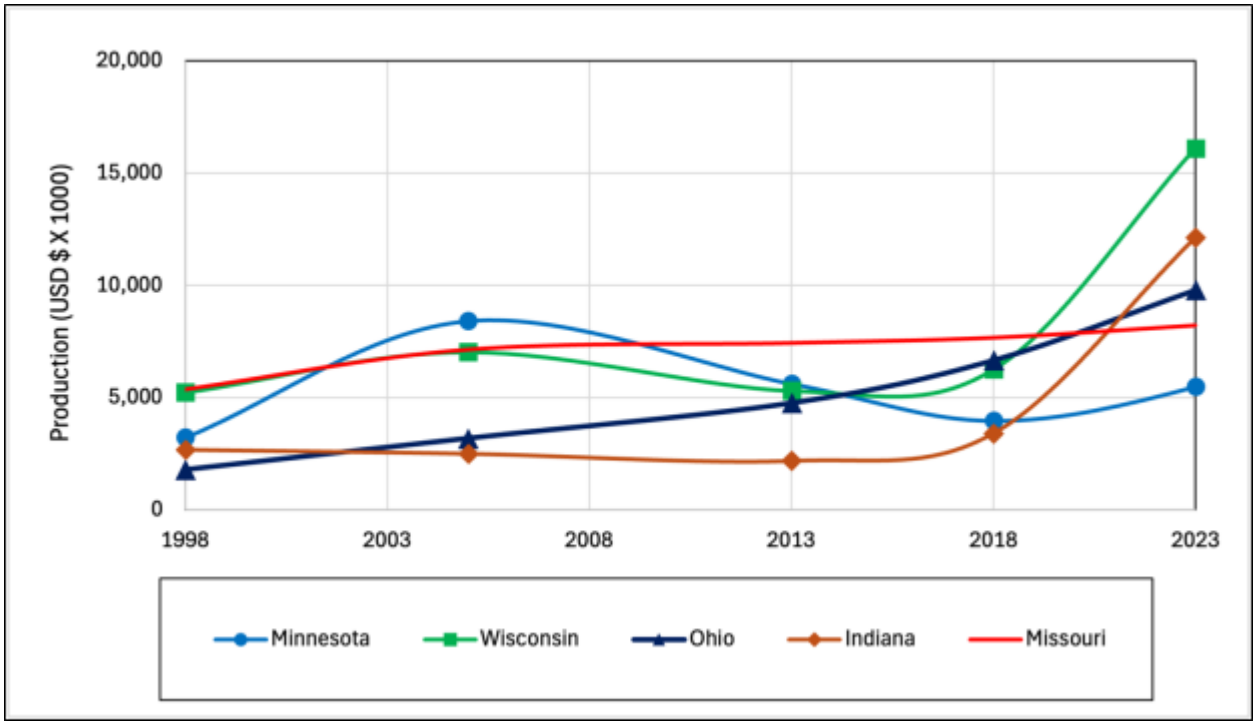
Figure 6. *North Central Region Total Aquaculture Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

According to the 2023 Census data displayed in Figure 6, Wisconsin leads the region in total aquaculture production. However, a detailed breakdown reveals that only $2.76 million comes from food fish and $4.03 million from baitfish, representing $6.8 million of its $16 million total. The remaining $9.8 million in production has the category withheld, likely to avoid disclosing data from individual farms, which may indicate a significant contribution from a single producer. Indiana has surged to second place, driven by significant growth in food fish production, while Ohio holds third place, with steady growth across baitfish, sport fish, and food fish sectors. Minnesota has demonstrated growth in total aquaculture production over the past five years, primarily attributed to increased baitfish and sport fish production (USDA, 2024).

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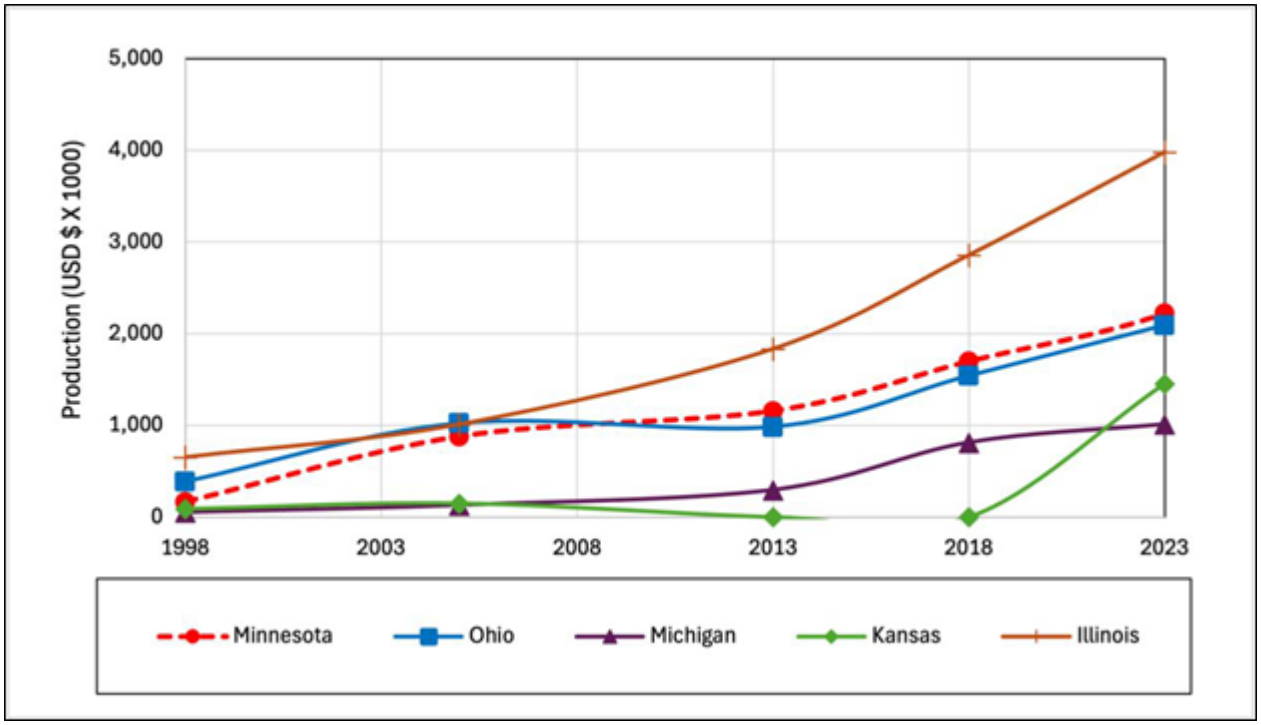
Figure 7. *North Central Sport Fish Aquaculture Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

The sport fish sector has consistently grown, with states like Illinois, Minnesota, and Ohio leading the way (Figure 7) (USDA, 2024). This growth is closely tied to state natural resource programs and opportunities for private-sector contract growers. Fluctuations in growth often depend on a state's ability to meet hatchery production goals and the need to contract private aquaculture entities. Stocking private water bodies has also significantly contributed to driving growth in this sector.

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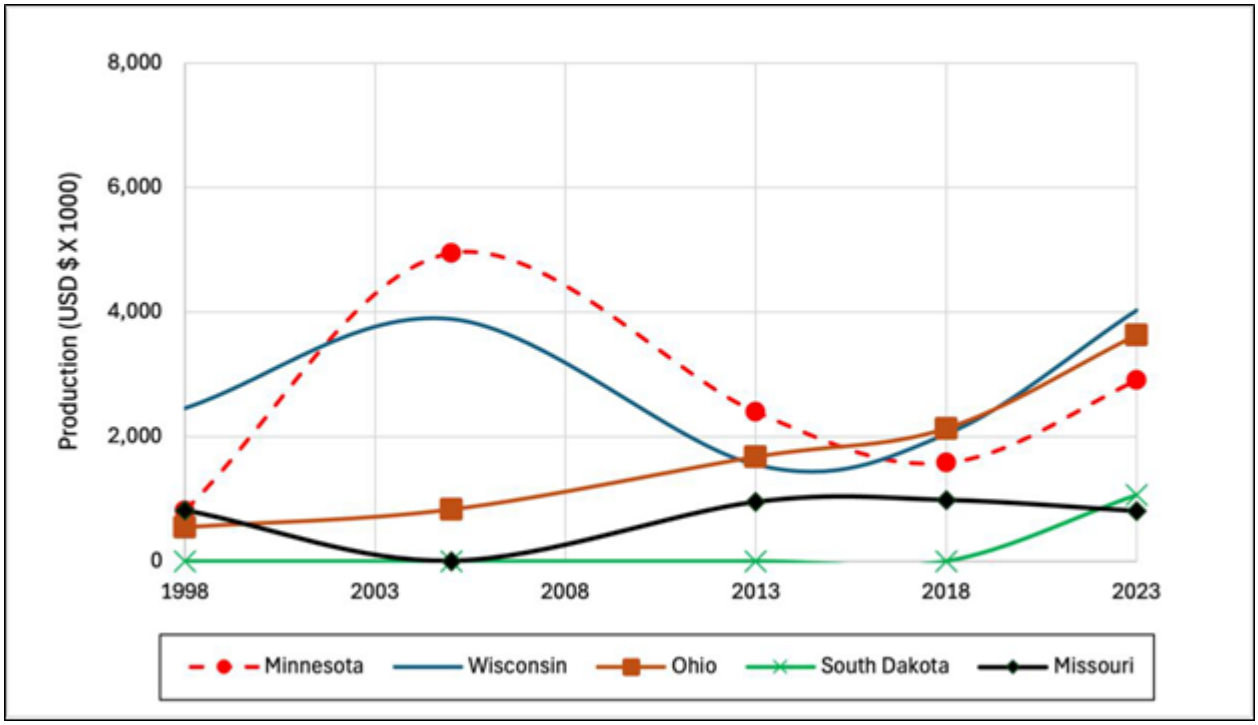
Figure 8. *North Central Baitfish Aquaculture Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

The baitfish sector has exhibited inconsistent growth trends. In Minnesota and Wisconsin, production spiked in 2005, declined from 2013 to 2018, and recently experienced an upswing (Figure 8) (USDA, 2024). This variability may suggest a production ceiling in this sector. Ohio, in contrast, has maintained steady growth throughout the data period and now ranks second in regional baitfish production.

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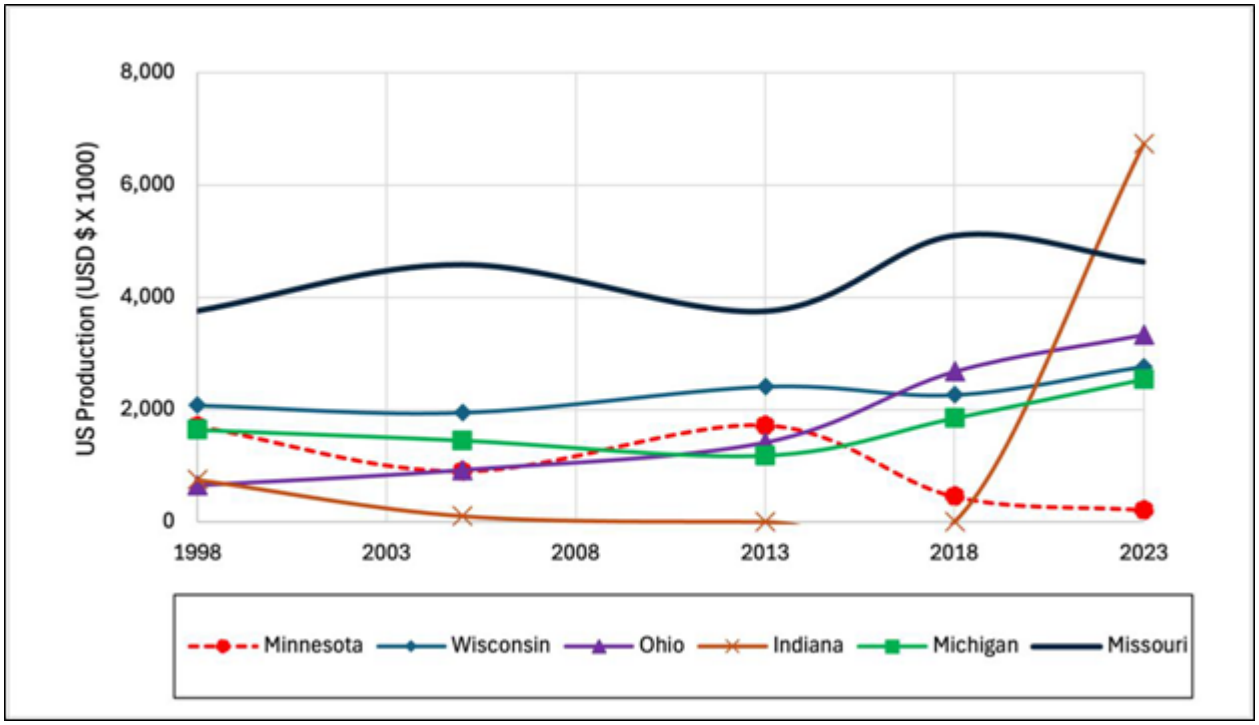
Figure 9. *North Central Food Fish Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

Food fish production in the North Central region has seen notable developments (Figure 9). Missouri had consistently dominated this sector until 2023, when Indiana claimed the top spot, likely due to establishing a large food fish RAS production facility. The steep increase in production is likely associated with purchasing existing and permitted infrastructure, allowing the production to be fast-tracked. Ohio's consistent growth can likely be attributed to a strong aquaculture association with a long history of development and guidance in the state (Ohio Aquaculture Association, 2023). Meanwhile, Minnesota's food fish production has declined significantly over the past decade, highlighting the need for targeted strategies to revitalize this sector.

The North Central region provides valuable lessons for Minnesota's aquaculture development. By analyzing successful strategies in leading states like Missouri, Ohio, and Indiana, Minnesota can identify opportunities to enhance its competitiveness across all aquaculture production sectors. These insights will be critical as the state seeks to strengthen its position within the region and the broader U.S. aquaculture industry.

4.0 Minnesota Aquaculture

In Minnesota, aquaculture is segmented into conservation and commercial practices, each playing a unique role in the state's aquatic resource management and economic development. Conservation aquaculture is primarily associated with public agencies or under contracts with public agencies to support wild fish stocks by providing angling opportunities, ecological sustainability, and the restoration of native species through practices such as stocking endangered or popular sportfish. These efforts enhance recreational fishing and contribute to ecological balance and biodiversity. Commercial aquaculture is private sales of baitfish, sport fish, and food fish species, each with distinct market dynamics and growth potential. This structure allows for targeted strategies that address each category's specific needs and opportunities. The subsequent sections will analyze the current economic impact of these practices and outline strategic growth plans tailored to maximize their potential.

Background

Aquaculture in Minnesota benefits from the state's extensive water resources and agricultural heritage, supporting conservation and commercial efforts. While agriculture is a significant industry in the state, contributing over $106 billion annually (MNDLI, n.d.), aquaculture has emerged more recently, with its roots in conservation efforts dating back to 1877 (MNDNR, 2024). Despite challenges such as outdated infrastructure and declining production in specific sectors, Minnesota's abundant natural resources and evolving consumer demand for locally grown seafood position the state for growth in sustainable and innovative practices (AURI, 2021).

Fish hatcheries were started to address the decline of Minnesota's fish populations due to overfishing, habitat degradation, and pollution. Interest in food aquaculture development in Minnesota began in the 1980s when abandoned mine pits in northern Minnesota were identified as potential water resources. In the late 1980s, a commercial aquaculture facility was established, producing Salmon for the local and regional markets, and although it ultimately failed, this led the state to recognize aquaculture as agriculture, and the Minnesota Department of Agriculture (MDA) was designated the lead agency for aquaculture development in the late 1980s (AURI, 2021). While MDA's Marketing Services Division provided development assistance, regulatory authority stayed with the MNDNR and, when needed, a discharge permit from the Pollution Control Agency (PCA). When aquaculture development decreased in the 1990s, there was less need for MDA's oversight, and the Marketing Division reprioritized its focus on marketing other agricultural products (AURI, 2021).

Current Status and Economic Impact

Conservation aquaculture encompasses the use of aquaculture for the conservation, restoration, and enhancement of aquatic resources, serving as a vital tool to support wild populations, such as restocking recreational species and endangered fish. Commercial aquaculture focuses on cultivating captive aquatic organisms for commercial purposes, such as human consumption. While conservation and commercial aquaculture tend to have different end goals, these two parts of aquaculture overlap and are interdependent. For example, developing hatchery infrastructure

and aquatic health management practices for conservation aquaculture benefits the recovery of threatened and endangered aquatic species and creates production technologies and scientific understanding that are transferrable to the commercial sector. The following sections provide an overview of both conservation and commercial aquaculture, highlighting their current impact, challenges, and growth potential in Minnesota.

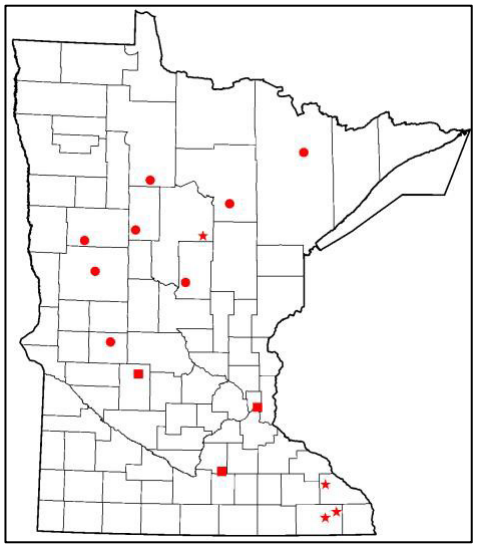
Conservation Aquaculture Overview

Minnesota, often celebrated as the "Land of 10,000 Lakes," is a premier destination for over 1.4 million anglers annually. Recreational fishing contributes $5.9 billion to the economy and supports 35,000 jobs (Mitchell, 2024). The MNDNR plays a critical role in fishery management through its resource surveillance, comprehensive stocking programs, regulatory authority, and habitat restoration efforts (MNDNR, 2024b).

The Minnesota Department of Natural Resources (MNDNR) Hatchery Program raises millions of fish annually to replenish fish populations and enhance recreational fishing across 4,300 lakes and over 16,000 miles of fishable rivers. The program operates 15 state hatcheries (Figure 10). To maintain the state's vibrant angling scene, these hatcheries focus on species like Walleye, which accounts for over 73% of output (MNDNR, 2024c).

Despite its successes, the program's infrastructure, primarily built in the 1950s, faces challenges. For example, the aging facilities at Waterville and Crystal Springs require significant updates to meet current standards in biosecurity, system efficiency, and worker safety (MNDNR, 2024d; MNDNR, 2023). Efforts are currently being made to repair and update these facilities.

Figure 10. *Map showing MNDNR Hatcheries throughout the state. Circles designate cool-water hatcheries. Stars designate cold- water hatcheries. Squares designate cool- and warm-water hatcheries*



Note. Reprinted from "Minnesota's fish hatchery system", by MNDNR 2024. Retrieved from https://www.dnr.state.mn.us/areas/fisheries/hatcheries.html

The MNDNR Hatchery Program helps supplement Minnesota's recreational fisheries, supporting its waterways' ecological health and the state's recreational fishing industry. The MNDNR evaluates populations and the efficacy of stocking and identifies waterbodies that would benefit most. The MNDNR hatchery system produces and stocks millions of fish annually.

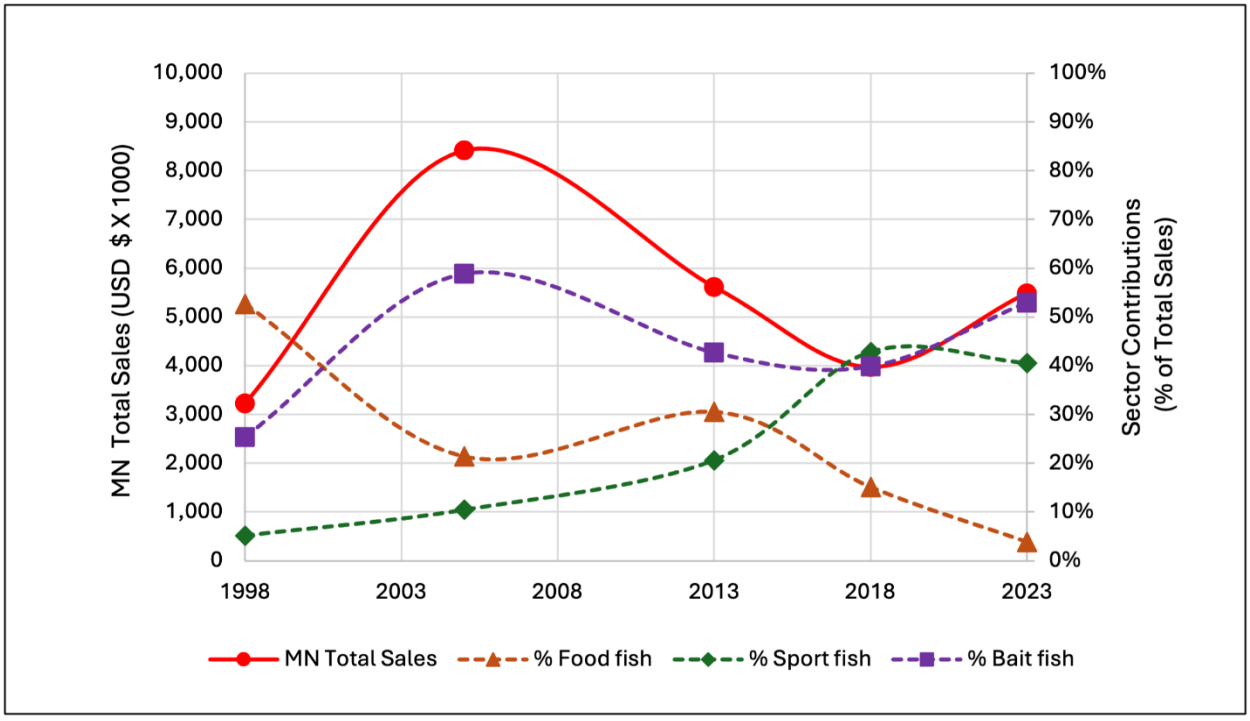
Commercial Aquaculture Overview

Currently in its development phase, commercial aquaculture in Minnesota is poised for growth. Integrating the state's robust agricultural expertise with emerging technologies like Recirculating Aquaculture Systems (RAS) and aquaponics presents opportunities to expand the commercial market. Strategic investments in technology and infrastructure, aligned with efforts to enhance food security and reduce the seafood trade deficit, could transform the state into a leader in sustainable commercial aquaculture, bolstering the state's economy.

Current Aquaculture Production Levels

Minnesota primarily produces baitfish, sport fish, and food fish. In recent years, baitfish have regained prominence, while sport fish production has grown steadily. Conversely, food fish production has stagnated, dropping to negligible levels over the last decade. Despite these challenges, the state's total aquaculture production has risen from $4 million to $5.5 million annually over the past five years, largely driven by baitfish and sport fish (Figure 11) (USDA, 2024). Targeted investments and strategic planning are needed to unlock Minnesota's commercial aquaculture potential, particularly in food fish production.

Figure 11. *Minnesota Aquaculture Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

Analysis and Growth Strategy

Building on Minnesota aquaculture's current status and production levels, the expansion of aquaculture in Minnesota should align with the National Aquaculture Development Plan's strategic goals, which include streamlining regulatory processes, addressing educational and research needs, and enhancing economic impacts. Given Minnesota's unique geographic, environmental, and economic attributes, the state's strategy must capitalize on its strengths and opportunities.

Minnesota's plan should consider the following factors:

- Minnesota is landlocked with no direct access to seawater or coastal regions
- The state has a shorter growing season compared to states farther south due to its location in the north-central region
- A strong tradition in conservation aquaculture and a robust recreational fishing industry

- An established small commercial fishing industry
- Eleven distinct tribal entities with unique heritages tied to natural landscapes and water resources
- Access to Lake Superior, enabling eligibility for NOAA Sea Grant funding
- State regulations prohibit the import of live baitfish across state lines but allow the importation of processed baitfish
- Adjacent to states that have VHS and other fish pathogens not currently found in Minnesota
- Abundant freshwater resources, including privately owned and managed water bodies

These unique attributes, combined with current market demands and federal priorities for aquaculture growth, present substantial opportunities for Minnesota to expand its commercial aquaculture sector. Immediate growth potential exists in the baitfish sector, with more limited potential in the sport fish sectors, which aligns with the state's successful recreational fisheries. Over the last 25 years, these sectors have consistently grown in the U.S., supported by well-established techniques for stocking sizes and conservation aquaculture practices (USDA, 2024). The sport fish sector's growth may be constrained unless a significant portion of state hatchery production is contracted to commercial facilities. Baitfish production does not presently meet demand, so there is much room for expansion within the state. Once the state's needs are met, export opportunities could expand this sector. Regulatory restrictions on the importation of live bait currently support growth in this sector.

The U.S. seafood trade deficit exceeds $20.3 billion, presenting significant opportunities in high-demand species like Shrimp and Salmon (Davis & Rexroad, 2024). Although Minnesota lacks coastal access for traditional Shrimp farming, advances in Recirculating Aquaculture Systems (RAS) and biofloc technologies offer viable land-based alternatives. These innovative systems reduce environmental impacts and allow for consistent production throughout the entire calendar year. However, challenges such as saltwater discharge restrictions and economic feasibility must be addressed to scale Shrimp production effectively. Despite these barriers, Minnesota's existing producers, and interest in Shrimp farming, position the state for early-stage growth in this sector. Furthermore, Shrimp byproducts, such as chitin, hold high-value applications in medicine, agriculture, and environmental sustainability, further enhancing the sector's potential (Dave et al., 2021).

Shrimp is the most consumed seafood product in the U.S., with a 2023 trade deficit of $6.5 billion (Mutter, 2020). Globally, Shrimp are traditionally farmed in large outdoor ponds along sensitive coastal regions, often causing significant environmental damage. Alternative systems, such as biofloc and clearwater RAS, address these concerns by enabling near-zero discharge operations in less sensitive environments (Howell, 2023). Although Shrimp farming faces challenges, including low rearing density and complex economic pathways, the potential for multiple production cycles per year makes it an intriguing option for Minnesota. Small-scale systems are currently operational or in the planning phase across the U.S. There is a current producer in Minnesota, and there appears to be interest in growing the species. This could be considered an early-stage growth opportunity for the state that could grow over time and should be supported.

Salmon farming represents another opportunity for Minnesota. U.S. Salmon imports reached $4.3 billion in 2023, with 218 metric tons being fresh or chilled Salmon fillets worth $2.8 billion (Salinas, 2024). Targeting just 5% of the fresh or chilled fillet market would require the state to produce 15,000 metric tons of live-weight Salmon annually. Recirculating Aquaculture Systems (RAS) technology has proven effective for raising Atlantic Salmon in freshwater environments, offering a sustainable alternative to traditional open-pen marine systems. With the support of public-private partnerships, Minnesota can establish itself as a leading producer of sustainably farmed Salmon, addressing local and national seafood demands while reducing the environmental footprint of imported salmon.

Regional niche species such as Steelhead Trout, Coho Salmon, and Tilapia have grown in states like Missouri, offering premium prices and opportunities for smaller-scale development. Minnesota's natural resources and long history in conservation aquaculture create additional opportunities to commercialize native species like Walleye and Perch. Walleye are one of the most valued food fish in the Midwest. However, most of the Walleye consumed in the region is wild-caught and imported from Canada, representing a large market that could be supported by commercial aquaculture (Shamback, 2020). While these species face production challenges, such as poor growth performance and disease susceptibility, investments in domesticated breeding programs could unlock their potential. Cultured Walleye, like other farmed fish, can help mitigate concerns about mercury contamination that are sometimes associated with wild-caught fish, resulting in a healthier and more marketable product (Harvard Health, 2014).

To drive aquaculture growth, Minnesota should focus on proven commercially viable species, invest in breeding programs for regional fish, and leverage public-private partnerships to mitigate risks and costs. Minnesota can position itself as a leader in sustainable and economically impactful aquaculture by developing infrastructure, streamlining regulations, and exploring premium niche markets.

Baitfish Sector

Background

Minnesota's commercial baitfish harvesting industry is critical to supporting the state's recreational fishing sector. Baitfish are harvested in large quantities from both public and private waters to meet the high demand from anglers targeting species like Walleye, Northern Pike, Muskie, Crappie, and Bass (MNDNR, 2024e). Despite regulations designed to ensure sustainability, protect ecosystems, and prevent the spread of invasive species and diseases, the industry continues to face challenges in maintaining quality harvests to meet demand. (MNDNR, 2024e).

In Minnesota, the live bait industry began in the 1920s and has continued to grow steadily to accommodate the increasing numbers of anglers (MNDNR, 1980). Throughout this history, live bait dealers experienced shortages of desired species and grade sizes. The MNDNR responded by investigating and promoting baitfish propagation, restricting harvesting gear and waters, and altering license structures to promote improved utilization of the baitfish resource. Concurrently, bait dealers encouraged minnow conservation by experimenting with culture as early as the 1940s and successfully introducing other live bait to fishermen (MNDNR, 1980).

Today, the main species harvested for baitfish in Minnesota include:

- Fathead Minnows: The most harvested baitfish in Minnesota, valued for their hardiness and availability. They are widely used by anglers targeting Walleye and Crappie, with 30% to 50% of production occurring in aquaculture-licensed waters.
- Shiners: Species such as Golden, Spottail, Emerald, and Common Shiners are predominantly wild-caught and less abundant than fathead minnows.
- Suckers: Small White Suckers, used as bait for larger predatory fish like Northern Pike and Muskie, are mostly raised in aquaculture-licensed waters.
- Leeches: A popular live bait for various species, Leeches are primarily trapped in the wild. (MNDNR, 2024e).

The MNDNR regulates the baitfish harvesting industry to prevent overharvesting and protect native fish populations. Harvesters must obtain a minnow dealer license to collect, transport, and sell baitfish from most water bodies. Additional permits are required to harvest baitfish from waters infested with invasive species such as Zebra Mussels or Spiny Water Fleas. These permits impose species-specific conditions to mitigate the risks of spreading invasive species or diseases, such as viral hemorrhagic septicemia (VHS) (MNDNR, 2012, 2024f).

Aquaculture licenses are required for baitfish production in private or aquaculture-designated waters. A waterbody may be set aside for raising fish if specific conditions are met, riparian ownership is established, and there are minimal impacts on the local environment. These licenses can include conditions to ensure environmental protection and separation of public and private aquatic life. Despite these efforts, limited access to suitable water bodies and public concerns about using public waters for commercial baitfish production remain ongoing challenges.

The state's robust recreational fishery and angler preference for live bait creates a high demand for live baitfish. The state's reliance on wild harvest means baitfish availability will vary with wild baitfish populations. Wild baitfish populations are impacted by natural population cycles, flooding, drought, invasive species, pollution, and winter/summer kills. Coupled with a strict state policy prohibiting the importation of live baitfish from out-of-state, and increasing exports of baitfish out-of-state, has created a significant shortage of live bait either seasonally or during certain years.

The baitfish industry in Minnesota faces several significant challenges:

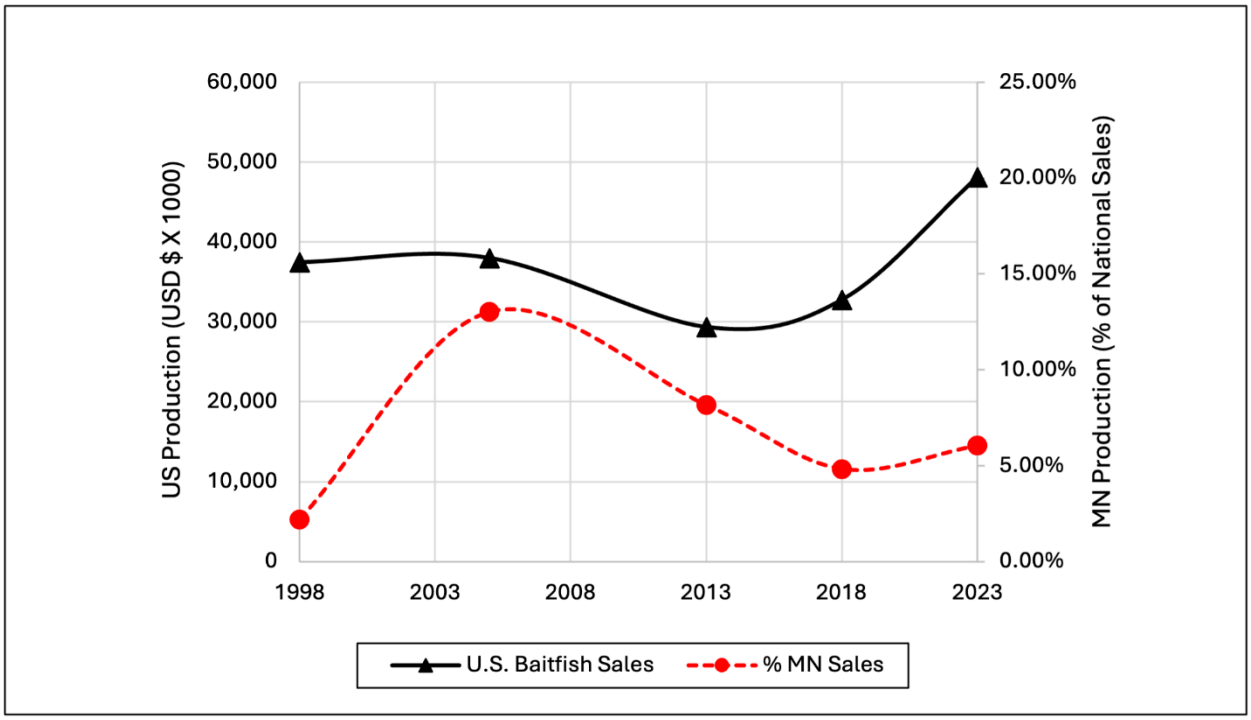
1. **Environmental Factors**
    - Climate change leading to extreme weather events, such as winter kill, summer kill, flooding and drought, which impact baitfish habitats
    - Degradation of aquatic habitats, reducing breeding and growth areas
    - Pesticide and nutrient runoff affecting water quality and fish health

2. **Regulatory and Disease Control Measures**
    - Regulations on harvest locations and transportation to prevent the spread of invasive species and diseases
    - Adjacent to states that contain fish pathogens such as VHS and invasive species
    - Restricted supply due to bans on live baitfish imports from other states
    - Restricted access to public and private waters due to competition with waterfowl hunters.
3. **Market and Supply Chain Disruptions**
    - Declining numbers of baitfish trappers and reduced availability of wild-trapped products
    - High reliance on wild harvest of baitfish
    - High export rates of minnows to other states, limiting in-state supply (MDNNR, 2024e)

Status and Economic Impact

Baitfish production in Minnesota peaked in 2005 at $5 million in annual sales, representing over 10% of national production. Between 2005 and 2015, both state and national production declined. However, a recovery began in 2018, with Minnesota contributing approximately 6% of national production by 2023 (Figure 12) (USDA, 2024). This recovery highlights the potential for targeted growth in the industry.

Figure 12. *Baitfish Production in the U.S. and Minnesota (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

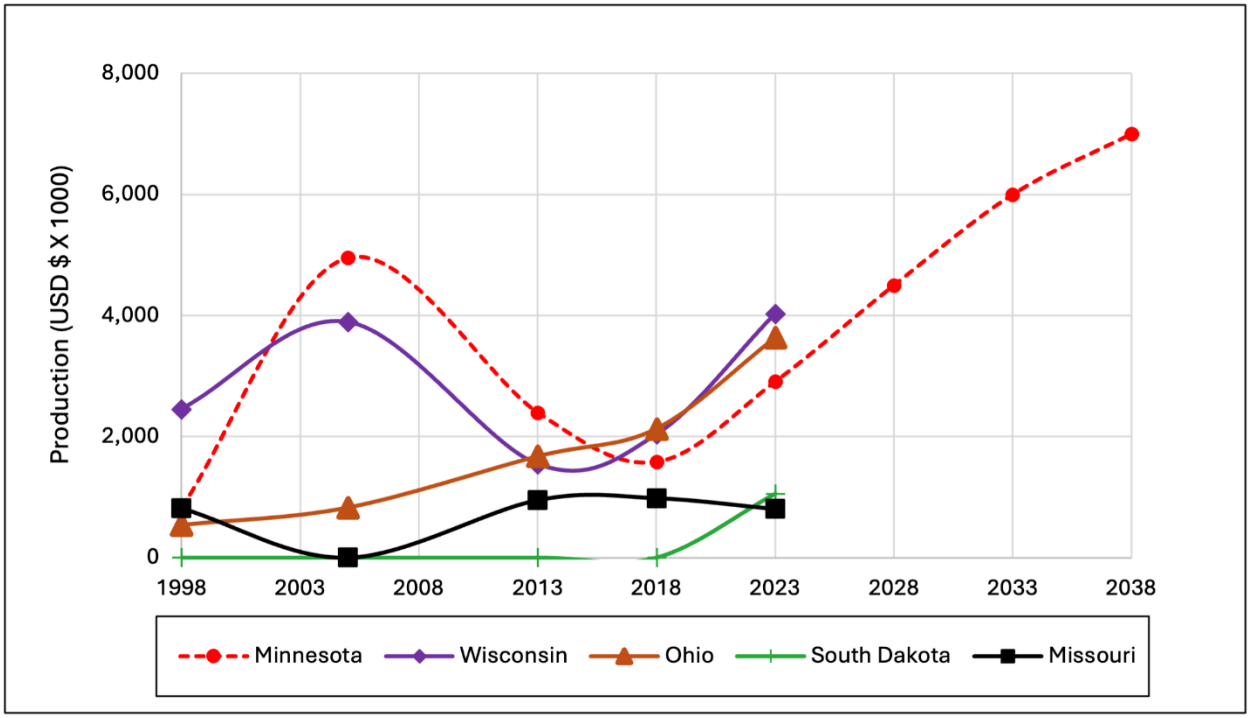
Potential for Growth

Baitfish is a unique market tied closely to Minnesota's recreational fishery. While fishing license sales have remained relatively steady at an average of 1.1 million annually since 2000 (Staff, 2018), the current opportunity in baitfish production lies in stabilizing the supply (Gunderson, 2018).

Efforts to address shortages include expanding aquaculture production through RAS and artificial ponds, improving access to underutilized water bodies, and monitoring disease. Minnesota recently created VHS-free zones in 2022 because, after more than 15 years of testing, Minnesota is the only "Great Lake State" that has not had a VHS detection in inland waters. This policy has opened more waters to minnow harvest and reduced the disease testing burden on harvesters. Minnesota is also exploring increased in-state baitfish production, such as golden shiners, through aquaculture projects, including the Minnesota Sea Grant Golder Shiner program, which was supported by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) (Minnesota Sea Grant, 2024).

Baitfish aquaculture offers several financial and operational advantages, including a high value-to-biomass ratio, short production cycles, no processing requirement (live bait) and the ability to be reared in new technology, like RAS, that is resilient against climate change and diseases. These are all favorable metrics to the feasibility of commercial baitfish aquaculture and overcome many of the financial obstacles faced by the commercial aquaculture of food fish. With targeted investment and support, baitfish aquaculture in Minnesota could return to historical production levels, potentially generating $7 million annually by 2038 (Figure 13).

Figure 13. *Minnesota's Forecast Baitfish Aquaculture Production (1998 – 2038)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

Strategies for Success

The baitfish industry should aim to increase the available supply of baitfish to ensure that it does not limit the growth of recreational fishing in the state.

- Provide a variety of bait species and sizes throughout the calendar year at a reasonable cost to anglers.
- Develop diverse production methods encompassing species, technology, and scale to meet varying demands.
- Protect and enhance the fishing experience in Minnesota, encouraging more visitors from both within and outside the state to enjoy fishing in Minnesota waters by improving catch rates through live bait.
- Implement measures to safeguard the target recreational fish species that generate demand for baitfish in the first place.

Key Considerations

Market Analysis

A comprehensive market analysis of the baitfish industry is needed to understand its current size and potential for growth. While the in-state industry's overall size appears limited, quantifying this is crucial. Out-of-state markets also need to be quantified for the export of Minnesota-grown baitfish. Further investigation is needed into the relationship between baitfish demand, wild harvests, and exports to identify how aquaculture can complement the existing supply chain.

Research

Research is needed to clarify Minnesota's seed stock and broodstock requirements for key baitfish species. This includes determining the growth rates and feeding requirements necessary to raise seed stock to a marketable size. These parameters will help establish the most suitable fish propagation technologies and evaluate production methods' economic feasibility. Addressing these research gaps will provide a foundation for optimizing aquaculture operations and improving the baitfish supply.

Regulatory

Higher regulation may be required to ensure the sustainability of aquaculture and manage wild populations effectively. This includes reducing wild harvests during population recovery periods and allowing aquaculture production to meet demand. Long-term restrictions on wild harvest would help stabilize supply and pricing while protecting natural resources.

Key examples of regulatory needs include:

- **Licensing and Permit Structure:** Develop a clear and consistent licensing and permit cost framework to streamline aquaculture operations.
- **Collaborative Regulatory Studies:** Conduct regulatory studies in cooperation with the Minnesota Department of Natural Resources (MNDNR) to assess impacts and opportunities for improved management.
- **Mandatory Reporting System:** Implement a state-mandated reporting system to collect accurate aquaculture data, which should be submitted to the USDA for inclusion in the Census of Aquaculture.

Cooperation with Agencies

Expanding commercial aquaculture operations for baitfish requires a clear understanding of the goals and objectives of state agencies that may influence the long-term financial viability of private operations. State agencies like the MNDNR often operate under 10-year action plans to address forecasted production or harvest management needs. Commercial operators must also trust that legislation regarding the importation of minnows will remain stable, ensuring predictability in the industry.

The MNDNR is expected to adopt a long-term strategy to address the baitfish shortage through habitat restoration, production efforts, and potential legislative changes. This strategy would allow private entities to address the immediate need for baitfish while the state implements its broader solutions. Researchers at the University of Minnesota Sea Grant Program (NOAA) Sea have developed husbandry and culture technologies for Golden Shiners, which could potentially be applied to other minnow species and significantly advance production goals for baitfish in Minnesota.

Recommendations

Based on data from the Census of Aquaculture, Minnesota should aim to develop baitfish farms that generate approximately $200,000 in gross annual revenue. To achieve the target production goal of $7 million in annual revenue by 2038, the state would require approximately 20 new production facilities over the next 13 years while maintaining existing production capacity. Production efforts should focus on four primary species: Golden Shiner, White Sucker, Leeches, and Chubs. Each species should be supported by four production facilities—two utilizing Recirculating Aquaculture Systems (RAS) and two employing outdoor pond or flow-through technologies—for a total of 16 facilities. The remaining four facilities could remain flexible, advancing successful species and techniques or exploring additional baitfish opportunities. This facility size and structure are appropriate for fostering early diversity, collecting key economic data, and refining production methods before scaling operations (see **Appendix A: Table 3** for additional details).

Baitfish aquaculture stands out as one of the most financially promising models for commercial aquaculture, largely due to its high value-to-biomass ratio. However, initial investments need to be incentivized to attract and support startups. Over the next eight years, an estimated $2 million in funding incentives would be required to stimulate the establishment of the recommended 20 new facilities, averaging $100,000 per facility. This figure represents the expected investment shortfall that private equity is likely to impose, given projected rates of return. With 12 years of operation, it is estimated that every $1.00 of incentive provided would yield a $24.00 return on investment (see **Appendix A: Table 5** for additional details).

To further reduce the financial burden on new baitfish facilities, the following strategies should be explored:

- **Leverage Existing Facilities**: Support established baitfish production facilities in expanding their capacity or integrating baitfish production into existing sport fish operations.
- **Collaborate with Established Producers:** Encourage sport fish producers with existing infrastructure to incorporate baitfish production into their operations.

Growth recommendations for baitfish aquaculture should align with national aquaculture priorities, as outlined in the National Aquaculture Development Plan (NADP). This includes recognizing baitfish aquaculture as a sector that intersects commercial and conservation priorities. Baitfish aquaculture supports recreational fishing and conservation efforts while maintaining the potential for independent financial viability. Given its dual role, maintaining a stable baitfish supply should remain a high priority for Minnesota's aquaculture development plans.

Achieving the state's production goals will require close coordination with the MNDNR's roles and responsibilities. Key coordination points include:

1. **Expand Aquaculture Operations**: Increasing baitfish aquaculture capacity is a critical short-term strategy to address immediate supply shortages. However, long-term profitability will depend on this strategy on the effectiveness of state restoration goals. Infrastructure investment, propagation research, and breeding programs will be essential components.
2. **Restore Aquatic Habitats**: Protecting and restoring ponds, wetlands, and other habitats could enhance natural baitfish populations and improve harvest values. This could reduce the reliance on cultured baitfish while maintaining ecological balance.
3. **Balance Ecosystem Protection and Wild Harvests**: Developing a balanced approach that protects aquatic ecosystems while increasing wild harvests and supporting commercial production will allow for immediate growth and long-term profitability.

The MNDNR should develop a comprehensive 10-year action plan to support baitfish aquaculture. This plan should include:

- Habitat restoration and restocking efforts
- Broodstock management programs
- Considerations regarding minnow importation from other states
- Projections for increased wild harvest rates
- Projected deficits to be supplemented by private industry
- Plans for public-private partnership agreements

By implementing a detailed plan, the MNDNR can give the private sector the confidence needed to develop sustainable business models and effectively address short-term production deficits.

Justification

It is estimated that developing 20 new baitfish facilities could create approximately 20 full-time jobs, with one job added for every $200,000 in revenue generated (see **Appendix A: Table 5** for

additional details). The baitfish sector's economic potential and critical role in supporting recreational fishing make it a key area for targeted investment and strategic growth. A coordinated effort between private and public stakeholders will ensure the long-term success and sustainability of Minnesota's baitfish aquaculture industry.

The 2023 Minnesota Legislature directed the Department of Natural Resources to submit recommendations to ensure a viable Minnesota-grown bait supply. The statutory requirements for this report, as mandated in Minnesota Session Law 2023, Chapter 60, Article 4, Sec. 109 are:

> "By January 15, 2024, the commissioner, in consultation with bait producers, bait harvesters, retailers, and other fishing interest groups, must submit recommendations to the chairs and ranking minority members of the House of Representatives and Senate committees and divisions with jurisdiction over environment and natural resources to ensure a viable Minnesota-grown bait supply and sustainable bait industry for anglers of Minnesota that minimizes the risk of spreading aquatic invasive species or fish disease in Minnesota."

The 2024 report that fulfilled this requirement is titled "Ensuring a Viable Minnesota Grown Bait Supply Legislative Report." Its primary recommendation is to explore opportunities to utilize ponds and other minnow-rearing techniques to supplement the wild bait supply. This would align commercial baitfish production with state agency priorities.

Baitfish is also listed in the USDA's Aquaculture National Program 106 Action Plan for 2025-2029. Component #3 of this plan includes problem statement 3B, which addresses aquatic pest management in baitfish aquaculture. More specifically, this concerns wild harvests and defining effective strategies for removing aquatic pests and invasive species before transport. This effort reduces the risk of spreading invasive and nuisance species while transporting baitfish.

Sport Fish Sector

Background

Sport fish aquaculture involves cultivating aquatic organisms to support the recovery and growth of species primarily associated with recreational fishing. These fish are typically sold live at stocking size and released into public or private waterbodies. While state and federal agencies play a significant role in this sector, their production facilities are not included in the USDA Census of Aquaculture (2023) production figures. Only private or corporate-owned operations are accounted for in these numbers.

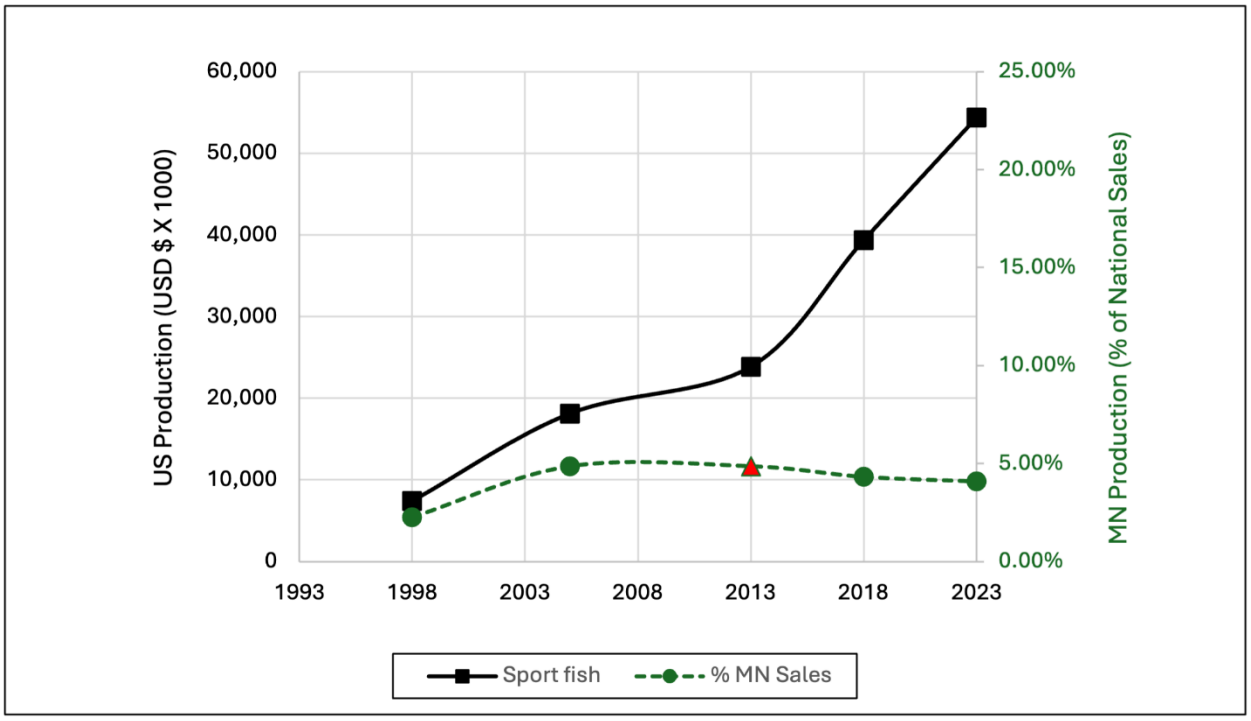
Demand for sport fish comes from private landowners and state or federal agencies. Private landowners and hunting and fishing clubs often stock fish in private waterbodies for personal use. State-operated natural resource departments may contract private companies to supply fish for stocking public water bodies. In these cases, the state sets criteria for the fish and often provides fertilized eggs to ensure genetic specifications are met. Before the state purchases the fish, private entities must meet standards such as disease-free certification, size, quantity, and other quality measures. In Minnesota, conservation aquaculture is significant, presenting opportunities for collaboration to grow the commercial sport fish industry.

Status and Economic Impact

Sport fish aquaculture has grown steadily over the past two decades and has now surpassed baitfish in national economic impact. Nationally, sport fish aquaculture contributes approximately 3% of total aquaculture production. In 2023, this translated to $48 million in national output, with Arkansas and California accounting for 60% of production. Minnesota ranked sixth nationally, contributing $2.2 million, or nearly 5% of the national output (Figure 14) (USDA, 2024).

In Minnesota, conservation aquaculture and sport fish production provide substantial downstream benefits, including contributions to recreational fishing, tourism, job creation, and the preservation of ecosystem services. These activities also form the foundation for sustainable economic growth by maintaining fish populations, biodiversity, and aquatic ecosystem health. This long-term sustainability prevents costly environmental degradation while enhancing Minnesota's reputation as a premier destination for outdoor recreation.

Figure 14. *U.S. Production of Sport Fish Compared to Minnesota's Production (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/
Red triangle data points are estimated due to unavailable or restricted data.

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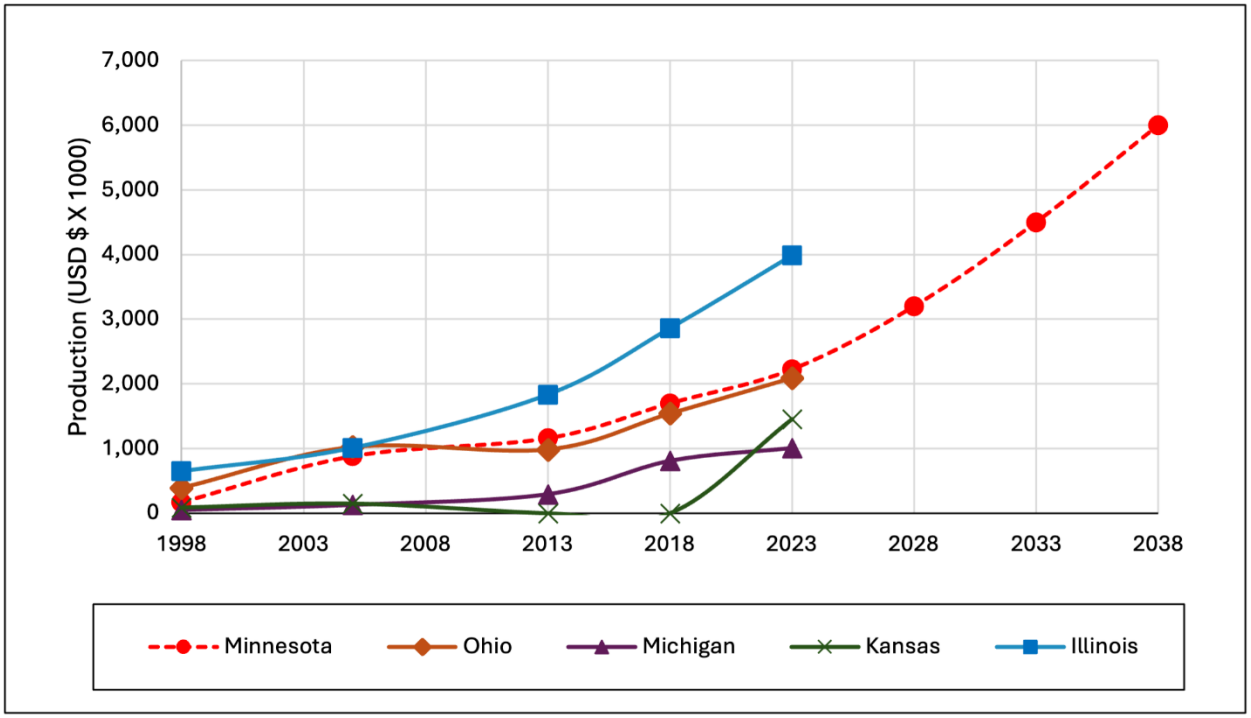
Potential for Growth

Minnesota's potential for growth in sport fish aquaculture is limited unless fish are distributed out of state or private production replaces state production. Projections suggest annual production could grow to $6 million in sales within 13 years (Figure 15).

Figure 15. *Minnesota's Projected Sport Fish Aquaculture Production (1998 – 2038)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

Illinois currently leads the sport fish sector among north-central states, with $4 million in revenue in 2023. The predominant species produced is Largemouth Bass, which accounts for 80% of its production, with a smaller contribution from Sunfish (USDA, 2024). Collaborating with neighboring states to identify successful species and techniques can help Minnesota develop a robust strategy. It is recommended that Minnesota develop a 10-year plan in partnership with the MNDNR to identify critical areas of collaboration and focus on key species.

Strategies for Success

Minnesota's sport fish sector plan should prioritize a diverse industry encompassing multiple species and production technologies aligned with MNDNR requirements. The focus should remain on fostering an industry that balances ecological sustainability with economic growth. Key species for growth include:

- Walleye
- Muskellunge
- Rainbow Trout, Brown Trout, Lake Trout
- Yellow Perch, Bluegill, and Black Crappie
- Sturgeon

Key Considerations

- Conduct a detailed study of stocking schedules for all fish species in Minnesota to identify gaps in production capacity where public-private partnerships could be beneficial.
- Analyze the private lake stocking market to estimate its size and potential growth.
- Examine the potential for out-of-state sales

Recommendations

Based on the average farm size identified by the USDA Census of Aquaculture, Minnesota should target sport fish farms that generate about $250,000 in gross annual revenue. Achieving the target production goal of $6.0 million in annual revenue in 2038 would require approximately 15 new production facilities over the next 13 years while maintaining the current production capacity. The goal should be to generate two or three production facilities for each of the five species groups listed above, distributed between RAS and Partial Recirculating Aquaculture (PRAS) and outdoor pond/flow-through technology. This facility size is considered appropriate while new species and culture technologies are being explored to promote early diversity and gain knowledge and key economic data before scaling up production (**Appendix A: Table 3** for details).

Sport fish has a good financial model for commercial aquaculture due to its value-to-biomass ratio, but startups still need to be incentivized. Based on the growth trends of this sector, funding requirements should be slightly more than baitfish. To stimulate the targeted growth in this sector would require an estimated $3.375 million USD in incentives over the next 8 years. These incentives should support the design and development of the recommended 15 new facilities, equivalent to $225,000 of incentives per facility. This is the estimated investment shortfall that private equity would likely place on the development of these facilities based on the estimated return on investment. Based on 12 years of operation, the state would see a return on investment of $13.33 generated for every $1.00 of incentive provided (**Appendix A: Table 5** for details).

Justification

The development of 15 new sport fish facilities is expected to create approximately 15 full-time jobs, with one job added for every $250,000 in revenue (see **Appendix A: Table 5** for additional details). This growth will support biodiversity, ecosystem health, and Minnesota's economy through recreational fishing, ecotourism, and environmental services.

Incorporating Native American heritage into conservation aquaculture efforts adds a cultural and environmental dimension. For Indigenous peoples, aquatic ecosystems and fish species are integral to their livelihoods, spiritual practices, and cultural identity. Collaborating with Native American communities can enhance ecological restoration and preserve Indigenous traditions.

Conservation aquaculture principles can be integrated into commercial aquaculture to improve sustainability, genetic health, and public perception. These efforts will support Minnesota's recreational fishing and tourism industries while fostering eco-friendly growth in the commercial sector. A coordinated approach will ensure the sustainability of both farmed and wild aquatic populations, benefiting the state's ecology and economy.

Food Fish Sector

Background

Minnesota's history with the food fish aquaculture industry has been uneven, with many startups and subsequent failures mirroring trends in other states. Production numbers in Minnesota have remained stagnant at just under $2 million annually for nearly 15 years before declining over the past decade (USDA, 2024). Several factors contribute to the challenges of sustaining production facilities, including capitalization issues, prolonged timelines to reach steady-state production, and operational challenges such as water quality, disease, feed, and genetics.

Building and maintaining standing biomass presents significant financial risks, especially for species with long production cycles and global competition for the most popular species like Shrimp, Atlantic Salmon, and Tilapia. Market shifts can also reduce or eliminate revenue streams, further compounding operational difficulties. Often, it is not a single issue but a combination of smaller challenges that lead to the failure of a facility. Food fish production requires precision and expertise, making it crucial to have knowledgeable individuals guiding the sector's growth.

When considering RAS technology, capital investment forces a very strict bioplan that generates constant production and has a high utilization rate for a facility’s culture system. Downtime is minimized, and one production cycle must lead right into the next. Managing different cohorts and moving and sorting fish to maximize utilization can easily be underestimated. Site selection, even for RAS operation, is critical. RAS cannot go anywhere in the world. Some places are better suited than others for RAS, and the choice of location will likely have a long-standing impact on a facility’s operation costs. Food fish production is challenging; the margins can be slim, and the risk can be great. Minnesota offers a blank slate from which to work and has several engaged entities ready to support its growth. It will be critical to have knowledgeable people who understand the industry and respect the delicate nature of these systems leading the growth.

Historically, growth in the U.S. food fish aquaculture sector has been slow and conservative, driven by government incentives such as research grants and outreach programs. While this approach allows for adjustments and flexibility, it limits the scale and speed of industry growth. More recently, private-sector investments, often backed by foreign capital, have shifted focus to large-scale production facilities targeting high-value species like Atlantic Salmon. This shift demonstrates two competing growth strategies: the traditional, conservative model and an aggressive, high-volume approach designed to achieve economies of scale.

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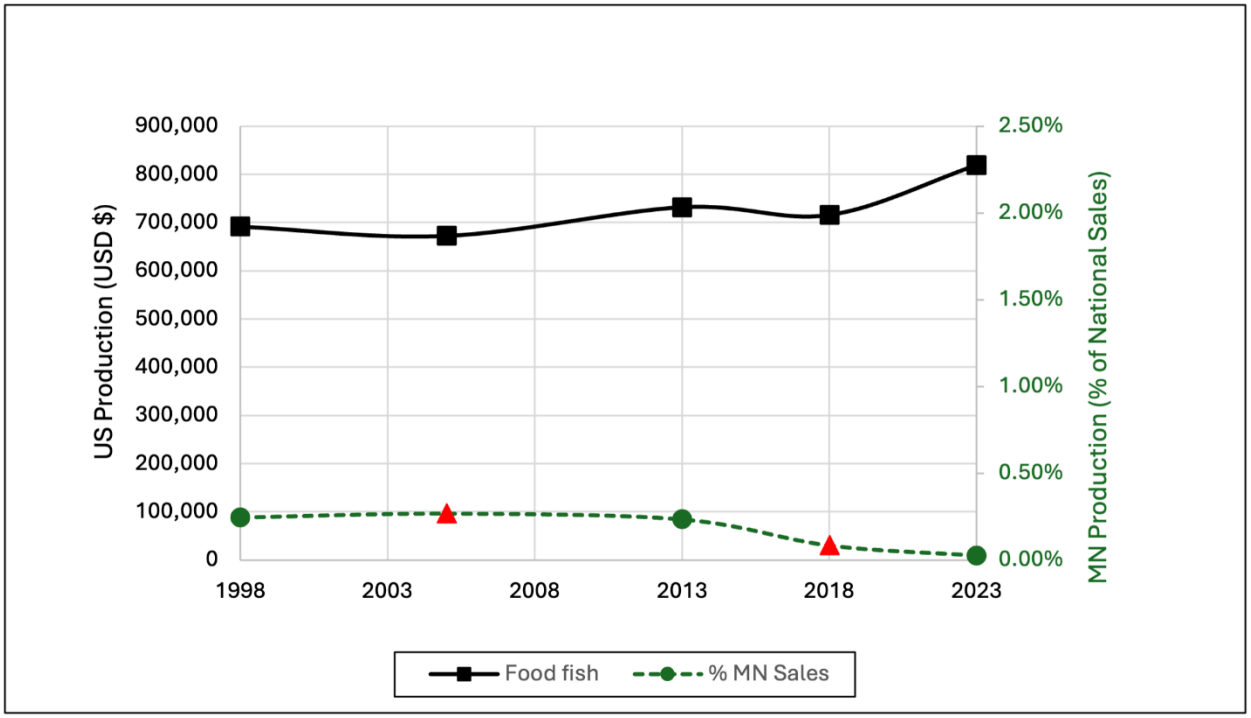
Status and Economic Impact

According to the USDA Census on Aquaculture in 2023, the economic impact of food fish aquaculture in Minnesota is currently negligible (Figure 16). However, the state's potential for developing this sector remains untapped, offering significant opportunities for future growth.

Figure 16. *U.S. and Minnesota Food Fish Production (1998 – 2023)*



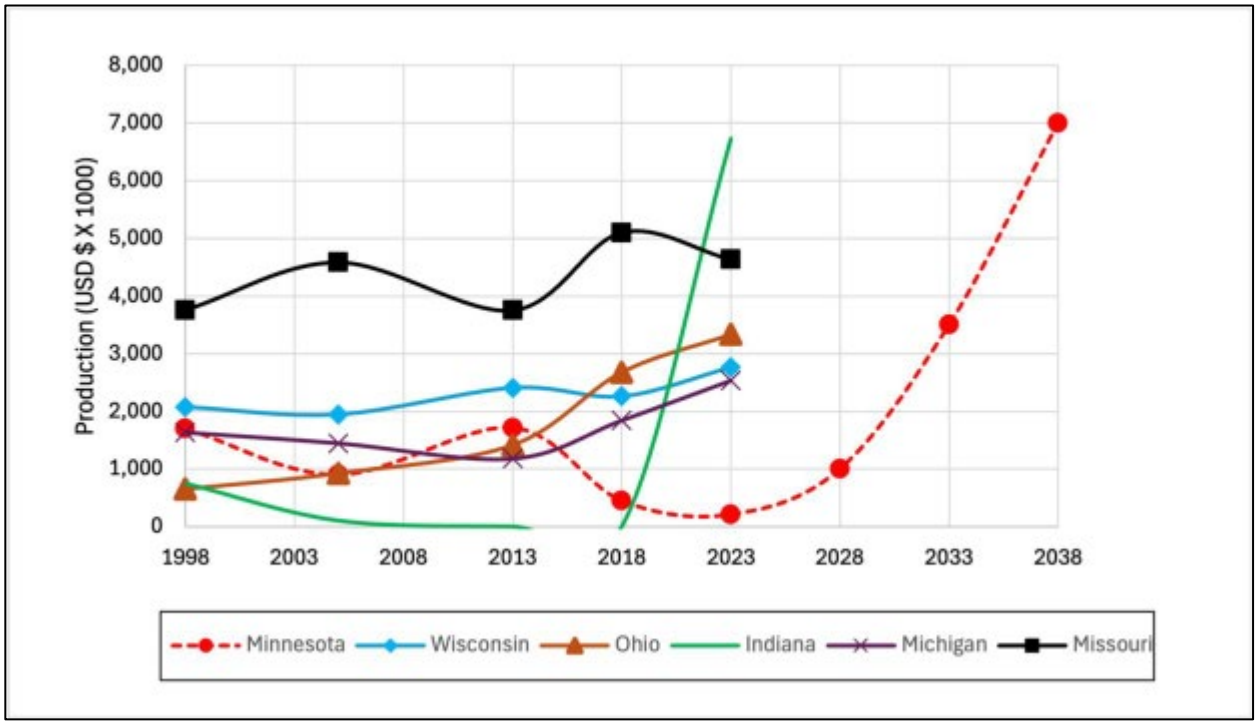
Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/
Red triangle data points are estimated due to unavailable or restricted data.

<< Continued on next page>>

Potential for Growth

Adopting a conservative growth strategy could lead to a diverse aquaculture industry in Minnesota, featuring multiple species and small production facilities utilizing various technologies. Projections estimate this approach could generate $7 million annually within 13 years, with real growth occurring in subsequent decades as successful operations expand and struggling ones exit the market. This method distributes financial risk and provides a foundation for future diversification (Figure 17).

Figure 17. *North Central Regional Food Fish Production with Conservative Minnesota Projections (1998 – 2023)*



Source: Data up to 2023 from USDA Census of Aquaculture (2024). https://www.nass.usda.gov/Publications/AgCensus/2022/

An aggressive growth strategy targeting large-scale, land-based salmon production could significantly increase the economic impact. Salmon imports alone represented a $4.3 billion trade deficit in 2023, with 218,000 metric tons of fresh or chilled Salmon fillets imported, valued at $2.8 billion (Salinas, 2024). Capturing just 5% of this market could position Minnesota to produce 10,000 metric tons of fillets annually, generating approximately $133 million in total revenue, including an additional $4.75 million from the 4,750 metric tons of by-products like trimmings and fish racks. (Nunes et al., 2022).

To achieve this, Minnesota would require five facilities producing 3,000 metric tons each, leveraging advanced RAS and PRAS technologies at an estimated cost of $300 million total (see **Appendix A: Table 11** for additional details). These technologies offer sustainability benefits, such as reduced water use, isolation from environmental impacts, and nutrient recycling options, aligning with the state's environmental priorities. RAS technology is the leading option for this to take place, but this technology comes with its own challenges:

1. RAS technology requires strategic siting, careful planning, strict financial oversight, and proper long-term management.
2. RAS technology is capital-intensive and requires large upfront investments. Therefore, every species considered will require unique solutions to achieve successful financial outcomes.
3. RAS technology is advanced and requires knowledgeable designers, management, and operators.

For a landlocked state like Minnesota, in the northern climate zone of the United States, food fish aquaculture offers the most significant growth potential of any other category recognized by the USDA. Raising food fish to market size differs from the sport fish and baitfish aquaculture categories in a few critical ways:

- Food fish aquaculture requires longer culture times and much larger fish sizes for market than baitfish and sport fish. This requires significantly more standing biomass, larger production volumes, and extensive production facilities.
- Food fish aquaculture requires more aggressive feeding regimens to promote fast growth on commercialized diets. This requires more water use and potential nutrient discharge.
- Food fish aquaculture requires higher production densities and constant production. This presents a higher risk of disease transmission or mechanical failure.
- Food fish aquaculture has a much different market landscape than sport fish and baitfish aquaculture, making the management, production, and processing requirements more challenging.
- Food fish markets compete with global aquaculture and wild-caught markets, making the economic landscape for food fish much more competitive.
- Water would most likely need to be heated to achieve ideal growth rates for food fish aquaculture, which would support higher metabolism, feeding rates, and growth.

Strategies for Success

The strategy for Minnesota's food fish sector employs a dual approach: maintaining a traditional growth model to ensure steady, sustainable expansion and risk diversification, while simultaneously implementing an aggressive growth strategy aimed at rapidly scaling production capabilities. This dual approach is designed to maximize economic gains while fostering a resilient and diverse industry within the state.

- **Establish Public-Private Partnerships (PPP):** Encourage private entities to provide equity, technology, construction services, and operational management. Facilitate public sector contributions through site predevelopment, access to water resources and discharge permits, tax incentives, utilization of existing infrastructure, transparent regulatory frameworks, and crop insurance for aquaculture operations. Feedback from the private equity side indicates that the startup cost burden and risk mitigation must be shared equally in a PPP to truly incentivize growth in this sector. Ensure a balanced risk-sharing model, with

incentives covering 25%–50% of the startup cost burden to engage private sector participation. Additional regulatory and permitting support that shortened the development timeline would also be beneficial to industry growth.

- **Optimize Farm Scale and Capital Investment:** Recommend farm scales that align with realistic capital investment capacities while ensuring tight operational margins. Incorporate state and federal government incentives to address challenges in technology implementation, workforce training, and infrastructure development. Align sector goals with the National Aquaculture Development Plan (NADP) to secure government support and funding.
- **Promote Sustainability through Nutrient Recycling:** Develop systems to recycle nitrogenous waste and other key nutrients for use in agriculture, Controlled Environment Agriculture (CEA), and pet food production. Investigate opportunities for partnerships with land-based agriculture producers and other industries to create sustainable byproduct applications.
- **Reduce Barriers to Industry Growth:** Shorten development timelines through streamlined regulatory and permitting processes. Provide pre-permitted sites and infrastructural support to mitigate startup risks and foster rapid development. Encourage the adoption of efficient and sustainable aquaculture technologies, such as Recirculating Aquaculture Systems (RAS).
- **Develop an Educated and Skilled Workforce:** Implement training programs for aquaculture operations to address the technical demands of new technologies. Support educational initiatives that provide industry-specific skills and promote awareness of the sector's potential.
- **Fish Processing Development:** Encourage investment in fish processing infrastructure that not only supports the aquaculture sector but also benefits other industries in Minnesota, such as commercial fishing.
- **Utilize Waste Products for Revenue:** Develop revenue streams for byproducts such as fertilizer, pet food, and other applications. These efforts would further benefit industries like agriculture and commercial fishing, creating a circular economy within the state.
- **Broodstock and Fish Genetics Innovation:** Focus on developing broodstock capable of spawning year-round and fish genetics optimized for growth in RAS. Ensure strict regulations to prevent these fish from being introduced into Minnesota’s natural waters.

Key Considerations

Minnesota's food fish aquaculture industry should prioritize targeting local markets and providing communities with locally grown products. Comprehensive market research is essential to identify regional markets, price points, and opportunities. Efforts should include evaluating live markets to minimize processing challenges and exploring value-added products to enhance the sector's economic viability. Quantifying locally purchased finfish imports, particularly from countries like Canada, is also crucial. This research must address true market size, product pricing, current seafood sources, and production cost drivers to evaluate the economic feasibility of food fish aquaculture in Minnesota.

A significant area of support required by the state is identifying suitable locations for these facilities. While Recirculating Aquaculture Systems (RAS) are efficient in water use, they concentrate potential pollutants such as nitrogen and phosphorus in discharge flow. For example, an annual production of 15,000 metric tons (MT) would generate approximately 2,500 kilograms of Total Nitrogen (TN) per day. At a typical discharge concentration of 60 mg/L, achieving 10,000 MT of salmon fillets would require a water flow of 7,500 gallons per minute (GPM), distributed across five facilities at 1,500 GPM each[2]. This distribution reduces environmental impact while allowing sites to leverage shared state-level resources.

Minnesota's nitrogen discharge limits present additional challenges. Current plans target a TN limit of 30 mg/L, with further reductions to 10 mg/L in the future (Minnesota Pollution Control Agency, 2014). Meeting these restrictions would necessitate increased water flow, enhanced effluent treatment, or nutrient recycling strategies to absorb excess nutrients. These strategies, while achievable, impose additional costs and complexity on startups, which can hinder industry growth. To align state regulations with industry needs, an initial discharge limit of 60 mg/L is recommended, with gradual reductions over time. Similar phased strategies should be applied to phosphorus, starting at 5 mg/L. These adjustments would enable the industry to scale up while utilizing Minnesota's agricultural sector to repurpose nutrient-rich waste effectively.

Conceptual facility designs should be developed to determine the infrastructural and resource requirements for production growth. This includes identifying and quantifying sources for feed, seed stock, water, energy, labor, and technical resources. These foundational elements are critical for ensuring the long-term success and scalability of food fish aquaculture operations.

In addition to market, infrastructure, and resource needs, several biological challenges must be addressed. These challenges, highlighted during the 2017 Food-Fish Aquaculture Workshop hosted by the Minnesota Sea Grant Program, include:

- Determining nutritional and feed requirements for each species at various life stages
- Developing broodstock for regional species, such as Walleye, to ensure year-round availability of gametes
- Selective breeding programs to produce healthy, fast-growing fish adaptable to various facilities
- Advancing and implementing biosecurity practices to mitigate disease risks effectively

Addressing these needs holistically will position Minnesota's food fish aquaculture sector for sustainable growth while aligning with environmental and economic priorities.

[2] Estimate by EDA-Aquatic Design Services, LLC. RAS Design Consultant.

Recommendations

The conservative growth strategy for food fish aquaculture should aim to establish 23 new production facilities by 2038, each generating an average annual revenue of $300,000, culminating in a total of $7.0 million per year. These facilities should focus on diverse species, including Walleye, Largemouth Bass, Rainbow Trout, Perch, Tilapia, Shrimp and Sturgeon. Many of these species overlap with the objectives outlined in the sport fish sector, enabling the leverage of shared technologies, processes, and genetic resources. The recommended production systems should incorporate Recirculating Aquaculture Systems (RAS), Partial RAS (PRAS), and some outdoor pond and flow-through technologies (see **Appendix A: Table 3** for additional details).

For the aggressive growth strategy, the focus should be on constructing five large-scale facilities, each with the capacity to generate $26.6 million annually, equating to a combined production value of $133 million per year. These facilities would target a production volume of 3,000 metric tons of live-weight Salmon per site (see **Appendix A: Table 2** for additional details). They should be geographically distributed across the state to minimize localized environmental impacts while leveraging communal resources. The primary species for this strategy is Atlantic Salmon, given its high production potential and well-established U.S. market.

The food fish sector faces unique financial challenges, primarily due to its reduced value-to-biomass ratio compared to other aquaculture sectors. Significant funding will be required to attract private equity and stimulate targeted growth. The conservative growth approach would necessitate an estimated $18.4 million over the next eight years to support establishing diversified smaller-scale facilities. Meanwhile, the aggressive growth approach would require approximately $98 million USD to support the development of the five large-scale facilities. These incentives would address investment shortfalls and enhance the sector's viability. The return on investment is projected at $4.50 for every $1.00 of incentive provided under the conservative strategy and $16.29 for every $1.00 of incentive under the aggressive strategy (see **Appendix A: Table 5** for additional details).

The initial focus for the food fish sector should be on species that are already domesticated and have a proven track record in aquaculture. Key economic and sustainability drivers such as growth performance, feed conversion ratios (FCR), and fish-in: fish-out ratios should guide species selection. High-value domesticated species with established commercial breeding programs and year-round availability of eggs or fry, such as Trout, Salmon, and Hybrid Striped Bass, present the best opportunities for rapid growth. Additionally, species with straightforward captive breeding processes, such as Perch, Tilapia, and Sturgeon, offer excellent options for startup facilities.

Native species, including Walleye, Perch, and Largemouth Bass, hold significant potential for Minnesota. However, their growth trajectory is hindered by limited domestication. Efforts should be directed toward breeding and husbandry advancements to initiate domestication and enhance growth and survival rates for these species in food fish aquaculture. Breeding programs for native species should align with and leverage existing sport fish programs while maintaining distinct objectives. Unlike sport fish breeding programs, food fish initiatives should prioritize genetic traits such as disease resistance, efficient feed conversion, rapid growth, reduced aggression, and fry adaptability to commercial diets. These efforts will support the development

of a unique and marketable food fish aquaculture sector in Minnesota while benefiting from the genetic resources and technologies established through conservation aquaculture programs.

Justification

The traditional food fish growth agenda is estimated to create approximately 25 jobs, based on a revenue-to-job ratio of $275,000 per job. In comparison, the aggressive food fish growth strategy is projected to generate 443 jobs, reflecting a revenue-to-job ratio of $300,000 per job (see **Appendix A: Table 5** for additional details).

The high capital investment required is a significant barrier to growth in this sector. Achieving an annual production of 15,000 metric tons (MT) of live weight would require an estimated capital investment of approximately $300 million. Additionally, a two-year working capital budget of nearly $170 million is necessary to sustain operations during the early stages. The lengthy timeline—spanning 5 to 7 years for planning, permitting, construction, and achieving steady-state production in large land-based RAS facilities—further deters private equity investments. Developers and investors typically seek substantial financial incentives from state and federal governments to mitigate these risks and support industry development.

Despite these challenges, the food fish aquaculture industry holds substantial economic potential. It creates jobs across various sectors, including farming, processing, distribution, feed production, and equipment manufacturing. The development of this sector can stimulate economic growth, particularly in rural areas where employment opportunities in other industries may be limited.

Commercial aquaculture also addresses the pressing issue of overfishing, which has depleted many wild fish stocks and threatens marine biodiversity. Aquaculture alleviates pressure on wild fish populations by offering an alternative seafood source, allowing them time to recover. This contributes to the long-term sustainability of marine and freshwater ecosystems. Furthermore, food fish aquaculture is often more environmentally sustainable than other forms of animal protein production. With higher feed conversion efficiency than livestock like cattle, aquaculture requires less feed, reducing strain on land resources and lowering the overall carbon footprint. Additionally, aquaculture can be practiced in areas unsuitable for traditional agriculture, contributing to food production without competing for land and water resources.

Diversifying the global food supply is essential for enhancing resilience to disruptions caused by climate change, natural disasters, or market fluctuations. Commercial aquaculture offers a reliable and consistent food source, strengthening the global supply chain.

Moreover, the aquaculture industry drives innovation in areas such as feed technology, genetics, disease management, and water treatment systems. These advancements improve sustainability, efficiency, and product quality. For instance, innovations in recirculating aquaculture systems (RAS) enable fish farming in inland areas with minimal environmental impact. Such technologies make aquaculture more accessible and environmentally friendly across diverse locations.

Finally, aquaculture development provides rural communities with alternative income sources, preserving their economic and cultural ties to agriculture while diversifying their revenue streams. Many rural areas stand to benefit significantly from the job creation and economic stimulation brought by aquaculture.

This program aligns closely with the National Aquaculture Development Plan (NADP) and qualifies for federal assistance programs and government incentives, making it a viable and strategic opportunity for sustainable growth in Minnesota's food fish aquaculture sector.

Minnesota Aquaculture Potential

By implementing the growth strategies outlined in the Minnesota Aquaculture Plan across the three primary aquaculture sectors, Minnesota can position itself as a leader in aquaculture within the north-central United States. The combined value of these sectors, with both growth strategies applied to the food fish category, is projected to reach $153 million annually. This growth would require an estimated $122 million in incentives over an 8–10-year period. At current prices, over a 12-year production cycle, this investment could generate $1.7 billion in total production, representing an average return of $14.55 for every dollar invested by the state. Additionally, the expansion of aquaculture would create approximately 503 jobs across all sectors (see **Appendix A: Table 5** for additional details).

Financial risks associated with upfront capital investment must be mitigated to stimulate interest in aquaculture production. Historically, the high costs of essential infrastructure, such as pond construction and RAS systems—particularly for food fish production—have been a significant barrier to growth. However, the recommended aquaculture sectors offer substantial downstream benefits to other industries and the state, making them strong candidates for state-supported incentive programs.

While RAS and Partial-RAS technologies are leading options for aquaculture in Minnesota, these systems present challenges, including:

- High capital investment requirements
- Energy-intensive operations
- Technically advanced management demands
- Dependence on mechanical equipment and infrastructure
- Elevated operational costs
- Concentrated discharge streams requiring advanced treatment
- Competition with other states and countries

Investors want to know that their business is welcomed and supported by the state and townships they consider for development. Private equity investors are seeking significant state and federal financial incentives to offset these upfront capital risks.

As Brandon Gottsacker, CEO of Superior Fresh, noted:

> *"If the state implemented a program to support 50% of the capital costs for a land-based RAS salmon farm, Superior Fresh and others would strongly consider expanding in Minnesota."*

Globally and domestically, agriculture has long benefited from a variety of incentive mechanisms to encourage production, ensure food security, and promote sustainability. These incentives—such as direct subsidies, tax benefits, research and development support, and rural development programs—can now be extended to aquaculture following its recognition as a form of agriculture by the USDA. Although securing 25–50% startup incentives is ambitious, investments in rural infrastructure development (e.g., water resources, discharge systems, power, building upgrades) could address significant funding needs while benefiting multiple industries and reducing state investment risk. Regulatory support could further minimize development timelines and investment risks.

A recommended state investment of $75–150 million in incentives and rural development for aquaculture could attract private equity interest and enable significant land-based food fish aquaculture production in Minnesota. Key areas for investment include:

1. **Rural Site Development**: Investments that reduce project timelines and costs include providing water resources, discharge options, upgraded power services, and repurposing underutilized infrastructure. Additional focus on education, outreach, and workforce development would further support growth.
2. **Regulatory Support**: Pre-permitted sites, industry-specific nutrient recovery and reduction plans, veterinary resources, approved disease treatment protocols, and crop insurance could significantly reduce operational risks.
3. **Communal Industry Services**: Support for feed supply development, integration with pet food industries, nutrient recovery systems, marketing initiatives, and consumer education will be critical to building a robust aquaculture sector.

To achieve the ten-year production target of $153 million annually, Minnesota must take immediate steps to attract private sector investment in food fish aquaculture while continuing to support the development of sport fish and baitfish aquaculture.

Issues Affecting Aquaculture Expansion

The expansion of aquaculture in Minnesota faces multifaceted challenges, requiring coordinated solutions and strategic investments to overcome these obstacles effectively. Below are the primary issues affecting the growth of this vital industry:

- **Financial and Investment Challenges**
  Access to credit, financing, and insurance is limited for aquaculture ventures due to the high capital costs associated with constructing and operating advanced facilities, such as Recirculating Aquaculture Systems (RAS). Traditional lenders and insurance providers often lack familiarity with aquaculture, making them hesitant to support projects with perceived risks and long return-on-investment timelines. Attracting private investment is further complicated by the need for proven business models, reliable returns, and minimized risks.

- **Production Constraints**
  Feed costs and availability remain significant hurdles, with fishmeal and fish oil prices fluctuating and creating sustainability concerns. Developing alternative feed solutions, such as plant-based or insect-derived proteins, requires significant research and development, particularly for species with specific dietary needs, like Walleye and Perch. Additionally, disease management, water quality optimization, and biosecurity measures are essential for maintaining healthy production systems.

- **Processing, Distribution, and Market Accessibility**
  Processing challenges for food fish include species-specific equipment requirements, labor-intensive procedures, and managing biomass loss. The lack of established processing infrastructure for aquaculture products in Minnesota adds operational complexity, often driving producers to sell live or whole fish to avoid processing difficulties. Additionally, insufficient market data hampers decision-making, making it challenging to align supply with demand or address consumer preferences.

- **Infrastructure Gaps**
  Key infrastructure, such as feed supply chains, water resources, and waste treatment systems, must be developed to support industry growth. High construction and operational costs for facilities, particularly those utilizing advanced technologies like RAS, further strain resources. Additionally, sustainable practices and technologies to minimize environmental impacts must be integrated into facility designs to meet regulatory standards and ensure long-term viability.

- **Regulatory and Environmental Barriers**
  The complexity of regulatory processes, including permitting and compliance with environmental standards, creates significant delays and costs for aquaculture operations. Stricter nitrogen and phosphorus discharge limits, coupled with the need for nutrient recycling strategies, demand technological innovations that add to startup and operational expenses. Moreover, competition for water resources and concerns over aquaculture's environmental footprint complicate expansion efforts.

- **Labor and Education Needs**
  The aquaculture sector faces labor shortages, with challenges in recruiting and retaining skilled and unskilled workers, particularly in remote locations. Advanced production systems also require technically skilled labor, necessitating enhanced training and education programs. Furthermore, public awareness and understanding of aquaculture practices are limited, contributing to misconceptions about farmed fish products and constraining market acceptance.

- **Leadership and Coordination**
  The lack of centralized leadership and coordination in Minnesota’s aquaculture industry creates fragmented efforts and inconsistent strategies. Without a dedicated agency or representative to advocate for aquaculture, producers face challenges in navigating regulatory landscapes, securing funding, and accessing technical support.

- **Nutrient Discharge**
  Food fish aquaculture can contribute to nitrogen and phosphorus nutrient loading in the region, raising concerns over water quality and environmental sustainability. Strict discharge regulations require facilities to implement nutrient management strategies, including advanced filtration, water recycling, and effluent treatment systems. These measures increase operational costs and present technical challenges, particularly for new entrants in the industry. Additionally, competition for water resources and concerns about cumulative nutrient impacts further complicate site selection and permitting for aquaculture expansion. Addressing these challenges requires coordinated efforts to develop cost-effective nutrient recycling technologies, regulatory frameworks that balance environmental protection with industry growth, and collaborative research to enhance waste management practices.

While these challenges may seem daunting, they also present significant opportunities for innovation, collaboration, and growth. The Minnesota Aquaculture Action Plan is designed to address these barriers directly, providing a strategic framework that aligns state resources, stakeholder efforts, and private investment. By tackling the financial, regulatory, and infrastructural hurdles head-on, the action plan lays a foundation for a thriving aquaculture industry that not only meets local and regional needs but also positions Minnesota as a leader in sustainable aquaculture. The following section outlines the specific actions and strategies that will transform these challenges into opportunities for growth and success.

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Minnesota Aquaculture Action Plan

This Minnesota Aquaculture Action Plan charts a strategic path for positioning the state as a leader in the aquaculture industry, leveraging its agricultural expertise, abundant natural resources, and culture of innovation. The plan demands dedicated effort and collaboration from diverse stakeholders, including government, industry, and academia, to build the necessary infrastructure and foster responsible development. With substantial opportunities ahead, Minnesota is uniquely poised to transform its aquaculture sector into a benchmark of sustainability and economic prosperity, but it will require a concerted commitment to realize this potential.

The plan consists of 15 actions, broken up into the following categories:

- ⇒ Governance and Strategic Planning
- ⇒ Financial Support and Incentives
- ⇒ Research, Development, and Innovation
- ⇒ Market Development and Consumer Engagement
- ⇒ Infrastructure Development and Environmental Management
- ⇒ Regulatory Compliance and Policy Development

Governance and Strategic Planning

1. A Legislative Directive to Establish a Minnesota Aquaculture Working Group

Objective: To create a non-governing body that can assist in the strategic policy development of Minnesota's aquaculture industry.

Who:

- The lead agencies should include The Minnesota Department of Agriculture, Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, Minnesota Department of Employment and Economic Development, and Tribal representatives.
- The committee members should include Minnesota Aquaculture Association, the University of Minnesota, the UMN Minnesota Sea Grant Program, the North Central Regional Aquaculture Center Representative, USDA Federal Representatives, The Minnesota Soybean and Corn Growers Associations, Legislative Reps from the Minnesota House of Representatives and Senate, a Producer Representative (for food fish, sport fish, baitfish, and tribal entities), the Great Lake Aquaculture Collaborative, AURI, and an aquaculture technology representative.

When: Q4 2025

How:

- Form the committee and elect a chairperson.
- Develop a charter to guide the committee's objectives, strategies, and operations.
- Implement annual progress reporting to maintain transparency and accountability.
- Foster collaboration across public, private, and tribal sectors to align efforts and resources.
- Establish metrics for success, utilizing tools such as the USDA Census of Aquaculture to measure and evaluate outcomes.

2. Formalize a 10-year Minnesota Aquaculture Development Plan

Objective: To outline a comprehensive, long-term strategy for the growth and sustainability of the aquaculture sectors within Minnesota.

Who: Directed by Minnesota Aquaculture Working Group (recommendation 1).

When: Q2 2026

How:

Form a specialized working group to develop detailed plans for each aquaculture sector:

- Sport fish: Walleye, Muskellunge, Trout, Perch, Sturgeon.
- Baitfish: Golden Shiner, White Sucker, Chubs, Leeches, Flathead Minnows, Northern Dace (Rainbows), Bullheads
- Food fish: Salmon, Trout, Perch, Tilapia, Sturgeon, Shrimp, Walleye.

Each plan should include:

- Alignment with MNDNR requirements and protocol
- Alignment with the National Aquaculture Development Plan (NADP)
- Public/Private Partnership opportunities
- Relevant regulatory policy
- Preapproved culture technology
- Prequalified siting locations
- Aquaculture educational plan
- Resource list
- Funding options
- Production goals
- Economic benefits
- Research requirements

3. Expand Online Resources for Aquaculture Development

Objective: To enhance access to information and resources for aquaculture start-up and growth companies, and also foster an informed community engagement

Who: Minnesota Department of Agriculture and Minnesota Pollution Control Agency, working with academic agricultural extension and Minnesota Sea Grant.

When: Ongoing

How:

- Expand the aquaculture resource content page on the Minnesota Department of Agriculture's webpage:
  - Include updates on initiatives and opportunities for the public to engage in aquaculture growth.
- Expand the aquaculture resources content pages on the Minnesota Pollution Control Agency webpage:
  - Include aquaculture-specific regulations for permits for subsurface water resources.
  - Include aquaculture-specific regulations for surface water discharge permits.

Financial Support and Incentives

4. Commit to Long-Term Incentive Program

Objective: Establish financial incentives to reduce barriers to entry and expansion in the aquaculture sector, facilitating the growth of both startup and existing operations.

Who: Minnesota Department of Agriculture, Minnesota Department of Natural Resources, Minnesota Department of Employment and Economic Development, and the Minnesota Legislature, and private lenders

When: Within the next legislative session

How:

- **Legislative Action**: Develop and propose legislation to establish incentives for aquaculture growth equivalent to $150 million over 10 years.
  - Design incentives for rural aquaculture development.
  - Create startup provisions to support new entrants in the industry.
  - Offer tax incentives to lower operational costs.
  - Provide growth and diversification incentives for existing businesses.
- **Benchmarking Success**: Model these programs on successful agricultural incentives, such as those outlined by the National Sustainable Agriculture Coalition, adapting strategies to suit aquaculture's unique challenges.
  - Overview: Farm Bill Programs & Grants – National Sustainable Agriculture Coalition

5. Develop Funding Structures for Small Businesses

Objective: Construct financial frameworks that provide targeted support for the development and expansion of small aquaculture companies.

Who: State agencies that have business development and expansion grants and loans should make those available to aquaculture producers and businesses

When: Within the next legislative session

How:

- **Business Planning Support**: Offer resources for drafting business plans and conducting market feasibility studies specifically tailored to small-scale aquaculture operations.
- **Financial Assistance Programs**: Introduce legislation to create grants and low-interest loan programs designed to meet the particular needs of small aquaculture businesses, facilitating easier access to capital for equipment, technology upgrades, crop insurance, and operational expansion.
- Update existing grant and loan qualifications that exclude aquaculture to include aquaculture producers and businesses

Research, Development, and Innovation

6. Create an Information and Technology Hub for Aquaculture.

Objective: To centralize and enhance access to aquaculture resources and innovations, fostering an environment that supports industry growth and technological advancements

Who: University of Minnesota, Minnesota Sea Grant

When: Q2 2026.

How:

- Establish extension association positions and develop outreach programs.
- Use Wisconsin's Northern Aquaculture Demonstration Facility as a model.
- Work with the Central Lakes College for Aquaponics
- Include resources for entrepreneurs, researchers, and producers, with a focus on technology transfer and innovation and feasibility studies.

7. Support Advancements in Aquaculture Feeds

Objective: To innovate and improve the sustainability and efficiency of dry and live aquaculture feeds

Who: University of Minnesota, Minnesota Department of Agriculture, and private industry partners

When: Ongoing

How:

- Fund research into alternative protein sources such as soy, insect, marine algae, and duckweed/water lentil protein as alternative protein sources to fish meal.
- Develop and implement feed strategies that enhance feed conversion ratios and minimize environmental impacts.

8. Address Research Needs and Technology Gaps.

Objective: To identify and address scientific and technological challenges that hinder the growth and sustainability of the aquaculture industry

Who: University of Minnesota, Minnesota Aquaculture Association, Minnesota Sea Grant, private industry partners

When: Annually / biennially

How:

- Conduct surveys and workshops to engage with industry stakeholders and gather insights.
- Identify priority areas for research, including breeding programs, disease management, and recirculating aquaculture systems (RAS).
- Use state and federal grant programs to advance aquaculture research

Market Development and Consumer Engagement

9. Fund and Conduct Market Research on Food Fish

Objective: To better understand and effectively respond to market demands and consumer preferences for food fish in Minnesota's target market

Who: University of Minnesota, Minnesota Sea Grant, Minnesota Department of Agriculture, and private industry partners

When: Annually / biennially

How:

- Conduct detailed market analyses to identify regional opportunities and niche markets for various food fish species.
- Analyze consumer demand trends, pricing dynamics, and preferences to accurately guide production and marketing strategies.

10. Explore and Develop New Aquaculture Markets and Products

Objective: To diversify the aquaculture sector by exploring and developing new markets for unconventional aquaculture products

Who: Minnesota Department of Agriculture, Minnesota Department of Natural Resources, Minnesota Herpetological Society, The University of Minnesota, and Industry Partners

When: Ongoing

How:

- Research emerging species and innovative aquaculture products, including aquatic plants, invertebrates, turtles, and ornamental fish.
- Assess potential markets for these novel products, particularly focusing on sectors like food, pharmaceuticals, and cosmetics.
- Develop industry best practices for the sustainable production and processing of these new products.
- Promote the development of value-added products and by-products to enhance profitability and sustainability.

11. Develop Markets, Sales Strategies, and Value-added Aquaculture Products

Objective: To enhance the economic impact of aquaculture products through strategic market development and innovative value-addition

Who: Minnesota Department of Agriculture and the Agriculture Utilization Research Institute

When: Ongoing

How:

- Formulate comprehensive market strategies that effectively position Minnesota's aquaculture products in local, national, and international markets.
- Implement consumer education programs to increase awareness and acceptance of aquaculture products, emphasizing their quality and sustainability.
- Identify and capitalize on opportunities to add value to aquaculture products, such as through specialized processing techniques or the development of high-value by-products, to maximize economic returns.

12. Identify and Develop Sustainable Aquaculture Sites

Objective: To strategically expand aquaculture by identifying and preparing optimal sites that support sustainable practices and economic viability

Who: Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, Minnesota Department of Employment and Economic Development, and the University of Minnesota

When: By Q4 2026

How:

- Conduct detailed site assessments using water quality analysis, GIS surveys, and other environmental evaluations to pinpoint suitable locations for aquaculture.
- Assess the economic feasibility of each site and ensure regulatory conditions favor development.
- Use NOAA's "Aquaculture Opportunity Areas" as a benchmark for adopting sustainable site selection practices applicable to both marine and freshwater contexts.

13. Promote Ecologically and Economically Sustainable Commercial Aquaculture

Objective: To proactively foster the growth of the aquaculture industry through environmentally and economically sustainable methods

Who: The Minnesota Department of Agriculture, The Minnesota Department of Natural Resources, The University of Minnesota, The Minnesota Pollution Control Agency, and Private Industry Partners

When: Ongoing

How:

- Develop and promote non-fed aquaculture systems like aquaponics and algae cultivation that reduce reliance on traditional feed sources and enhance nutrient recycling.
- Implement advanced closed culture technologies such as Recirculating Aquaculture Systems (RAS) that efficiently manage waste and minimize environmental footprints.
- Address key production challenges by developing strategies for economic sustainability, domesticating new species for local conditions, managing off-season breeding cycles, and maintaining consistent stock levels to ensure year-round production capability.
- Explore and promote the use of green energy in aquaculture

14. Collaborate with MNDNR Aquaculture Efforts

Objective: To strengthen partnerships with key government bodies to enhance support for the aquaculture sector's growth

Who: The Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, Minnesota Department of Agriculture, and industry partners

When: Ongoing

How:

- Improve interagency coordination among different government agencies involved in aquaculture to ensure cohesive policy implementation and resource sharing.
- Partner with MNDNR on research and technology transfer to support sport fish and baitfish commercialization.
- Expand contract growing opportunities and focus on species suited for commercialization, like trout, perch, and walleye.

15. Streamline Permitting Processes

Objective: Focus on shaping policies that support sustainable growth in the aquaculture sector and ensure compliance with environmental, economic, and social standards.

Who:

- **Primary**: Minnesota Department of Agriculture (MDA) and Minnesota Department of Natural Resources (MNDNR) would lead this effort, given their primary roles in regulating and supporting aquaculture
- **Supportive**: Minnesota Pollution Control Agency (MPCA), which handles environmental compliance, and the Minnesota Department of Employment and Economic Development, which could address economic aspects
- **Consultative**: Tribal representatives, industry stakeholders such as the Minnesota Aquaculture Association, and legal experts to ensure all perspectives are considered in policy-making

When: Initiate by Q1 2027

How:

- **Simplify and Accelerate the Permitting Process**: Develop a more streamlined and cost-effective approach that reduces bureaucratic delays and simplifies the entry for new and existing aquaculture operations.
- **Develop and Update Regulations**: Regularly review and update aquaculture regulations to reflect the latest scientific findings and technological advancements, ensuring that regulatory frameworks promote industry best practices and sustainability.
- **Strengthen Policy Alignment**: Ensure that all aquaculture policies are aligned with state, federal, and tribal regulations, and facilitate the integration of aquaculture into broader agricultural and environmental policy frameworks.

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6.0 Appendices

Appendix A: Incentive Justifications and Growth Strategies for Minnesota

Table 2. *Target Growth by 2038*

Sector	2023 Revenue ($ x 1000)	2038 Target Revenue ($ x 1000)	15 Year Target Growth Revenue ($ x 1000)	New Facilities (Quantity)
Baitfish	2,907	7,000	4,093	20
Sportfish	2,224	6,000	3,776	15
Food Fish	210	7,000	6,790	23
Food Fish Aggressive	0	133,000	1,330	5
Total	**5,341**	**153,000**	**147,659**	**63**
Projected Growth	--	**-**	**213%**	**5**

Table 3. *New Facilities by 2038*

Species	Baitfish – Target Size $200k Total Revenue per Year	Sportfish – Target Size $250K Total Revenue per Year	Food Fish (Conservative) – Target Size $300K Total Revenue per Year	Food Fish (Aggressive)- Target Size $26.6M per Year	Outdoor	Indoor
Golden Shiner	5	-	-	-	3	2
White Sucker	5	-	-	-	3	2
Leech	4	-	-	-	2	2
Chubs	4	-	-	-	0	4
Walleye	-	3	2	-	3	2
Largemouth Bass	-	1	2	-	1	2
Rainbow Trout / Steelhead	-	3	4	-	3	4
Perch	-	2	2	-	2	2
Tilapia	-	-	4	-	-	4
Sturgeon	-	3	4	-	2	5
Atlantic Salmon	-	-	-	5	-	5
Shrimp	-	-	2	-	-	2
Undecided	2	3	3	-	3	5
Total Quantity	**20**	**15**	**23**	**5**	**22**	**41**

Table 4. *10-year Incentive Plan to Achieve 2038 Target Growth*

-	Units	Baitfish	Sportfish	Food Fish (C)	Food Fish (A)	Total
Current Production (2023)	$/year	$3,000,000	$2,250,000	$100,000	-	$5,350,000
15 Year Growth	$/year	$4,000,000	$3,750,000	$6,900,000	$133,000,000	$147,650,000
2038 Target Production	$/year	$7,000,000	$6,000,000	$7,000,000	$133,000,000	$153,000,000
15 Year Growth Plan	Total Growth	133%	167%	6900%	-	2760%
10 Year Incentive Plan	$/Year	$200,000	$337,500	$1,840,000	$9,800,000	$12,177,500

Table 5. *Estimated Capital Shortfalls per Sector*

Estimated Capital Shortfalls	Unit	Baitfish	Sportfish	Food Fish (C)	Food Fish (A)	Total
Average Fish Size Sold	(g)	6	40	600	5000	-
Average Fish Size Sold	Fish per lbs.	76	11	0.76	0.09	-
Average Revenue	($/lbs. Live wt.)	$16	$11.00	$6.00	$4.03	-
Average Revenue	($/gal)	$128	$88.00	$48.00	-	-
Average Revenue	($/Fish)	$0.21	$0.97	$7.93	-	-
Average Operating Cost	($/lbs.)	$8.00	$6.00	$4.00	$2.50	-
Production Capacity per Facility	(Lbs./Facility-yr)	12,500	22,727	50,000	6,600,000	-
Production Capacity per Sector	(Lbs./Sector-yr)	250,000	340,909	1,150,000	33,000,000	**34,740,909**
Production Capacity per Facility	(Gal/Facility-yr)	1,563	-	-	-	-
Production Capacity per Facility	(Gal/Facility-yr)	31,250	-	-	-	-
Production Capacity per Facility	(Fish Per Year)	945,833	25,955	37,833	599,280	-
Gross Profit	($/lbs.)	$8.00	$5.00	$2.00	$1.53	-
Gross Profit	($/facility)	$100,000	$113,636	$100,000	$10,100,000	-
Gross Profit Margins	%	50%	45%	33%	38%	-
Payback on Investment	(Years)	4	4	4	4	-
Private Equity Capital Justified per Facility	($ per Facility)	$400,000	$454,545	$400,000	$40,400,000	**$41,654,545**
Private Equity Capital Justified per Sector	($ per Sector)	$8,000,000	$6,818,182	$9,200,000	$202,000,000	**$226,018,182**
Private Equity Capital Justified per lbs.	($ per lbs.)	$32	$20	$8	$6.12	-
Estimated Investment Needed (no land or structures)	$/lbs. produced-yr)	$40	$29.90	$24	$9.09	-
Total Estimated Investment Needed (no land or structures)	($ per facility)	500,000	$679,545	$1,200,000	$60,000,000	-
Private Equity Shortfall per Lbs.	($ per lbs.)	$8	$10	$16	$3.0	-
Private Equity Shortfall per Facility	($ per Facility)	$100,000	$225,000	$800,000	$19,600,000	-
Private Equity Shortfall per Sector	($ per Sector)	$2,000,000	$3,375,000	$18,400,000	$98,000,000	**$121,775,000**
Incentive Depreciation (Equipment)	Years	12	12	12	12	-
Total Revenue generated	$	$48,000,000	$45,000,000	$82,800,000	$1,596,000,000	**$1,771,800,000**
States Return on Investment	Revenue generated per $	24.00	13.33	4.50	16.29	**14.55**
Jobs Created	Revenue per job	$200,000	$250,000	$275,000	$300,000	-
Jobs Created	#	20	15	25	443	**503**

Table 6. *Aggressive Food Fish Production Strategy for Minnesota (Atlantic Salmon)*

Atlantic Salmon Production Facility	Units	Production System	System per Facility	MN Facilities
Production Systems	#	1	6	5
Annual Production Target	mt live weight	500	3,000	15,000
Annual Production Target	kg Live Weight	500,000	3,000,000	15,000,000
Average Fish Weight	kg	5.0	5.0	5.0
Culture Timeline	Months	24	24	24
Annual Fish Production	#	100,000	600,000	3,000,000
Fillet Yield	%	67%	67%	67%
Fillet Production	mt/yr	333	2,000	10,000
Fillet Value	USD/kg	$ 12.84	$ 12.84	$ 12.84
Fillet Revenue	USD/yr	$ 4,280,000	$ 25,680,000	$ 128,400,000
Trimmings Yield	% Weight loss	95%	95%	95%
Trimmings Yield	mt/yr	158	950	4,750
Trimming Value	USD/kg	$ 1.00	$ 1.00	$ 1.00
Trimming Revenue	USD/yr	$ 158,333	$ 950,000	$ 4,750,000
Total Revenue	USD/yr	$ 4,438,333	$ 26,630,000	$ 133,150,000
Culture Technology	Type	RAS	RAS	RAS
Total Nitrogen discharge limitation	mg/l TN	30	30	30
Feed Conversion Ratio	FCR	1.2	1.2	1.2
Annual Feeding Rate	kg feed per year	600,000	3,600,000	18,000,000
Avg. Daily feeding Rate	kg feed per day	1,644	9,863	49,315
MAX Daily Feeding Rate	kg feed per day	2,055	12,329	61,644
Feed Protein Content	% Protein by weight	45%	45%	45%
Total Protein Fed	kg Protein/yr	270,000	1,620,000	8,100,000
Average Feeding Rate	% Biomass/day	0.8%	0.8%	0.8%
Average Standing Biomass	Metric Tons Fish	257	1,541	7,705
Average Standing Biomass	% of Annual Production	51%	51%	51%
Standing Biomass Value	USD	$ 2,198,630	$ 13,191,781	$ 65,958,904
Average Fish Density	kg/m3	40	40	40
Culture Volume	m3	6,421	38,527	192,637
Average Total Nitrogen Production	kg TN /day	68	408	2,042
MAX Total Nitrogen Production	kg TN /day	85	510	2,552

Atlantic Salmon Production Facility	Units	Production System	System per Facility	MN Facilities
Total Phosphorus	kg TP /day	-	-	-
Average Flow Required	LPM	1,575	9,452	47,260
Average Flow Required	Gal/min	417	2,501	12,503
Max Flow Required	LPM	1,969	11,815	59,075
Max Flow Required	Gal/min	521	3,126	15,628
Avg. Culture Volume Water Exchange	%/day	35%	35%	35%
Culture Volume Water Exchange	L/kg feed	1,380	1,380	1,380
Potential Soy Protein Content	-	0	0	1
Potential Soy Protein Content	MT Soy Protein/yr	41	243	9,315

Table 7. *Cost of Goods Sold per Kilogram for Food Fish Production Strategy for Minnesota (Atlantic Salmon)*

Annual Costs of Goods Sold (COGS)	Unit	Production System	System per Facility	MN Facilities
Feed	$/kg	$ 2.64	$ 2.40	$ 2.10
Labor	$/kg	$ 2.25	$ 2.00	$ 1.75
Power	$/kg	$ 1.05	$ 0.88	$ 0.70
Oxygen	$/kg	$ 0.20	$ 0.18	$ 0.16
Water and Discharge	$/kg	$ 0.20	$ 0.20	$ 0.20
Purge and Processing	$/kg	$ 0.40	$ 0.40	$ 0.40
Other	$/kg	$ 0.60	$ 0.50	$ 0.40
Live Weight COGS	**$/kg**	**$ 7.34**	**$ 6.56**	**$ 5.71**
Fillets COGS	**$/kg**	**$ 11.01**	**$ 9.83**	**$ 8.57**

Table 8. *Cost of Goods Sold per Year for Food Fish Production Strategy for Minnesota (Atlantic Salmon)*

Annual Costs of Goods Sold (COGS)	Unit	Production System	System per Facility	MN Facilities
Feed	$/yr	$ 1,320,000	$ 7,200,000	$ 31,500,000
Labor	$/yr	$ 1,125,000	$ 6,000,000	$ 26,250,000
Power	$/yr	$ 525,600	$ $2,638,000	$ 10,512,000
Water and Discharge	$/yr	$ 100,000	$ 600,000	$ 3,000,000
Purge	$/yr	$ 200,000	$ 1,200,000	$ 6,000,000
Other	$/yr	$ 300,000	$ 1,500,000	$ 6,000,000
Total COGS	**$/yr**	**$ 3,670,600**	**$ 19,668,000**	**$ 85,662,000**

Table 9. *Profit per Year and Kilogram for Food Fish Production Strategy for Minnesota (Atlantic Salmon)*

Profit	Unit	Production System	System per Facility	MN Facilities
Sales (Gross) Profit	$/year	$ 767,733	$ 6,962,000	$ 47,488,000
Sales (Gross) Profit	$/kg Fillet	$ 2.30	$ 3.48	$ 4.75

Table 10. *Capital Investment Breakdown for Atlantic Salmon Production with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	% Total	Cost per kg of Annual Production (up to 1,000 mt Scale)	Cost per kg of Annual Production (up to 3,000 mt Scale)	Cost per kg of Annual Production (up to 20,000 mt Scale)	% of Category Incentivized	% of total Incentivized
Design and Planning	10%	$ 3.0	$ 2.5	$ 2.00	50%	5%
Source Water and Treatment	8%	$ 2.0	$ 1.75	$ 1.50	50%	4%
Discharge Treatment and Permit	5%	$ 1.5	$ 1.25	$ 1.00	50%	3%
Power and Utilities	10%	$ 2.0	$ 2.0	$ 2.00	50%	5%
Building and HVAC	30%	$ 10.0	$ 8.0	$ 6.00	50%	15%
Production Systems	30%	$ 10.0	$ 8.0	$ 6.00	0%	0%
Processing Equipment	8%	$ 1.5	$ 1.5	$ 1.50	25%	2%
TOTAL Construction Capital	100%	$ 30.0	$ 25.0	$ 20.0	-	33.1%

Table 11. *Capital Investment Breakdown for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	% Total	Cost per System	Cost per Facility	MN State Total	% of Category Incentivized	Total Incentive
Design and Planning	10%	$ 1,500,000	$ 7,500,000	$ 30,000,000	50%	$ 15,000,000
Source Water and Treatment	7%	$ 1,000,000	$ 5,250,000	$ 22,500,000	50%	$ 11,250,000
Discharge Treatment and Permit	5%	$ 750,000	$ 3,750,000	$ 15,000,000	50%	$ 7,500,000
Land, Power and Utilities	7%	$ 1,000,000	$ 6,000,000	$ 30,000,000	50%	$ 15,000,000
Building and HVAC	33%	$ 5,000,000	$ 24,000,000	$ 90,000,000	50%	$ 45,000,000
Production Systems	33%	$ 5,000,000	$ 24,000,000	$ 90,000,000	0%	$ -
Processing Equipment	5%	$ 750,000	$ 4,500,000	$ 22,500,000	25%	$ 5,625,000
TOTAL Construction Capital	100%	$ 15,000,000	$ 75,000,000	$ 300,000,000	33%	$ 99,375,000

Table 12. *Payback in Years With and Without Incentives for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	Units	Cost per System	Cost per Facility	MN State Total	Notes
Capital Payback with Sales Profit	years	19.5	10.8	6.3	Without Incentives
Capital Payback with Sales Profit	years	13.1	7.2	4.2	With Incentives

Table 13. *Working Capital Estimates for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Working Capital Investment Breakdown	Units	Per System	Cost per Facility	MN State Total	Notes
Working Capital required	$	$ 7,341,200	$ 39,336,000	$ 171,324,000	-
Working Capital required	% Capex	49%	52%	57%	-
Working Capital required	Annual COGS	2.0	2.0	2.0	Years of working capital required

Table 14. *Development Capital (CAPX) and Working Capital Investment Estimates for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	Units	Cost per System	Cost per Facility	MN State Total	Notes
Total CAPX and Working Capital	$	$ 22,341,200	$ 114,336,000	$ 471,324,000	-
CAPX: Annual Revenue	Years of Revenue	5.0	4.3	3.5	-
Total CAPX and Working Capital	$/kg Live Weight	44.7	38.1	31.4	-
Payback With Sales Profit	years	29.1	16.4	9.9	Without Incentives
Payback With Sales Profit	years	19.5	11.0	6.6	With 33% Capex Incentives

Table 15. *Estimated Land and Water Requirements for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	% Total	Cost per System	Cost per Facility	MN State Total
Land Area Required	Acres	0.75	3.75	15
Water Required	MGD	0.58	3.50	17.50

Table 16. *Estimated Investment Multiplier over Deprecation Period for Atlantic Salmon Facilities with Aggressive Food Fish Production Strategy*

Capital Investment Breakdown	% Total	Cost per System	Cost per Facility	MN State Total
Power Required	KW	500	2,500	10,000
Revenue/job Created	Revenue/job	$250,000	$275,000	$300,000
Jobs Created	total	18	97	444
Average Salary	$/yr	$63,368	$61,960	$59,144
Depreciation	years	12	12	12
Total Revenue	$/Depreciation Period	$53,260,000	$319,560,000	$1,597,800,000
Investment Multiplier	$:$	$10.72	$12.86	$16.08

Appendix B: Roles of Federal Institutions

Federal institutions are critical in regulating, supporting, and promoting sustainable aquaculture in the United States. Their involvement spans regulatory oversight, research, extension services, and economic assistance. Below is an overview of their primary roles, with references for further information.

In total, there are over 20 agencies involved in various activities, including marketing services, business and farm grant programs, Aquaculture extension, regulatory agencies, research assistance, and more. The complex nature of aquaculture, involving multiple factors such as environmental conditions, species biology, and market demands, necessitates a collaborative approach among various federal agencies. These agencies often work together to pool their expertise, resources, and data to ensure effective regulation, research, and extension services. This collaboration is essential for promoting sustainable aquaculture practices, protecting aquatic ecosystems, and supporting the industry's economic growth (Interagency Working Group on Aquaculture, 2014).

Many federal agencies have regulatory jurisdiction across multiple aspects of the aquaculture industry; sometimes, several agencies within the same department have different responsibilities. More than 1,300 laws apply to U.S. aquaculture, with significant compliance categories including environmental management, food safety, legal and labor standards, interstate transport of aquatic products, fish health, and culture of commercially harvested species (Engle & Stone, 2013)

Regulatory Agencies

Several federal agencies oversee aquaculture regulation to ensure environmental sustainability, food safety, and ecosystem health:

- U.S. Department of Agriculture (USDA): The USDA regulates the import/export of aquaculture species and promotes disease control through the Animal and Plant Health Inspection Service (APHIS).
- National Oceanic and Atmospheric Administration (NOAA): NOAA balances economic benefits with environmental protection. It oversees permits for coastal aquaculture and ensures compliance with regulations such as the Endangered Species Act and the Magnuson-Stevens Fishery Management Act.
- Food and Drug Administration: The FDA ensures the safety of drugs and feed used in aquaculture and monitors the quality of seafood for human consumption.
- Environmental Protection Agency (EPA): EPA manages effluent and waste discharge, enforces water quality standards, and regulates pesticide use in aquaculture.
- U.S. Fish and Wildlife Service (USFWS): The USFWS supports conservation hatcheries and regulates species transport under the Lacey Act.
- U.S. Food and Drug Administration (FDA): The FDA ensures the safety of aquaculture drugs and feeds while monitoring the quality of seafood for human consumption.
- U.S. Army Corps of Engineers (USACE): The USACE plays a key role in regulating activities in navigable waters under Section 10 of the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act. Section 10 requires permits for structures or work in navigable waters, including aquaculture-related equipment like cages, racks, and buoys. Section 404 regulates the discharge of dredged or fill materials into U.S. waters, including activities like substrate preparation for larval growth and impoundment construction for aquaculture purposes.

Refer to the Federal Aquaculture Resource Guide (2014) for detailed information.

Aquaculture Research and Extension

Federal agencies contribute significantly to advancing aquaculture through research, innovation, and technical assistance:

- USDA Agricultural Research Service (ARS): Conducts research to improve production systems and sustainability.
- National Institute of Food and Agriculture (NIFA): Operates Regional Aquaculture Centers (RACs) to address region-specific challenges.
- Sea Grant Programs (NOAA): This program provides research funding, education, and technical support to develop sustainable aquaculture practices.
- U.S. Fish and Wildlife Service (USFWS): This agency supports the only federal hatchery system, with 70 National Fish Hatcheries and additional Fish Technology and Health Centers. These facilities focus on conserving aquatic species and developing new technologies to improve aquaculture productivity and sustainability.
- National Science Foundation (NSF): This organization funds fundamental research in aquaculture, including innovations in genetics, disease control, and sustainable production practices. NSF-supported projects often drive technological advancements that benefit both research institutions and industry stakeholders.

These programs foster government, academia, and industry collaboration to enhance aquaculture's sustainability and competitiveness.

For more details, visit NOAA's Sea Grant Aquaculture Programs.

Economic Assistance

Federal economic assistance programs provide vital funding and support to aquaculture businesses:

- USDA: Offers grants and loans through the Farm Service Agency (FSA) and the Agricultural Marketing Service (AMS).
- NOAA Fisheries Finance Program: Provides loans for aquaculture infrastructure and facility expansion.
- Small Business Administration (SBA): Supports aquaculture businesses with loans, disaster assistance, and entrepreneurial training.
- Small Business Innovation Research (SBIR) Program: The SBIR program provides competitive grants to small businesses engaged in high-risk, innovative research and development projects. Many aquaculture businesses have leveraged SBIR funding to develop new technologies, improve sustainability, and address industry challenges.

These programs help aquaculture producers address financial challenges, access new markets, and scale operations sustainably.

Additional information is available at Grants.gov and NOAA's Fisheries Finance Program.

Appendix C: Role of Institutions in Minnesota

Similarly to their federal counterparts, Minnesota's institutions help support the aquaculture industries by providing various services, including regulation, research and development, and economic assistance. Furthermore, these roles are not mutually exclusive, with many institutions involved in permit issuance, regulation, and development.

Minnesota's aquaculture industry is primarily regulated by two agencies: The Minnesota Department of Natural Resources (MNDNR) and The Minnesota Department of Agriculture (MDA). The MDA is mainly responsible for development assistance, and the MNDNR is charged with regulatory authority. However, some regulations and permits may fall under the purview of other agencies, such as the Minnesota Pollution Control Agency (MPCA), which deals with aquaculture discharge effluents. Regulation and oversight of the aquaculture industry are vital for protecting the environment and ensuring aquaculture does not harm Minnesota's natural resources.

The MDA defines aquaculture as privately raising fish or other aquatic life for consumption or sale. Aquaculture is considered agriculture, with farmed fish viewed as livestock. A private hatchery (an aquatic farm) is a licensed facility for hatching and rearing private aquatic life for sale. It may include ponds, vats, tanks, raceways, and other indoor or outdoor facilities that an aquatic farmer owns or has the right to use.

- Minnesota Statute 17.4981, general conditions for regulating aquatic farms, provides the legislative framework for aquaculture.

While the Minnesota aquaculture industry is still young, it has grown significantly in recent years. Various public and private institutions play crucial roles in supporting its development and ensuring its sustainability.

Regulatory

The Minnesota Sea Grant has created a simplified guide for Minnesota Aquaculture regulations that introduces planning and regulatory processes for operating an aquaculture business in Minnesota. It is recommended that users check out their guide for further insights into the aquaculture regulatory landscape in Minnesota: Aquaculture Regulations: A Simplified Guide for Minnesota

The Minnesota Department of Natural Resources; www.dnr.state.mn.us
The Minnesota Department of Natural Resources (MNDNR) is the state agency responsible for managing and protecting the state's natural resources. Its mission is to conserve and manage the state's natural resources to benefit present and future generations. In addition to managing Minnesota's fisheries resources, the MNDNR oversees most of the aquaculture regulatory authority and farm licenses. There are four licenses, permits, and forms required for aquaculture facilities in Minnesota:

- New aquaculture facility or pond application: This is the initial inspection of all licensed facilities, including public water wetlands and any additional ponds or facilities to be added to an aquaculture license.

- Private Fish Hatchery (two licenses: sales> $200 and sales<$200): This base license is required for aquaculture production in Minnesota and is granted after a facilities and/or wetlands inspection. The private fish hatchery license is equivalent to the aquatic farm license.
- Pond Acreage Fee: The annual rend acreage fee is in addition to the aquatic farm license. It includes all waters listed on the aquatic farm license, including the state's artificial and natural waters.
- Water Appropriation Permit: This permit is required for water appropriations exceeding 10,000 gallons per day or 1 million gallons per year.

Once an initial private hatchery (aquatic farm) license has been approved and purchased, operators may acquire endorsements for their license. There are six endorsements available for holders of aquatic farm licenses:

1) License to Take Sucker Eggs from Public Waters
2) Minnow Retailer License
3) Minnow Dealer License
4) Exporting Minnow Dealer License
5) Minnow Dealer, Exporting Minnow Dealer, and Minnow Retailer Vehicle Licenses
6) Fish Packer License

The endorsements allow the license holder to conduct the same activities as an individual license for that activity would allow. They are a way to consolidate all licenses into one for the convenience of the licensee.

The Minnesota Pollution Control Agency; www.pca.state.mn.us
The Minnesota Pollution Control Agency (MPCA) is focused on preventing and reducing air, land, and water pollution and leading Minnesota's efforts to protect against the effects of climate change. The MPCA comprises seven divisions: Remediation, Watershed, Environmental Analysis and Outcomes, Resource Management and Assistance, Industrial, Municipal, and Operations.

The Industrial division handles permitting, compliance assistance and enforcement, and licensing and certification for industrial wastewater and stormwater facilities, sources of air emissions, underground fuel storage tank facilities, and hazardous waste generators. A wastewater permit is required for any industrial facility, municipality, or private entity that proposes to discharge a specific amount of a pollutant into the surface or ground waters of the state. For aquaculture businesses, such as land-based RAS systems that discharge effluent, this would mean receiving an NPDES permit to discharge a specified number of effluent pollutants into surface water.

The Minnesota Department of Agriculture; www.mda.state.mn.us
While most aquaculture regulatory authorities fall under MNDR & MPCA, the MDA administrates the commercial fish feed manufacturing and distribution license. Before a person may manufacture or distribute animal feed in or into the state, a Minnesota Commercial Feed License is required. "Commercial Feed" is defined as materials or combinations of materials that are distributed or intended to be distributed for use as feed or for mixing in feed unless the materials are specifically exempt.

Aquaculture Research and Extension

Minnesota Department of Agriculture; www.mda.state.mn.us
The Minnesota Department of Agriculture's (MDA) role is to promote and regulate the state's aquaculture industry. As aquaculture continues to grow in Minnesota, the MDA focuses on supporting sustainable practices, ensuring regulatory compliance, and fostering economic opportunities for aquaculture producers, which aligns with the National Aquaculture Development Plan.

University of Minnesota; https://twin-cities.umn.edu
The University of Minnesota contributes to advancing Minnesota's aquaculture industry through its multiple research and extension programs. Their research delves into various aspects of aquaculture, including fish health, nutrition, genetics, and invasive species research.

While mainly focused on invasive species, the Aquatic Invasive Species Research Center hosts valuable resources for advancing aquaculture research within the state. MAISRC has access to high-quality well water at 200 GPM and filtration systems that can provide a clean and consistent water supply, as well as 27 large fish tanks and over 50 aquaria, giving controlled environments for research on selective breeding, disease resistance, and even pilot recirculating aquaculture systems for specific species. Coupled with the wealth of knowledge in aquarium systems, fish biology, and water quality management, the center's expertise can support the development of aquaculture in various ways in an environment that can be used for educational workshops or demonstrations to support aquaculture extension.

University of Minnesota Sea Grant Program; https://seagrant.umn.edu/
The Minnesota Sea Grant is part of the National Sea Grant College Program, a nationwide network of university-based programs funded by NOAA. MNSG is heavily involved in both aquaculture research and extension. Their research focuses on practical solutions for the industry, such as their aquaculture market study, which assessed the viability of a sustainable food-fish industry in Minnesota. The Egg-to-Market Yellow Perch Project is developing production-scale methods for raising Yellow Perch fish from egg to market size in a recirculating system (RAS). The MNSG and industry partners are investigating new strategies for producing Golden Shiner for Minnesota's bait industry.

Through extension efforts, MNSG provides technical assistance and educational resources to producers, fostering best practices and regulatory compliance. They also lead as a network hub of Great Lakes Sea Grant Programs called the Great Lakes Aquaculture Collaborative (GLAC), which connects industry stakeholders and promotes knowledge sharing. Public outreach programs raise awareness of aquaculture's benefits and challenges, potentially boosting consumer interest in locally raised seafood. By being part of the National Sea Grant network, Minnesota Sea Grant leverages a broader pool of expertise and resources, allowing them to tackle more significant issues, help develop national aquaculture policies, and, ultimately, better serve Minnesota's aquaculture industry.

Great Lakes Aquaculture Collaborative; https://greatlakesaquaculture.org/
The Great Lakes Sea Grant programs led by MNSG create the Great Lakes Aquaculture Collaborative (GLAC) to support an environmentally responsible, science-based, competitive, and sustainable aquaculture industry in the Great Lakes region. GLAC comprises Sea Grant programs from Illinois, Indiana, Lake Champlain, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. GLAC provides aquaculture producers and consumers, educators and teachers, legislators and policymakers, and those interested in raising, selling, eating, and stocking fish and other aquatic organisms in the Great Lakes region with science-based information, resources, and expertise.

North Central Regional Aquaculture Center; https://www.ncrac.org/
The NCRAC was formed in February 1988. It is one of five regional aquaculture centers administered by the USDA. The Center has concentrated on funding species with good potential as food fish for production in the North Central Region, such as yellow perch, walleye, and hybrid striped bass. In addition, NRAC has supported projects on sunfish, salmonids, crayfish, baitfish, aquaculture wastes and effluents, aquaculture drugs, and tilapia. All funded projects are directed at high-priority industry needs that include developing new technologies and applying research findings that will benefit diverse constituencies. Therefore, research and extension activities have been integrated into all funded projects to develop and implement educational outreach materials and programs.

Northern Aquaculture Demonstration Facility; https://www.uwsp.edu/nadf
The Northern Aquaculture Demonstration Facility (NADF), located at the University of Wisconsin-Stevens Point, although situated outside of Minnesota, plays a significant role in supporting the development of Minnesota's aquaculture industry. The NADF serves as a valuable resource for Minnesota through its research and extension activities. NADF researches various aspects of aquaculture, investigating areas like species selection and disease prevention in RAS, focusing on practical applications for regional species such as salmon, walleye, and percid species. Additionally, the facility acts as a living laboratory, showcasing various operating systems and technologies that producers can visit to learn about firsthand. For students, NADF partners with various public and private organizations through their research and demonstration, thus connecting graduates directly with their future employers. The facility boasts a near 100% job placement rating for students continuing their careers in aquaculture. They offer extension programs and workshops for aquaculture producers covering topics like best management practices, system maintenance, and business development, further supporting their close relationships with producers in the area.

Minnesota Aquaculture Association; https://mnaquaculture.org/
Minnesota Aquaculture Association (MNAA) was formed in 2019 to support aquaculture development within the state. The association's mission is to promote the long-term sustainability and economic growth of aquaculture, aquaponics, and the bait industry while minimizing the environmental impacts on the state's natural resources. MNAA works collaboratively with various industry producers and research and extension services provided by the University of Minnesota, MNSG, Minnesota Department of Natural Resources, and Minnesota Department of Agriculture.

Economic Assistance

Minnesota Department of Agriculture; www.mda.state.mn.us
Like the federal equivalent, the Minnesota Department of Agriculture (MDA) offers a variety of economic assistance programs to support the aquaculture industry in Minnesota and is considered the primary source of economic assistance for Minnesota's aquaculture industry. These programs provide financial, technical, and other resources for aquaculture producers. The State of Minnesota recognizes aquaculture as agriculture, meaning that many of the resources available to traditional terrestrial farming apply to the aquaculture industry. MDA offers value-added grants, sustainable agriculture demonstration grants, farm opportunity loans, livestock equipment expansion loans, and other kinds of financial support for which aquaculture may be eligible. Marketing programs such as the Minnesota Grown program, which connects Minnesotans directly to farmers, farmers markets, and other producers, and Make it Minnesota, whose goal is to increase the use of Minnesota agricultural ingredients, all work to increase the visibility of Minnesota Aquaculture products.

Minnesota Department of Employment and Economic Development; https://mn.gov/deed/
The Minnesota Department of Employment and Economic Development (DEED) focuses primarily on business recruitment, workforce development, and international trade. While aquaculture is not explicitly mentioned in many programs, there are indirect ways they can support the industry. The agency's mission is to support the economic success of individuals, businesses, and communities by improving growth opportunities. The business financing programs, including the Minnesota Investment Fund, Job Creation Fund, Emerging Entrepreneur Loans, and Launch Minnesota Grants, help companies from all backgrounds retain existing jobs and create new, high-quality jobs.

Agricultural Utilization Research Institute; https://auri.org/
The Agricultural Utilization Research Institute (AURI) is a non-profit organization that helps agricultural producers, food entrepreneurs, and innovators bring their ideas to market. AURI provides research and development, technical assistance, and market development to various entrepreneurs and businesses, including those within aquaculture.

Appendix D: Industry Methodologies and Technologies

The following table summarizes the various aquaculture production strategies employed throughout the industry.

Table 17. Aquaculture Production Methods & Technology

Methodology/ Technology	Category	Advantages	Disadvantages	Considerations
Outdoor (Extensive)				
Natural Lakes/ Wetlands	Outdoor	Low capital investment, natural resources	Environmental risks, limited control over water quality, potential for predation, potential conflicts between riparian owners, aquaculture, and anglers	Suitable for species tolerant of natural conditions
Constructed Ponds	Outdoor	Relatively low cost, moderate control of water quality	Environmental concerns, potential for algae blooms, susceptibility to weather	Ideal for species requiring open water environments
Pond-Side Tanks/ Floating Raceways	Outdoor	Increased control over water quality, reduced predation risk	Higher capital costs, potential for algae blooms	Suitable for species requiring more controlled conditions
Gravel/Mining Pits	Outdoor	Low capital investment, large scale-production potential	Environmental concerns, limited control over water quality	Suitable for species tolerant of low-quality water
Indoor (Intensive)				
Flow-Through Raceways	Indoor	High control over water quality, year-round production	High water usage, potential for disease outbreaks	Suitable for species requiring high-quality water and controlled environments
Partial Reuse/ Recirculating Aquaculture Systems (RAS)	Indoor	Reduced water usage, improved water quality	Higher capital costs, potential for technical issues	Ideal for high-density production of valuable species
Aquaponics	Indoor	Integrated food production, reduced wastes	Higher capital costs, complex management	Suitable for sustainable food production

Outdoor (Extensive)

Outdoor aquaculture, a method of cultivating aquatic plants or animals in open environments, has traditionally been employed for both conservation and commercial purposes. This practice involves utilizing natural water bodies like lakes, ponds, and rivers and man-made structures such as raceways or tanks. The water source for the culture environment is usually surface or groundwater, and the quality typically reflects that of nearby natural sources, offering limited control over conditions.

Outdoor aquaculture has historically been effective in supporting native species and recreational fishing. In Minnesota, conservation aquaculture has traditionally focused on supporting the management of native species, which has a strong presence in recreational fishing activities. Using natural water bodies supports the water quality and temperature requirements of the targeted local species and acclimates them to the conditions they will be exposed to. For anadromous salmonid species, it also provides the imprinting required to find their way home when preparing to spawn. Successful recruitment and capture of spawning adults completes the process and allows these conservation aquaculture programs to continue indefinitely. Additionally, outdoor aquaculture offers a culture option that requires the most minor capital and operating costs.

Natural waterbodies are also traditionally used in commercial aquaculture for similar economic incentives. Nearshore pen culture in oceans and freshwater has been the industry standard for Salmon culture for several decades. Large freshwater bodies offer a similar opportunity for some freshwater species. This methodology restricts the geographical area where aquaculture can occur, as outdoor culture provides little opportunity to manipulate the water quality conditions away from the ambient conditions of the water source. For commercial aquaculture, this often means that the animals being produced are being sold and shipped worldwide. The local inhabitants do not see the benefits of the activities but must accommodate the impacts these facilities have on their community and environment.

Natural lakes and wetlands

Using natural water bodies has traditionally been a means of developing and supporting conservation and commercial aquaculture. In Minnesota, conservation aquaculture has traditionally focused on managing native species, which is strongly present in recreational fishing activities. Using natural water bodies is inherently beneficial to this practice. Natural water bodies support the targeted local species' water quality and temperature requirements and offer a culture option requiring minor capital and operating costs to support the associated aquaculture activities.

Natural waterbodies are also traditionally used in commercial aquaculture for similar reasons. Near-shore pen culture in oceans has been the industry standard for Salmon culture for several decades.

Minnesota has an abundant number of natural lakes, streams, and ponds. Aquaculture has played an essential role in managing these water bodies through state and federal programs, which directly benefit the state economy.

Constructed ponds

Constructed ponds are widely used throughout the state for many aquaculture practices, and it is estimated that around 80% of the current aquaculture license holders in the state produce in ponds[3]. Ponds are the oldest and most common production method in the United States and can be divided into two main categories of ponds: natural and man-made. Natural ponds are existing bodies of water that cannot be drained, which makes harvesting fish more difficult. Artificial ponds tend to be smaller and are often constructed using liners, while they can be manually filled and drained for harvest.

Pond culture has generally proven to be the most economical means of producing fish culture. It can be a cost-effective way to make fish – especially when using a natural pond. During the production season, ponds can grow fish quickly and at low densities with minimal stress. Man-made ponds rely on groundwater and surface water, and users are recommended to draw from a nearby well with water.

So far, pond culture has been limited, mainly for seasonal stocking efforts or growing baitfish. Golden shiners, fathead minnows, and white suckers are all popular bait species that support recreational fisheries across Minnesota. These species can reach market size in one grow season and grow well on inexpensive feeds. This is essential for a state like Minnesota, where the outdoor culture season is limited to the warmer months before winterizing.

A limitation of pond culture is that it only allows seasonal fish grown in northern climates. This limits the growing season to 4-6 months, making it difficult to compete with southern states that can grow year-round. Additionally, farmers need to manage minerals, biological oxygen demand, aquatic vegetation, alkalinity, and unwanted species in their ponds. However, there are management practices to reduce some of the drawbacks associated with constructed pond culture. Using bird netting to reduce invasive species and predation, as well as strict biosecurity protocols for employees, are a couple of best management practices pond culturists can use.

The Natural Resource Conservation Service (NRCS), created a best management practice document on standard pond aquaculture (PDF) that goes into more depth on the considerations for constructed pond aquaculture.

Pond-Side Tanks / Floating Raceways

Fish management in ponds has always been challenging, and managing biomass is often a guessing game. New technology that helps manage biomass in a pond is being utilized abroad, which may support Minnesota's pond culture.

- Pond-Side Tanks
- Floating Raceways

Both technologies aim to manage the culture biomass in an enclosed space at higher densities while utilizing the pond's volume as a biological buffer. This can lead to better feed conversion ratios, faster growth, better biomass management, and more predictable harvests.

[3] Interview with MN DNR

Gravel/mining pits

Gravel and mining pits can allow access to groundwater and brownfield buildable land.

Indoor (Intensive)

In contrast to outdoor (extensive) aquaculture, which provides little control over the environment of the cultured organisms and subjects them to more natural food sources and environmental conditions, intensive aquaculture is highly controlled. Conditions such as temperature, dissolved oxygen, and diet are maintained within specific desired levels.

Flow Through Raceways and Tanks.

Raceways culture is a conventional way to produce fish using flow-through technology in the conservation and commercial aquaculture industry. Raceways utilize space efficiently and offer a convenient geometry to manage, sort, and harvest fish. There are many disadvantages of Raceways culture, including:

- Excessive water use and high turnover rate.
- Challenges with surface water disinfection and disease risk.
- Challenges with high volume/ low concentration discharge treatment.
- Cleaning and Maintenance

The Natural Resource Conservation Service (NRCS), created a best management practice document on fish raceways and tanks that can be accessed here, that goes into more depth on the considerations for raceway or tank culture.

Partial Reuse Aquaculture Systems (PRAS)

Partial Reuse Aquaculture System (PRAS) technology is applied when water resources are restricted or production needs to increase. By recirculating a portion of the water (50% - 95%) of the flow used in the culture tank and readjusting the gas concentrations and suspended solids, additional production capacity can be accomplished without additional water resources. Flow through aquaculture's limiting factor is the amount of dissolved oxygen available in the water for fish respiration and the level of carbon dioxide that accumulates. PRAS removes this constraint by recirculating the water, removing carbon dioxide, and adding oxygen. With the management of dissolved oxygen and carbon dioxide, production capacity can be increased 3-4 times the original capacity.

PRAS technology typically does not include biofiltration and ammonia nitrogen is flushed from the system with new water. Therefore, ammonia discharge restrictions should be considered when applying this technology.

Recirculating Aquaculture Systems

In recirculating aquaculture systems, culture water is cleaned and continuously reused in almost a completely closed circuit. The fish's waste products contain solid waste, ammonium, and carbon dioxide, which the system components either remove from the system or convert into non-toxic products. The purified water is saturated with oxygen and returned to the tanks.

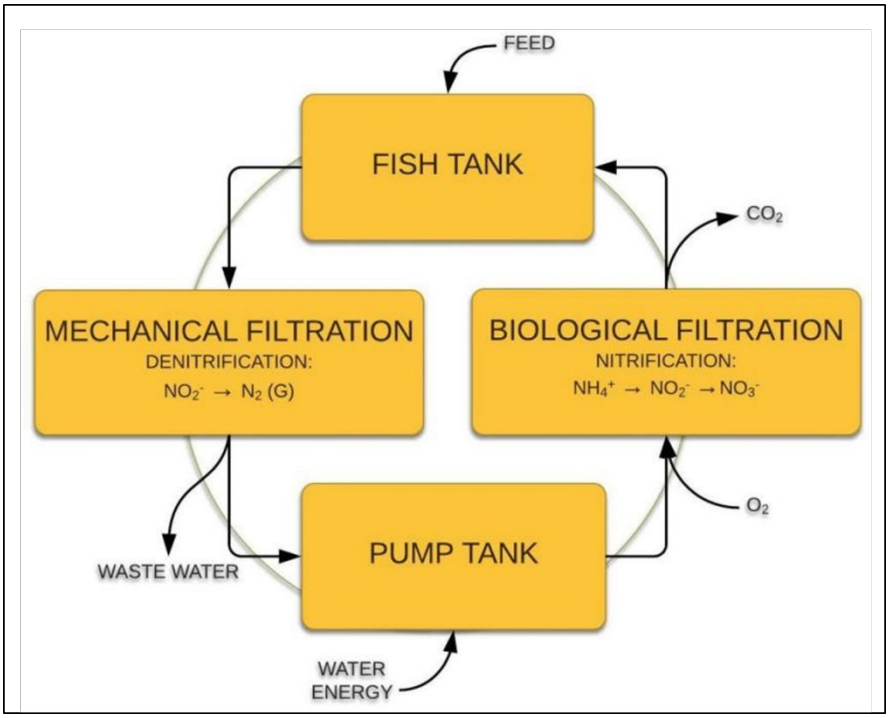
By recirculating the culture water, the water and energy requirements are limited to their absolute minimum. These systems can reuse about 95% to 99.5% of the flow to the culture tanks. Recirculating aquaculture systems provide multiple benefits, such as fully controlled environments for the fish, low water use, efficient land use, optimal feeding strategies, and disease control. A few constraints of recirculating systems are the necessity for electricity 24/7, high-quality feed that will not negatively impact system water quality, and technically skilled staff able to work the systems.

RAS systems typically include biological filtration that converts ammonia nitrogen into nitrate nitrogen. Total nitrogen, mainly nitrate, can accumulate to high concentrations in the discharge flow. This should be considered for discharge permits when using RAS.

The basic components of a recirculating system contain the following elements, as described below and shown in Figure 18.

- **Culture Tank:** This is the primary tank for the fish, designed to provide optimal conditions for the species, including temperature, pH, dissolved oxygen, and water flow
- **Mechanical Filter:** Removes large solid particles such as fish waste and uneaten feed from the water
- **Biological Filter:** Contains beneficial bacteria that convert harmful nitrogenous compounds (ammonia, nitrate) into less toxic forms of nitrogen
- **Pump Tank**: stores water and provides a pressure head for the system. Regulating water flow and pressure
- **Pump:** circulates water throughout the system
- **Other Components:** can include a UV filter, Oxygenation devices, Aeration devices, automatic feeds and monitoring systems

Figure 18. *The Basic Components of a Recirculating Aquaculture System*



Note. Reprinted from "Recirculating aquaculture system, by Aquaculture ID (221). https://www.aquaculturеid.com/recirculating-aquaculture-system

The Food and Agriculture Originations of the United Nations created a Guide to Recirculating Aquaculture, which provides a comprehensive guide to RAS for people looking for more information.